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FOREWORD

The *41st International ICT Convention MIPRO 2018* was held from 21st to 25th of May 2018 in Opatija, the Adriatic Coast, Croatia. The Convention consisted of eleven conferences under the titles: *Microelectronics, Electronics and Electronic Technology (MEET), Data and Life Sciences Supported by Distributed Computing (DS-DC), Telecommunications & Information (CTI), Computers in Education (CE), Computers in Technical Systems (CTS), Intelligent Systems (CIS), Information Systems Security (ISS), Business Intelligence Systems (miproBIS), Digital Economy and Government, Local Government, Public Services (DE/GLGPS), Engineering Education (EE), Software and Systems Engineering (SSE)*. A special conference was dedicated to the works of students: *MIPRO Junior-Student Papers (SP)*.

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

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

To all who helped organizing the 41st International ICT Convention *MIPRO 2018* as well as editing of this Book of Proceedings we extend our heartfelt thanks.

Prof. Karolj Skala, PhD
Acting International Program Committee
General Chair

M E E T

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INVITED PAPER

An Experimental View on PureB Silicon Photodiode Device Physics

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***Abstract* - PureB silicon photodiode technology is distinguished by enabling nm-shallow junction depths that bring the light-sensitive region right up to the Si surface. Robust light-entrance windows can be made from as little as a layer of 2-nm-thick pure boron while obtaining low dark currents. The understanding that these attractive properties are due to the creation of a layer of fixed negative charge when boron is deposited on silicon is supported by extensive experimental observations some of which will be reviewed in this paper. For example, PureB p^+n-like diodes with equally attractive *I-V* characteristics can be fabricated with boron layers deposited in the temperature range from 700°C down to 400°C, at which temperature no doping of the bulk Si can be expected. A number of electrical test structures, specifically developed to study the behavior of as-deposited PureB junctions will be discussed along with experiments designed to investigate the influence of post-processing steps, in particular thermal/laser annealing steps. The experiments show that post-processing can degrade the interface and cause an increase in the otherwise ideal diode saturation current even in situations where the interface is replaced by ultrashallow p^+-doped bulk Si regions.**

Keywords – pure boron; silicon; chemical vapor deposition; photodiodes; laser annealing;

I. INTRODUCTION

In PureB technology, chemical-vapor deposition (CVD) of pure boron is used to create the p-type surface region of shallow, less than 10-nm deep, silicon junction diodes [1]. In the first photodiode detector applications of this technology, a 700ºC deposition temperature was applied to grow nm-thin amorphous boron layers selectively on silicon through openings in an oxide isolation layer [2]. For the fabrication of ultrashallow p^+n-like diodes this technology proved attractive because the junction formation is damage-free and the diode saturation currents are almost as low as those of conventional deep diodes. Moreover, for photodiode detector fabrication, 700ºC PureB technology had several additional advantages: high CMOS compatibility, the pure boron layer was found to be chemically robust in many situations, and the fabricated detectors surpassed the performance of other existing technologies on points such as internal/external quantum efficiency, dark current, and irradiation-induced degradation of responsivity [3, 4]. For example, for the detection of beams that only penetrate a few nm into the Si, such as vacuum-ultraviolet light and low-energy electrons down to 100 eV, 2-nm-thick PureB-layers were reliably implemented as the front-entrance window [5].

While the 700ºC PureB is compatible with front-end CMOS, it is of interest to study low-temperature processes that enable back-end compatibility. Initial results with B deposition temperatures down to 400ºC showed that the low saturation currents typical of the 700ºC diodes could indeed be reproduced at such temperatures [6]. Similar results were also achieved with 400ºC deposition of pure Ga, another group III dopant in Si [7]. On Ge islands grown on Si, a sequential deposition of pure B on pure Ga was also demonstrated to successfully form p^+n-like photodiodes with exceptionally low dark currents [8]. In addition to linear-mode photodiodes, both these "PureGaB" Ge-on-Si diodes and PureB Si diodes were used to fabricate single-photon avalanche diodes (SPADs) with low dark-count rates even at room temperature [8, 9].

For all these diodes, the PureB/Ga Si and PureGaB Ge-on-Si diodes, the excellent electrical characteristics can be ascribed to an effectively high Gummel number of the Pure(Ga)B p-type region giving a high blocking of electron injection from the n-substrate [4, 10]. For the 700ºC PureB, the electron injection currents were extracted to be as low as a few 10^{-20} A/μm^2 which is comparable to those achieved in deep heavily-doped junctions [10]. This corresponds to a Gummel number of a bulk Si region doped to the order of 10^{14} - 10^{15} atm/cm^2, which is decades higher than what would be expected of nm-shallow junctions formed by the doping of the silicon at 700ºC. Similar results have not been achieved with other types of ultrashallow diodes produced by techniques that only aim at damage-free doping of the Si. Methods include CVD layers grown with precursors containing dopant atoms to either grow shallow highly-doped Si surface layers or provide layers that can function as doping-source for drive-in/activation techniques such as flash or laser annealing [11, 12, 13, 14]. The thus fabricated diodes function as conventional p-n diodes where the actual bulk Si doping corresponds to the observed Gummel numbers. To our knowledge, the Pure(Ga)B technology is the only example of diode

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fabrication where the deposited dopant atoms are not driven into the Si. Nevertheless, since the high electron blocking is seen for these group III dopants deposited in layers on Si or Ge it does seem plausible that a layer of acceptor states could be formed at the interface, a complete monolayer of which would correspond to 6.78×10^{15} atm/cm^2. This is in the range of the doping concentration value that would be needed to explain the high PureB Gummel number.

In this paper, a number of experiments are discussed with focus placed on the measurement techniques used to study the electrical properties of PureB Si diodes fabricated at low temperatures. This includes recently developed electrical test structures for fast turnaround-time evaluation of as-deposited B-layers by extracting the conductance along the PureB-to-Si interface [15] and the electron injection current into the PureB layer [16]. The results give strong evidence that the bulk properties of the boron layer itself, as sometimes was suggested in the past [17, 18] have no beneficial influence on the electron blocking power. The overall experimental evidence that now is available, and is discussed here, confirms that it is the B coverage on the Si that is the important factor for all whether the diodes are fabricated with 700ºC or down to 400ºC deposition temperatures. A comparison is also made to preliminary experiments where the PureB layer is driven into the Si by excimer laser annealing which is a method expected to result in B doping levels well above the solid solubility [19, 20].

II. Electrical Test Structure Fabrication

The basic process for fabricating PureB photodiode detectors is shown in Fig. 1. The experiments discussed in detail here were performed on n-type Si (100) wafers with a resistivity of 1-10 Ω-cm. A 235-nm-thick thermal oxide was grown and windows were opened with wet landing on the Si. The pure boron was deposited from diborane in an ASM Epsilon 2000 CVD reactor at temperatures from 400°C to 700°C with varying deposition times. For nm-thin layers the deposition of the PureB will be disrupted by any native oxide, particle contamination or other residues on the Si surface [1]. Therefore, before loading into the CVD reactor, the wafers were immersed in a diluted HF solution to remove native oxide and H-passivate the surface against native oxide formation. Marangoni cleaning was then used to remove particles and prevent the formation of drying spots. After drying, the samples were immediately put in the load-lock of the reactor where they were continuously purged by oxygen-free N_2 gas. Metallization was performed by sputtering of pure Al in which the interconnect pattern was etched. To open light-entrance windows to the PureB, the Al was first plasma-etched back to a thickness of about 100 nm after which it was wet-etched to the PureB by using diluted HF [5].

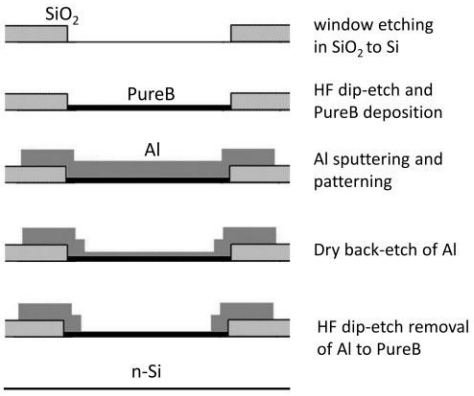


Figure 1. Schematic process flow for fabrication of PureB photodiodes with PureB-only light-entrance windows.

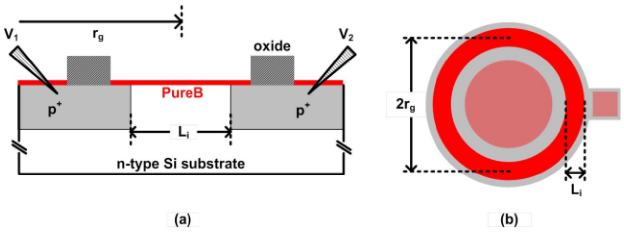


Figure 2. Schematic cross section (a) and layout (b) of the ring-shaped test structures. In each set the perimeter of the PureB-only region is constant and equal to $4\pi r_g$ while the width of the ring has varying values L_i.

The PureB layers of interest for photodiodes are preferably tunneling layers less than 3 nm thick, because the series resistance associated with the high resistivity of the PureB layer itself can degrade detector performance. For such thin layers any post-deposition processing steps, such as the deposition/removal of metal layers can be detrimental. Therefore, besides the metal-contacted diodes, it was important to study the characteristics of as-deposited layers. This was done by fabricating electrical test structures as illustrated in Fig. 2 following the first process steps shown in Fig. 1. After the oxide growth, guard rings were formed by implanting B^+ and annealing to give a p^+ junction depth of 0.5 µm with a peak doping concentration of 10^{19} cm^{-3}. Windows for B-deposition were etched but no metallization was applied. These structures were developed in [15] to measure the sheet resistance along the B-to-Si interface, R_{sh}. Here the diode *I-V* characteristics were also measured and used to determine the electron injection, I_e, into the PureB region in the manner described in [16].

Metallized diodes were also fabricated as illustrated in Fig. 3 to study the application of PureB layers as a source of dopants for ultrashallow junction formation by full-melt high-power excimer laser annealing (LA) in the manner described in [21]. The laser energy densities were varied from 400 mJ/cm^2 to 900 mJ/cm^2.

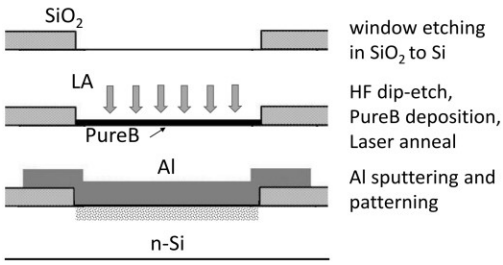


Figure 3. Schematic process flow for fabrication of laser annealed diodes using a PureB layer as dopant source.

III. As-Deposited Boron Layers

The PureB research is at present directed towards developing PureB layers at lower and lower temperatures while maintaining the properties that are attractive for photodiode applications. In Fig. 4 high-resolution transmission-electron-microscopy (HRTEM) images are shown of PureB layers deposited at 400ºC and 700ºC along with a schematic of the boron concentration profile that emphasizes the differences between the two cases as explained by the fixed-negative-interfacial-charge model. Five different structural regions were described in [22]:

(1) A uniform, compact layer of amorphous boron is seen to be deposited directly on the Si surface.

(2) The surface of the compact B layer is covered with a rough increasingly incomplete layer of non-compact B. This layer is quite thick for 400°C layers but barely noticeable for 700°C layers. At this temperature very uniform layers with low surface roughness are formed as a result of the high diffusion length of the boron atoms along both Si and SiO_2 surfaces [23]. As the deposition temperature is lowered the mobility along the surface diminishes and the layers become rougher.

(3) For the 700°C layer the Si surface is roughened and some mixing of the B and Si is visible in a region less than 1 nm wide at the interface. The 400ºC deposition leaves the Si surface flat.

(4) At 700°C the boron can diffuse a few nm into the bulk Si, doping it to the solid solubility of 2×10^{19} cm^3. At 400°C no bulk doping is expected.

(5) For both the 400°C and 700°C depositions a layer of fixed negative charge is formed at the B-to-Si interface. The layer of holes that thereby is induced at the interface is responsible for the attractively low saturation current of the diode *I-V* characteristics. It is also determines the sheet resistance along n-type Si surfaces covered with PureB deposited at temperatures that give no significant doping of the Si, i.e., 400°C – 500°C. The resistivity of the amorphous boron layer itself is very high with values above 500 Ω-cm [23]. In the literature, other CVD layers of B have been reported to be semiconductors with a p-type doping in the 10^{16} cm^3 - 10^{18} cm^3 range [24, 25].

The chemical robustness of PureB layers has been very important for their successful application in micro-machined photodiode detectors [5]. For example, 2-nm-thick boron layers are resistant to etching in diluted HF solutions. They also can be used as diffusion barriers for

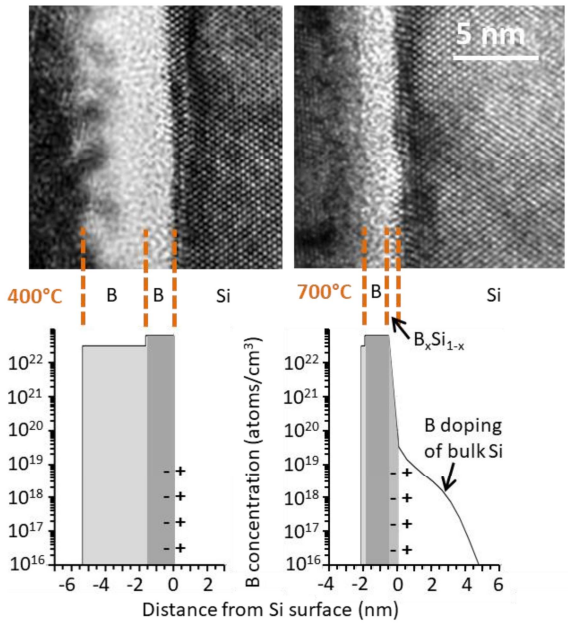


Figure 4. Top: HRTEM images of PureB layers grown at 400°C (left) and 700°C (right). Bottom: corresponding graphs of the B concentration. Taken from [22]. The dark grey regions represent compact bulk boron, the concentration in which was determined by SIMS [1]. The light grey regions on the B layer surface represent the non-compact surface regions, the indicated thickness of which is equal to the roughness extracted from ellipsometry measurements. The profile of the B-doping of the bulk Si is taken from simulations [4]. At the B-to-Si interface the minus and plus signs represent respectively the fixed negative charge and the associated hole accumulation. The medium grey region at the Si interface of the 700°C deposition represents a mixing of the B and Si at this interface.

Al metallization to prevent spiking of the Si [26]. The PureB has very good adhesion to the Si, which has allowed the deposition and selective removal of Al layers with diluted HF [5].

Electrically and optically the 400ºC and 700ºC PureB photodiodes have been shown to have very similar properties. In [4, 6] the 400ºC devices were found to have the same low saturation currents, high responsivity to VUV light / low-energy electron irradiation, and they were both stable with respect to high-dose irradiation. However, with respect to robustness the 400ºC layers were less resistant to standard cleaning steps and the deposition/removal of Al metal layers [4, 27].

The low-temperature, as-deposited PureB layers were first studied in [27]. In that paper the conductance along the PureB-to-Si interface was determined using the ring-shaped test structures described in Section II as a function of deposition time and temperature, substrate voltage, and n-doping concentration of the Si surface. The results gave support of the band-gap model shown in Fig. 5 incorporating the pivotal interface layer of fixed negative charge. In addition to the sheet resistance, R_{sh}, the electron injection current, I_e, is also measured here and the results are plotted in Figs. 6a and 6b as a function of B deposition time and temperature. The two parameters R_{sh} and I_e are seen to follow the same trends. For the 5 min deposition time the B-layer thickness was no more than about 1 nm. Therefore, an imperfect coverage is expected and indeed a high R_{sh} of ~100 kΩ/sq and very high I_e of 2 μA were

found. For the 10-min deposition the values drop significantly and for the 15-min deposition, with a layer thickness of 2.3 nm, and longer times, the values saturate at a R_{sh} = 37 kΩ/sq and an I_e from 1 nA to 2 nA.

In Fig. 6b the R_{sh} and I_e are plotted for B deposition temperatures from 400ºC to 700ºC. Also included is a sample for which the B was deposited at 700ºC and then annealed for 5 min at 850ºC. Both parameters decrease with increasing temperature which could indicate that some doping of the bulk Si is occurring even at 450ºC and higher temperatures. Alternatively, it could also well be the degree of B-coverage of the interface that is the differentiating factor at the lower temperatures. An incomplete coverage could entail recombination centers at the interface that decrease the hole mobility along the interface while also increasing the electron surface recombination velocity at the interface. Thus both R_{sh} and I_e would increase.

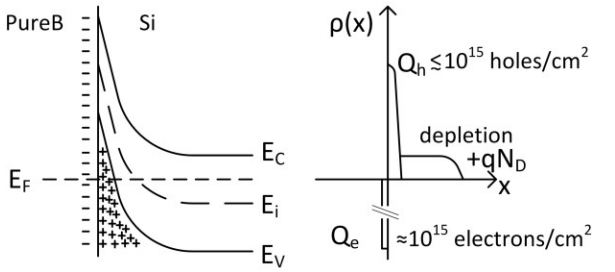
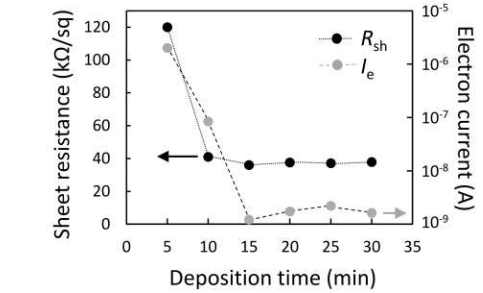
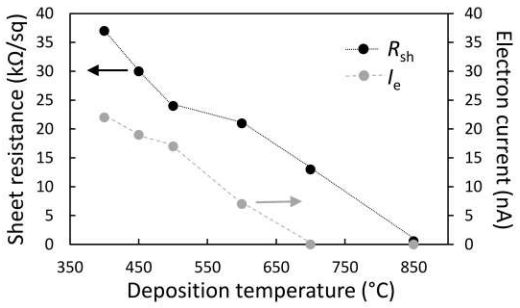


Figure 5. Energy band diagram (left) and charge distribution (right) illustrating the proposed model that a monolayer of acceptor states is formed at the PureB-Si interface. The fixed electrons at the interface are indicated with (-) and the inversion layer distribution of holes with (+) [7].



(a)



(b)

Figure 6. Sheet resistance measured with a substrate bias voltage of 0 V, and electron injection current extracted from measurements on ring-shaped test structures with L = 200 µm and r_g = 164 um, fabricated with PureB layers deposited (a) at 400ºC for different deposition times, and (b) at different temperatures for times long enough to give a layer thickness larger than 3 nm.

IV. Boron Dopant Drive-in Experiments

In this section diodes fabricated by drive-in of B from a PureB layer will be discussed with focus placed on the effects related to whether or not the PureB-to-Si interface was kept intact. As emphasized in the previous section, the electron injection into PureB layers is the parameter that must be kept low to achieve the low saturation currents typical of deep diffused p^+n junctions. With the applied test-structure configuration and at the low temperatures, the I_e increased to values of the same order as the hole injection current. For 700ºC B depositions the hole current dominated by at least a factor 10. In our experiments, the PureB-diode saturation current levels never went below those of comparable deep diffused p^+n diodes where an integral doping above 10^{15} cm^{-2} is easily achieved. This is not easily achieved in ultrashallow p^+n junctions a few tens of nm deep. Very often these junction diodes have high saturation currents dominated by the electron injection into the p-region. One possible method of nevertheless achieving a high doping concentration is full-melt laser annealing where the fast quenching time can result in concentrations well above the solid solubility of B in Si [19].

A. Thermal annealing

The responsivity of PureB photodiodes as a function of post-deposition anneal steps up to 900ºC was examined in [4, 28]. Without any such anneals, the photodiodes showed near-theoretical responsivity in the VUV spectral range, independent of the deposition temperature. This is demonstrated for 400ºC and 700ºC depositions, and the optical stability is also found to be high in both cases. A similarly high stability is also obtained for devices exposed to 900ºC thermal drive-in of the boron to 100-nm junction depths if a complete coverage of PureB is maintained on the surface. The advantage of the PureB layer in this respect is that it prevents oxidation and any associated illumination-induced charging effects that can degrade the optical stability. With respect to the responsivity, the deep junctions displayed up to about 50% lower values which was still very high compared to conventional deep junctions. The difference lies in the electric field that repels electrons from the surface right up to the PureB-to-Si interface because the IHL compensates for any doping roll-off. If the PureB layer was removed or seriously corrupted by the drive-in a much lower responsivity was measured than was the case when the layer was kept intact. Depositing an extra PureB layer after a detrimental thermal anneal was found to restore the high responsivity, plausibly by repairing damage-induced recombination centers and/or roll-off of the doping profile.

B. Laser annealing

Laser annealing has received considerable attention as a “room temperature” means of achieving high dopant activation since the bulk Si below the exposed area is not heated up [19]. Low-energy dopant implants are often used to introduce the necessary impurities but with the disadvantage of introducing damage that can be difficult to eliminate completely by the LA [21]. Therefore, dopant depositions have also been studied for this purpose [20]. Here some preliminary experiments using PureB layers as

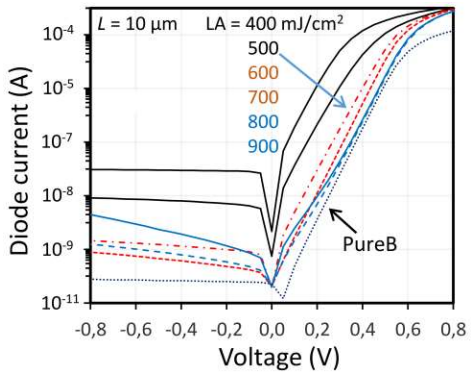


Figure 7. *I-V* characteristics of a non-annealed PureB diode and laser-annealed diodes for different laser anneal energies, for ring-shaped structures with r_g = 68.5 µm and L = 10 µm.

a source of dopants for p⁺n diode formation by high-power excimer laser-annealing are presented to underline the special properties of PureB diodes.

The PureB deposition was performed at 700ºC to a thickness of about 2 nm. In Fig. 7 the *I-V* characteristics of laser annealed diodes are shown as a function of the laser anneal energy for ring-shaped diodes with L = 10 um and r_g = 68.5 µm. The non-annealed PureB diode characteristics with ideality factor n = 1 are also included. For LA with 400 mJ/cm² the characteristics become Schottky-like, presumably because the B-layer is more light absorbing than Si at 308 nm wavelength and it was ablated without the Si being melted. For increasing LA energy the current levels start to decrease, indicating that some degree of B-diffusion into the Si is taking place. At the same time, non-ideal leakage currents become more and more evident. For a bare c-Si surface, melting of the Si is expected above about 800 mJ/cm². Here this is the energy at which the minimum saturation current of the LA diodes is reached. At 900 mJ/cm² the current is perhaps slightly lower but there is also a reduction in non-ideal leakage that may also partly account for this.

The melting of the Si achieved by LA is highly pattern dependent [19]. For micron-small devices the cooling due to heat transfer to the substrate will be much larger than for tens-of-micron large devices. This effect can also be seen from the data plotted in Fig. 8 where the current at 0.35 V forward bias is plotted for r_g = 68.5 µm and 3 values of L = 2 µm, 10 µm, and 40 µm, as a function of LA energy. The same trend is seen for all sizes. At

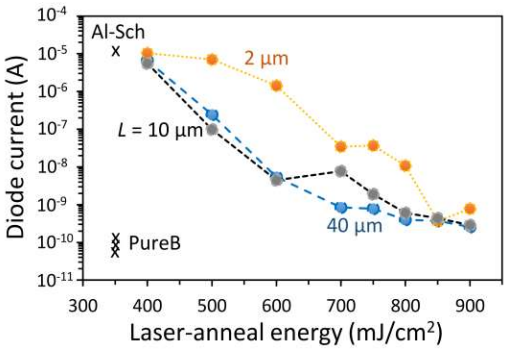


Figure 8. Diode current at a forward bias of 0.35 V as a function of laser-anneal energy for ring-shaped structures with r_g = 68.5 µm and L = 2 µm, 10 µm, and 40 µm. Crosses indicate the current in an Al-to-Si Schottky diode and non-annealed PureB diodes of the same sizes.

400 mJ/cm², they all show high current levels similar to Al-to-Si Schottky diodes. From 500 – 700 mJ/cm² the current decreases, saturating at PureB-like low levels at 800 - 900 mJ/cm². Unlike the non-annealed PureB devices, the laser-annealed devices have significant non-ideal leakage current. This appears to be a perimeter current that is much larger than the area-dependent bulk current. In these structures the length of the perimeter is kept constant while the area increases linearly with L. The narrow 2-µm-wide rings have the largest current levels and largest non-idealities, indicating that the recrystallization after LA is much more imperfect at the perimeter than in the center of the rings. The wide 40 µm rings have lower current levels, about the same as the 10-µm-wide rings, which indicates that the high perimeter currents are dominating. In contrast, the PureB diodes display linear current-area dependency with ideal characteristics for all values of L.

V. CONCLUSION

In this paper an overview was given of experiments using processing and device characterization techniques that provide a straightforward means of evaluating and developing new layer depositions for fabricating diodes. For the PureB diodes, the purpose was to determine parameters like the sheet resistance along the B-to-Si interface and the electron injection into the PureB layer. The results give support that the formation of a monolayer of fixed negative charge at the interface is responsible for the p⁺n-like PureB diode characteristics. The B-coverage directly on the Si is clearly the element of importance for achieving ideal *I-V* characteristics with a low I_e of about 10^{-20} A/µm and low R_{sh}, < 50 kΩ/sq, for deposition temperatures that are not expected to give B doping of the bulk Si. For incorporation in devices like photodiode detectors, the B-layer thickness becomes of significance for the diode series resistance that can be kept low by using a tunneling layer thickness below about 3 nm . Even at 400ºC it was possible to grow such thin layers while maintaining the ideal low electrical parameters.

The saturation current of the PureB junctions was comparable to that of bulk diffused B-doped layers. With the test diodes that were processed on lightly-doped n-Si substrates the determination of the electron currents injected into the PureB region makes clear that the hole injection into the substrate is dominating the current for 700ºC deposition but as the temperature goes down to 400ºC the electron injection starts to become equally significant, increasing by at least a decade over this temperature range. Presumably a less complete B-coverage of the Si surface is responsible for this but whether the mechanism that then increases the electron current is a reduction of the IHL concentration and/or an increase in recombination centers at the interface needs further investigation.

Several experiments with post-deposition processing steps also show that the B-to-Si interface is of primary importance for *I-V* behavior. When the interface is damaged, the level of electron injection goes up. This is underlined here by comparing PureB diodes to diodes where the B-layer is driven into the Si by full-melt excimer laser annealing. For LA energies where the amorphous B is ablated, high Schottky-like current levels

result. For energies that melt the Si, a high doping of the Si resulted and current levels comparable to those in PureB diodes were found. With respect to reproducibility, the LA diodes have the disadvantage of a strong pattern dependency and susceptibility to perimeter leakage. In other cases where the PureB interface was damaged by thermal dopant drive-in processes, the responsivity of the photodiodes was reduced as compared to ones where the damaged layer was replaced with a new PureB layer. All these experimental results show that the PureB-to-Si interface is important for maintaining a high electric-field gradient right up to the interface for repelling electrons and even a small reduction of the B-coverage can lead to an undesirable increase in electron recombination at the interface.

This paper has focused on the experimental material that led to the formulation and substantiation of the model that a layer of fixed negative interfacial-charge is decisive for the attractive properties of PureB photodiodes. More advanced models including the role of metal contact to the PureB are also being investigated with preliminary observations being treated in [29].

ACKNOWLEDGMENT

The author would like to thank the members of the former Silicon Device Integration Group and DIMES IC-Processing Group of Delft University of Technology for their contributions to the development of PureB photodiodes as well as Xingyu Liu, University of Twente, and T. Knezevic and T. Suligoj, University of Zagreb, for contributions to PureB device characterization.

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PAPERS

Characterization of thin Boron layers grown on Silicon utilizing Molecular Beam Epitaxy for ultra-shallow pn-junctions

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Ultra-thin layers of Boron deposited on Silicon (100) by means of Molecular Beam Epitaxy are utilized to form highly blocking pn-junctions. Growth temperatures and thicknesses are investigated ranging 500°C to 700°C and 3nm to 5nm. Diodes realized with these layers display high ideality, low series resistance and high reverse blocking ability The consequent usage of these layers for realization of Insulated Gate Bipolar Transistors is also discussed.

Keywords **– Pure Boron on Silicon, Molecular Beam Epitaxy, MBE, ultra-thin, high voltage**

I. INTRODUCTION

Given the continuous need for higher performance and lower power consumption, arises the necessity for device dimension miniaturization. Hence, imposing stricter challenges on device production. Ultra shallow junctions are extremely important for many device applications and are a focus of research since many years [1].

Considering its desirable physical and electrical properties, for decades, Boron (B) has been employed in many areas of research and industry [2]. Nowadays, used mainly in the semiconductor industry for the unique characteristics of its compounds and as a p-type dopant species by means of ionic implantation or epitaxy.

In this work, Molecular Beam Epitaxy (MBE) is utilized for the growth of B layers with nanometer thicknesses on Silicon (100) substrates targeting the formation of ultra-shallow $p^+n^-n^+$-junctions.

II. EXPERIMENTAL PROCEDURE

For the purpose of this work, we used commercially acquired Antimony (Sb) doped n+ Si (100) substrates with lightly n-type doped top layer grown by means of Chemical Vapor Deposition (CVD) with a thickness of 3 µm to realize ultra-shallow p+n-n+-junction.

In order to realize these device junctions, differential epitaxy was employed. It is previously known that B will not adhere to SiO2 [3-4]. Therefore, we used layers of SiO2 to create windows where B would be deposited directly onto the Si surface. The fabrication process is outlined in the following subsection and depicted in Figure 1.

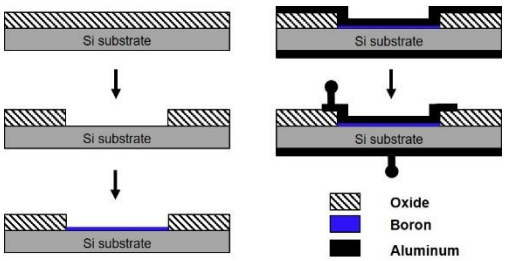

Figure 1. Fabrication process for ultra-shallow $p^+n^-n^+$-junction formation.

A. *Substrate preperation*

Prior to sample introduction to the clean room, substrates were treated to a standard organic and particle cleaning step. This was then followed by a four step standard RCA cleaning process:

- Cleaning in an Ammonia (NH_3)/Hydrogen Peroxide (H_2O_2) solution for removal of organic contamination and particulates – 10mins
- Native oxide (SiO_2) stripping by Hydrofluoric Acid (HF) solution – 10s to 15s
- Ionic cleaning in Hydrochloric Acid (HCl)/H_2O_2 solution – 10mins
- Chemical oxide (SiO_2) stripping by HF – 20s, directly before oxide mask deposition

B. *Oxide mask window formation*

Directly after cleaning, we introduced the substrates into the Plasma Enhanced CVD (PECVD) reactor chamber. For our purposes, Tetraethyl Orthosilicate (TEOS) oxides were used as oxide masks. A 300nm layer of TEOS oxide was deposited to the substrates at a temperature of 390°C.

The oxide mask layers are subsequently structured by a lithography step. Etching of the oxide mask layers is achieved through Reactive Ion Etching (RIE) for majority of the oxide mask thickness. Oxide mask windows are then fully opened by wet etching in a buffered-HF solution.

These oxide mask windows are circular windows with diameters 80, 40, 20, 10, 5, 4, 3, 2, 1.5, and 1µm. These are used to investigate the effect of device dimensions to their operation.

After successful formation of the oxide mask windows, substrates undergo another standard cleaning as described earlier before introduction to the growth chamber.

C. MBE Growth

The growth of the B layers was performed in a 6-inch MBE system. Matrix materials used in this MBE are Si and Carbon (C), these are evaporated using electron beam evaporators. The dopant materials used are B and Sb for p- and n-type growth respectively. The dopant materials are evaporated from their elemental form using Knudsen effusion cells. The base pressure in the MBE is approximately $2 \cdot 10^{-10}$ mbar.

Growth temperatures are calibrated through a specially designed substrate with thermocouple elements for accurate temperature measurement. In-situ flux monitoring of the matrix materials is achieved using a quadrupole mass analyzer. Growth rates of the matrix materials are maintained at 1 Å/s. The flux for the dopant materials is calibrated by growth of n- and p-type Si at multiple evaporation temperatures. The resultant layers are then analyzed by Secondary Ionic Mass Spectroscopy (SIMS) for accurate calibration of evaporation rates. The evaporation rates for the dopant species are optimized for 10^{+20} cm^{-3} concentration at a growth rate of 1 Å/s. This corresponds to 10^{+12} $atoms \cdot cm^{-2} \cdot s^{-1}$ arriving at the growth interface.

Prior to the deposition, a thermal cleaning of the substrates is performed. The substrates are heated up to 900°C for 5 minutes allowing for removal of any native oxide and desorption of surface impinged gases.

For the purpose of this work, we investigate the growth of B with temperatures ranging from 500°C to 700°C and thicknesses ranging from 3nm to 5nm. The growth rate for the B layers is verified and calibrated using High Resolution Transmission Electron Microscopy (HRTEM) (see Figure 2).

D. Device structuring

Following B deposition, we cover both sides of the samples directly with Aluminum (Al) by sputtering. We then perform another lithography step for contact formation and final device structuring. Al contacts are etched using an Ion Coupled Plasma (ICP) RIE step followed by a Phosphoric Acid (H3PO4) wet etching step.

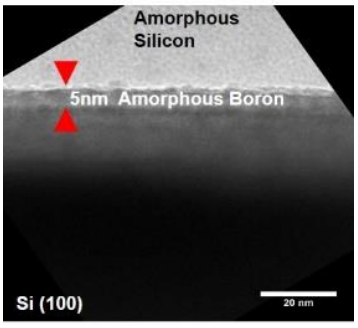

Figure 2. HRTEM imaging of grown B on Si with a thickness of 5nm.

III. CHARACTERIZATION AND RESULTS

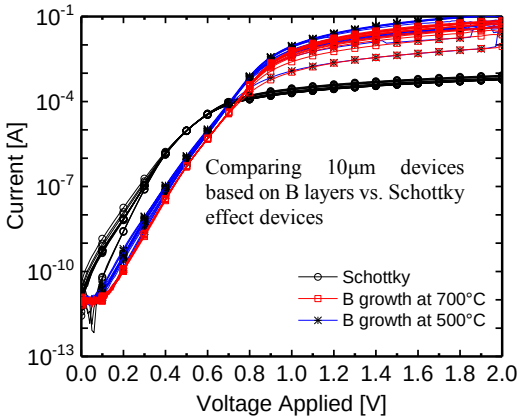

Figure 3. Forward I-V characteristics for multiple 10 µm ultra-shallow $p^+n^-n^+$-junctions utilising B as p^+ layers deposited at 500°C and 700°C resp., also shown are Schottky reference diodes with the same dimensions.

Following the fabrication of the ultra-shallow $p^+n^-n^+$ junctions featuring B layers as the p^+ terminal; we characterize the devices through DC measurements. Along with these devices, we perform measurements on metal junction Schottky diodes created using the exact fabrication procedure, however only excluding the B deposition. These metal junction Schottky diodes serve as a reference and are necessary to understand the operating mechanism of the ultra-shallow $p^+n^-n^+$-junctions.

As seen in Figure 3, ultra-shallow $p^+n^-n^+$-junctions fabricated with B layers at 500°C and 700°C show characteristic behavior of pn-junctions with a higher forward voltage drop as compared to the metal junction diodes. It is worth noting however, diode ideality factors as well as series resistance are affected by the B deposition temperature (see Table 1).

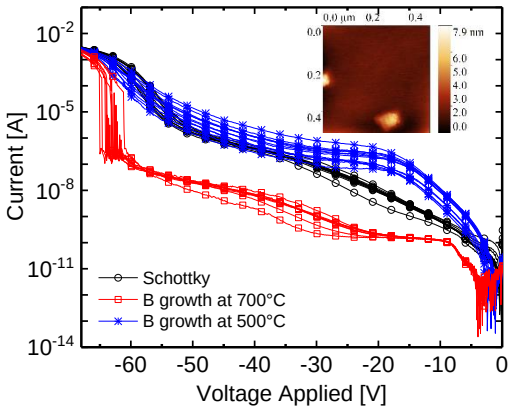

Figure 4. Reverse characteristics for multiple 10µm ultra-shallow $p^+n^-n^+$-junctions deposited at 500°C, 700°C and Schottky junctions. Atomic Force Microscopy (AFM) of sample at 500°C showing clustering and pitting.

TABLE I. TEMPERATURE DEPENDANCE OF ULTRA-SHALLOW $P^+N^-N^+$-JUNCTIONS' CHARACTERISTICS

B Deposition T [°C]	*Ideality Factor, η*	*Series Resistance, R_s [Ω]*
500	1.65 – 1.75	15.5
700	1.4 – 1.5	13

For the extraction of diode series resistances R_S, the diode current I_D and voltage V_D are related generally using Equation (1) where η is the ideality factor and V_T is the thermal voltage.

$$I_D = e^{\frac{V_D}{\eta V_T}} - 1 = e^{\frac{V_{Ideal} - R_S}{\eta V_T}} - 1 \quad (1)$$

$$R_S = \frac{d}{dI}\left(\frac{dV}{dI} \cdot I\right) \quad (2)$$

$$V_{Ideal} = V_D - I \cdot R_S \quad (3)$$

$$\eta = \left(V_T \cdot \frac{d}{dV_{Ideal}} \ln I\right)^{-1} \quad (4)$$

Using Equation (1), we can further derive a relation for R_S shown in Equation (2). After extraction of R_S, the ideal diode voltage V_{Ideal} is calculated using Equation (3). Finally, η is determined using Equation (4). Extracted R_S and η values are shown in Table (1).

This is in agreement with [5]; a Boron Silicide layer is expected to form at 700°C leading to a more conductive interface. However, for depositions at 500°C this is not observed. Schottky diodes show higher series resistance due to high contact resistivity on low doped n-type Si.

When considering the reverse characteristics, samples with B deposition at 700°C show breakdown characteristics typical of pn-junctions with clear onset of avalanche breakdown at approximately 64V. However, this is not observed for samples with B deposited at 500°C. In order to explain this behavior we must consider the B layer properties and growth mechanisms at different temperatures.

For B samples deposited at 700°C, B layers are largely uniform with 3-dimensional growth of B on the surface, indicating high atomic surface mobility. However, for 500°C samples, this is not the case where the layers show clustering of B with surrounding regions of reduced B thickness (pitting). This is due to the lower atomic mobility of the atoms once at the surface. Once clustering commences, only atoms in the immediate local region can join since atoms do not have sufficient energy to propagate far enough on the surface. This was confirmed through AFM as seen in Figure 4. Comparably, this is not the case for 700°C samples as the atomic propagation distance is sufficient to compensate for clustering.

Upon coverage with metal, Al seeps into those pits. At these regions, due to the reduced B thickness, Schottky parasitic currents will occur. Hence causing degraded reverse behavior of these junctions. This can be observed in Figure 4 as a severe increase in leakage current as well as Schottky junction reverse behavior instead of avalanche breakdown as observed in 700°C samples. Pitting does not affect the forward behavior of the junctions however, as the reduced thickness of B is still sufficient to dominate during forward bias. This is confirmed in Figure 3 and can be seen as a similarity of the forward characteristics for B layers at 500°c and 700°C.

Another justification for the reverse bias disparity could be inferred from the growth conditions. Due to the design of the MBE, atomic flux reaches the substrate at an angle. Therefore, due to the height of oxide mask windows, a shadowing effect occurs where parts of the Si surface experience a reduced B flux or none at all. Accordingly, this leads to a partial thinning of the B layer around the edges.

Other groups [6] have also reported perimeter effects leading to a higher electron injection at the B interface outer perimeter. This perimeter effect will profoundly impact the junction's ability at suppressing electron injection. The potential further thinning of the outer B perimeter then exacerbates this effect. This can also be observed upon closer inspection of the forward characteristics as a kink as seen in Figure 6. This kink is a direct result of the higher electron injection due to barrier lowering at the perimeter of the B layer.

One method of circumventing this effect proposed by [6], was the introduction of ion-implanted p^+ Guard Rings (GR) surrounding the B layer interface (see Figure 5). This would then suppress the perimeter barrier lowering and consequent undesired high electron injection.

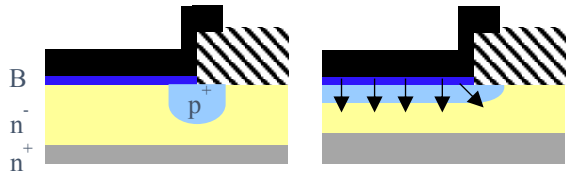

Figure 5. Suppression of perimeter barrier lowering by means of ion-implanted GR (left) [6], suppresion by means of thermal drive in (right).

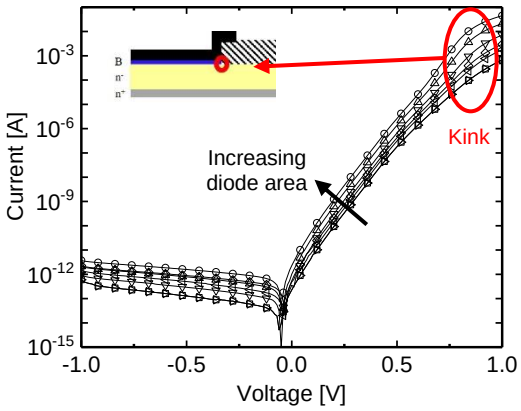

Figure 6. Kink in forward I-V characteristics due to increased electron injection at the perimeters observed for ultra-shallow $p^+n^-n^+$-junctions with B deposited at 700°C.

IV. PERIMETER EFFECT SUPPRESSION

Implementation of GRs is however not possible using in-house technological capabilities. Therefore, another solution had to be implemented. For our purposes, the

solution implemented was a thermal drive-in of the B into the underlying Si.

It was approximated that a 5 min thermal drive-in at 800°C post-deposition will provide sufficient in-diffusion to suppress the observed perimeter effects. This was performed directly after growth within our MBE system. Although not critical for the purposes of this work, the final depth of the junction is estimated to be less than 50 nm. In order to accurately determine the junction depth, further SIMS analysis would be required.

Implementation of the thermal drive-in proved to be successful in suppressing the kink observed in previous characteristics (see Figure 6). This can be seen in Figure 7 and 8 as removal of the kink in the forward I-V characteristics and a further delay of the junction breakdown by 10V.

However, due to a problematic oxide mask wet etching step, an under-etch of the oxide mask occurred. This was determined by observation of halo discoloration of the oxide surrounding the mask windows opened.

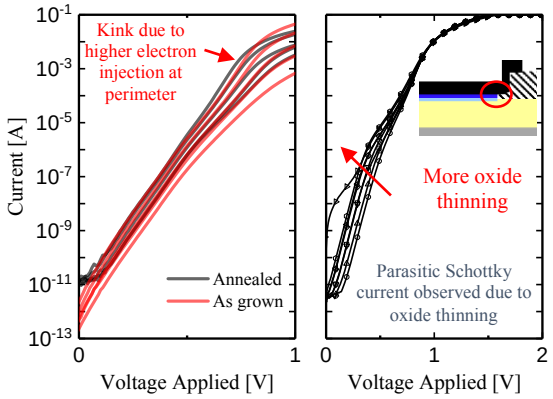

Figure 7. Forward I-V characteristics of multiple sized junctions (80µ to 5µ) with and without thermal drive-in showing suppression of kink caused by increased current injection at perimeters (left) parasitic Schottky current of 10µ junctions seen at various positions across the substrate due to oxide thinning (right). B layers with thickness of 3nm.

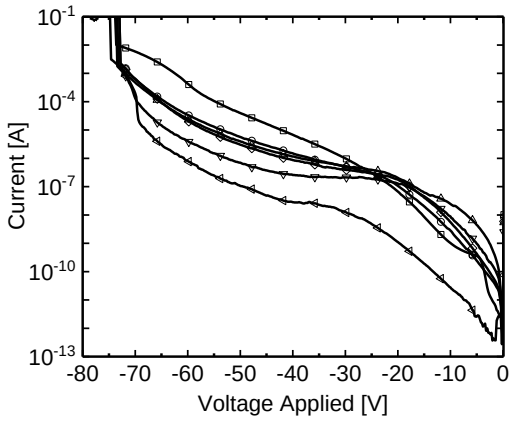

Figure 8. Reverse I-V characteristics showing improved breakdown but increased leakage current for multiple junctions on the same chip with 3nm B.

Due to oxide thinning around the edges, most devices suffered from a parasitic Schottky current that was dominant in the current range less than 10^{-6} A. Different devices across the substrate were affected to different extents due to the uneven etching. This can be observed in Figure 7 (right) as a variation in the severity of the Schottky parasitic current for multiple 10µ junctions across one substrate.

Another implication of the oxide thinning is an increase of the diode leakage current by almost two orders of magnitude. This implies a higher parasitic reverse current in the reverse regime. However, the shift of the breakdown point for the junctions indicates a change in the breakdown mechanism. For samples suffering perimeter effects, breakdown of the junctions occurs most readily at the edges where the highest electrical field is experienced. However for annealed samples, this effect is greatly reduced.

V. Insulated Gate Bipolar Transistors

Since their introduction, Insulated Gate Bipolar Transistors (IGBTs) have established themselves strongly for mid- and high-voltage applications. Due to their improved performance as compared to their predecessors, IGBTs are utilized in many areas of power electronics [7-8].

The IGBT is a minority carrier device displaying typical Metal Oxide Semiconductor (MOS) devices' high input impedance and large current driving abilities typical of Bipolar Junction Transistors.

Many efforts have been made to improve on device characteristics and performance to optimize conduction and switching losses for the best operation possible. Currently, Si based device characteristics have reached their theoretical potential due to the current maturity of Si production technologies. Presently, further improvements are made possible through structural modifications and introduction of new material systems [9].

For devices aimed at high-voltage ranges, the dominant contributor to device on-resistance is the thick low doped drift region. However, when scaling down devices for mid-voltage range, this does not hold and other parts of the device must be considered as well.

Through the results of this work, we propose utilizing ultra-thin B layers as a source for hole injection in the IGBT as a collector contact. Potential improvements would be a significant reduction in collector contact thickness (from hundreds of microns down to a few nanometers) and accordingly reduction of device on-resistance. Furthermore, a simpler scheme of fabrication and overall improvement in performance could be achieved. The proposed IGBT structure can be seen in Figure 9.

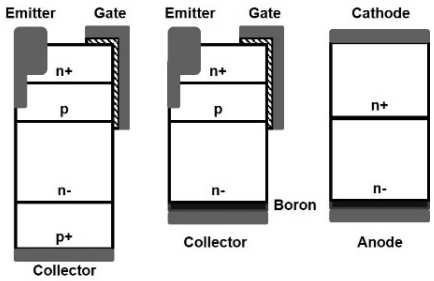

Figure 9. Proposed IGBT structure including B layer as compared to typical vertical IGBT.

VI. CONLUSION

We investigated B layer deposition using MBE. For high blocking junctions, we found B depositions at 700°C to be favorable. Reducing B thickness to only 3nm yielded fully functional devices. We investigated these layers by means of $p^+n^-n^+$-junction diodes for electrical characterization. We attempted to suppress previously observed perimeter effects through brief thermal drive-in of the junctions. Although leakage currents were higher due to other problematic aspects of fabrication, annealed samples displayed a reduction in the perimeter kink effect and improved junction breakdown characteristics. We proposed the use of these ultra-thin junctions as collector contacts for IGBTs for reduced device on-resistance and improved performance.

ACKNOWLEDGMENT

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Non-linear Behavior of Al-contacted Pure Amorphous Boron (PureB) Devices at Low Temperatures

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Abstract - Deposition of pure amorphous boron (PureB) layers on n-type Si results in p^+n-like devices even in cases where B in-diffusion during the deposition is not expected. It is suspected that such behavior is due to the formation of an interfacial hole layer (IHL) between the PureB and Si. To further investigate physical mechanisms governing conduction of holes across the PureB/Si interface and through the IHL, electrical measurements were performed from room temperature down to cryogenic temperatures as low as 100 K. In this paper, current-voltage (*I-V*) measurements are made on structures where the PureB connects to p-type Si regions. One set of devices comprises ring-shaped structures designed for measuring the conductance through the IHL. In these structures, the PureB layer is deposited in rings that are contacted at the inner and outer perimeter with Al. Another set of samples includes devices where the PureB layer was deposited on p-type bulk Si. At room temperature, a close to linear change of current with voltage was seen irrespective of the PureB layer thickness and post-deposition processing. Lowering the operating temperature led to an increasingly non-linear *I-V* characteristics. Plausible explanations for the non-linear behavior are considered and discussed in the paper.

I. INTRODUCTION

Aluminum deposition is a common way of contacting semiconductor devices such as those made in Si technology [1], [2]. Depending on the physics and chemistry of the metal-semiconductor contact [3], Al can form a Schottky barrier to the semiconductor the rectifying behavior of which is used in Schottky devices [2]. In other devices, the Schottky barrier may impede the desired operation because an ohmic contact of the Al to the semiconductor is required. Consequently, fabrication methods have been developed to enable tuning of the Schottky barrier height [3]–[5]. Alternatively, tunneling of majority carriers through the Schottky barrier can be promoted to achieve ohmic contacting [2]. This is, for example, the case when Al is deposited on highly doped p-type Si [2], [6].

Al-contacting is commonly used in pure amorphous boron (PureB) deposition technology for fabrication of PureB photodiodes [7]–[9]. The attraction of PureB technology lies in the formation of nm-thin PureB layers obtained by Si exposure to diborane (B_2H_6) at different processing conditions and temperatures from 400°C to 700°C [10], [11]. Although the combined thickness of the PureB layer and B-diffused Si obtained from 700°C depositions can be lower than 10 nm, the saturation current density of PureB photodiodes is in the range of conventional deep-diffused pn-junction devices and can be lower than 10^{-19} A/μm^2 [10], [12]. An effective electron blocking mechanism was determined by emitter Gummel number measurements of devices where PureB was incorporated in the emitter region [12]. The physical mechanisms governing such behavior need to be further investigated. It has been proposed that a monolayer of acceptor states formed at the PureB/Si interface is responsible for creating a layer of fixed negative charge that can maintain an interfacial hole layer (IHL) which effectively behaves as a highly doped p-region [10], [13]. The presence of this p-type region is substantiated by experimental evidence showing high conductance along the PureB-Si interface even for deposition at 400ºC where no doping of the bulk Si is expected [14]. In other earlier work on deposition of amorphous boron layers on Si, they were found to cause band bending at the interface with the Si [15]–[17], supporting the existence of an IHL. In PureB photodiodes, the bonding leading to the formation of the IHL has been assumed to be responsible for the exceptionally good performance with respect to low dark currents, high stability, and robustness in harsh environments [18]. Moreover, it has been shown that the PureB serves as a diffusion barrier for pure aluminum deposition [19].

The nature of the Al-on-PureB contact and the relationship to the PureB/Si IHL is still a subject of investigation [20]. The experimental evidence gathered on PureB p^+n-like diodes that were metallized, shows that the electron blocking properties are unimpeded when PureB layer thickness is larger than 2 nm. However, increasing the thickness of the PureB layer negatively impacts the series resistance [12]. For longer B_2H_6 exposure time, the PureB thickness can be increased to some nm and for such thick layers the contact resistivity was shown to increase linearly with the thickness. A boron resistivity from 500 Ωcm to 10 kΩcm was determined where the spread was related to the process history of the deposition chamber [21].

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However, for layers thinner than about 3 nm, the contact resistivity is attractively low and it is suspected that the PureB layer then behaves as a high-ohmic tunneling layer [12]. A simulation study of an Al-Si configuration where a thin Si layer, on top of bulk Si, mimics the PureB properties in terms of doping concentration and thickness showed that an IHL could well be responsible for the observed blocking of the electron injection [20]. In the model, it was proposed that Al forms a Schottky barrier to the boron top layer through which holes tunnel from the IHL to the Al. The plausibility of this model was supported by measurements from [12].

In this paper, low temperature measurements of two sets of PureB devices are presented. They were performed with the aim of investigating the nature and the physical properties of Al-contacts to PureB layers and the connection to the IHL formed at the PureB/Si interface. Current-voltage (*I-V*) measurements are performed at temperatures from 100 K to 300 K for ring-shaped devices fabricated with different PureB deposition and post-deposition steps. Non-linearities in *I-V* characteristics of ring-shaped structures were observed at cryogenic temperatures for thick PureB layers. Similarly, non-linear behavior of the *I-V* characteristics was seen for measurements performed at lower operating temperatures for thick PureB layers on p-type bulk Si even though the contact to substrate was ohmic.

II. DEVICE FABRICATION

Two types of devices were examined. One type, ring-shaped structures, were fabricated with the basic design described in [22] that allows the extraction of the sheet resistance along PureB/Si interface. The schematic cross section and layout are shown in Fig. 1 where the width, L_{PB}, and radius, r_g, of the ring are indicated. The PureB layer was deposited in the whole ring and the inner and outer perimeter was contacted by Al.

The substrates used for fabrication of the PureB ring-shaped diodes were 1-10 Ωcm n-type (100) Si wafers. Guard rings at the ring perimeter were created by B^+ implantation to a dose of 10^{13} cm^{-2} at an energy of 180 keV through a 300-nm thick thermal oxide. The backside of the wafer was implanted with P^+ to a dose of 10^{15} cm^{-2} at an energy of 150 keV. The activation of the impurities was performed with a 20-min anneal at 1000°C. Wet etching of the oxide was performed to expose the Si surface for the PureB layer deposition at a temperature of 700°C. The duration of the PureB layer deposition was either 6 min or 20 min which gave a PureB layer thickness of approximately 3 nm or 8 nm, respectively [23]. Some of the devices were subjected to subsequent annealing steps at either 800°C or 850°C for 20 min and 30 min, respectively.

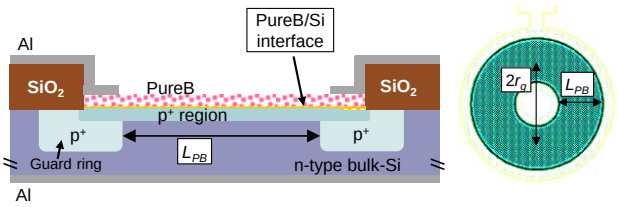


Figure 1. Schematic cross section (left) and top view (right) of ring-shaped devices that have PureB rings of varying width L_{PB} and radius r_g.

TABLE I. PUREB DEPOSTION AND POST-DEPOSITION FABRICATION STEPS FOR RING-SHAPED STRUCTURES.

Device name	PureB deposition	Post-deposition treatment	Junction depth (nm)
B[6,700]	6 min @ 700°C	-	6
B[20,700]	20 min @ 700°C	-	10
B[20,800]	20 min @ 700°C	10 min @ 800°C	35
B[20,850]	20 min @ 700°C	30 min @ 850°C	125
B[20,900]	20 min @ 700°C	20 min @ 900°C, PureB removal	190

The subsequent annealing had the effect of increasing the junction depth since the PureB layer can be used as an abundant source of B [10]. One of the samples where the PureB is deposited at 700°C for 20 min is subjected to a 900°C anneal lasting 20 min after which the PureB layer is removed by plasma etching. All the variations in the PureB deposition procedure and the post-deposition steps are listed in the Table I. Junction depths to a bulk doping concentration of 10^{15} cm^{-3} were obtained from the process simulations performed as described in [24]. Contacting of the devices was performed by the 875 nm Al deposition at 350°C which was patterned, and plasma etched down to about 150 nm followed by a HF wet etching to remove Al in the light-entrance windows. Al was deposited on the backside of the wafer at room temperature to a thickness of 675 nm to contact the cathode.

The second type of test structure, a simple contact to p-type bulk Si, was fabricated by depositing PureB in oxide windows to a p-type 2-5 Ωcm (100) Si substrate on which a 0.2-µm-thick surface doping of 10^{17} cm^{-3} was grown by epitaxy. The PureB layer was deposited in another reactor than for the ring-structures. It was a 10 min deposition at 700°C that gave a layer thickness of ~ 7 nm. With this reactor it was known that the resistivity of the PureB was in the 10 kΩcm range while for the ring-structures a much lower resistivity of about 500 Ωcm was expected [21]. The PureB was metalized as for the ring-structures on the front and back of the wafer.

III. CURRENT-VOLTAGE (*I-V*) MEASUREMENTS

Low temperature measurements of the ring-shaped PureB devices were performed in a cryostat. Liquid nitrogen was used as a cryogen so temperatures as low as 77 K could be achieved. A Keithley parameter analyser 4200 SCS was used to measure the *I-V* characteristics of the devices. The measurements of the PureB contacts to p-type bulk Si were performed through the wafer using a wafer prober with a temperature-controlled chuck that enabled temperatures down to 3.5°C.

A. Ring-shaped PureB devices

Ring-shaped structures with $L_{PB} = 70$ µm were measured at temperatures from 100 K to 300 K. The PureB deposition conditions and post-deposition treatments are listed in Table I. The *I-V* characteristics were measured from the outer to inner contacts of the ring-structure by applying a voltage V_D to the inner contact. The results for the devices B[6,700] and B[20,700] that have no post-deposition anneals are shown in Fig. 2a and 2b, respectively. The B[6,700] device displays linear *I-V*

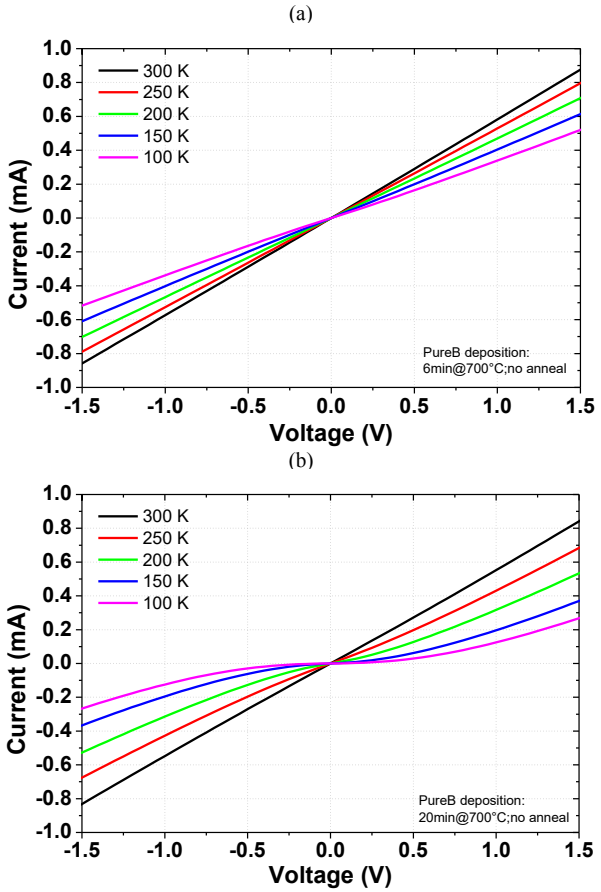


Figure 2. *I-V* characteristics of the PureB layer ring-shaped structures for temperatures between 100 K and 300 K where the PureB layer is deposited for (a) 6 min at 700°C, (b) 20 min at 700°C.

characteristics irrespective of the device temperature. At 300 K, the B[20,700] device also displays linear behavior but as the temperature decreases, the *I-V* characteristics start to show non-linear behavior.

Measurements on the structures where the PureB layer is deposited at 700°C for 20 min followed by post-deposition anneals show similar behavior in terms of non-linearities at low operating temperatures. The comparison of the *I-V* characteristics for the devices with various PureB deposition processes is shown in Fig. 3 for temperatures of 100 K and 300 K. Post-deposition anneals increase the junction depth of the p-type region under the PureB layer

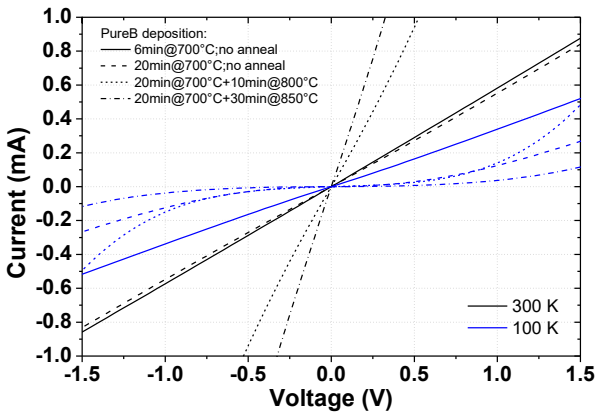


Figure 3. Comparison of the *I-V* characteristics for various PureB deposition and post-deposition steps for the temperatures of 100 K and 300 K.

due to B in-diffusion. These deeper junctions with higher peak doping have lower sheet resistance which could be seen from the *I-V* characteristics. As the temperature decreases, non-linear effects start to dominate the characteristics irrespective of the junction depth. Therefore, it is plausible that the thickness of the PureB layer is responsible for the observed non-linearities.

The current through the PureB ring was measured at 0.1 V for temperatures between 100 K and 300 K and plotted as an Arrhenius plot in Fig. 4. Measurements of the B[20,900] device where the PureB layer was removed prior to metallization is also shown for comparison. This device has the largest current level which is almost constant for the whole temperature range. The Al contact to the highly-doped p-type region obtained from the B in-diffusion forms a tunneling Schottky contact. Almost constant current with temperature was also measured for the device where the PureB layer deposition is performed for 6 min at 700°C. It is suspected that the PureB layer in such a device is sufficiently thin to allow for tunneling to the Al contact through the PureB layer. On the other hand, the devices with a thicker PureB layer deposited at 700°C for 20 min with different post-deposition annealing steps, show an exponential decrease of the current with decreasing operating temperature. The assumption that the holes tunnel to the Al contact through PureB layer, as proposed in the rudimentary model [20], would explain this behavior. A discussion on the tunneling mechanism and the connection to non-linearities in the *I-V* characteristics is provided in Section III.

B. Devices with PureB deposited on p-type bulk Si

To further study the impact of Al contact on conductance of holes in PureB devices, measurements were performed on PureB-on-p-type bulk devices with an area of 40×40 μm^2. The measured *I-V* characteristics for temperatures of 3.5°C, 10°C, 20°C, 30°C and 40°C are shown in Fig. 5. Non-linear behavior is observed even for temperatures as high as 40°C. The *I-V* characteristics are symmetrical around a bias voltage of 0 V. As the temperature decreases, non-linear effects start to become more prominent. As in the case of non-linearities in the ring-shaped structures, it is assumed that the thickness of the PureB layer is responsible for observed behavior. Moreover, for this sample a much higher PureB resistivity

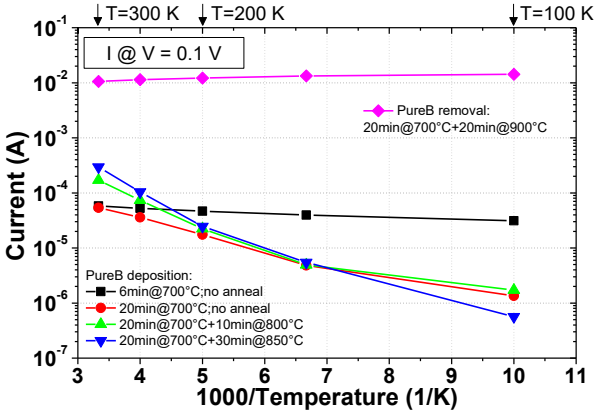


Figure 4. Arrhenius plot of the current measured at 0.1 V for the ring-shaped devices with various PureB deposition and post-deposition steps. For comparison, the measurements of the sheet resistance structure where the PureB layer is removed prior to the Al deposition is also shown.

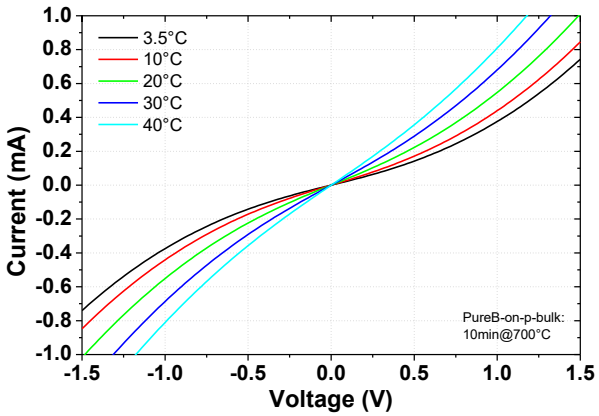


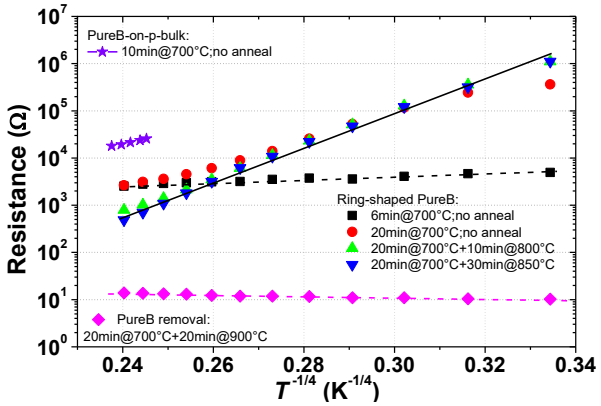
Figure 5. *I-V* characteristics of the device where PureB layer is deposited for 10 min at 700°C on p-type bulk for temperatures between 3.5°C and 40°C

is expected which may explain that the non-linearities could be observed even at room temperature.

C. *Comparison of temperarure dependent resistance extracted for various PureB devices*

From the *I-V* characteristics of the samples with $L_{PB} = 100$ µm, the resistance at 0.1 V bias voltage was calculated and the results are plotted with respect to $T^{-1/4}$ and shown in Fig. 6a for ring-shaped PureB devices with different deposition and post-deposition fabrication steps. For comparison, the resistance of the device where the PureB layer is removed and the device where the PureB layer is deposited on a p-type substrate is also plotted. The resistance of the B[6,700] device shows constant values irrespective of the temperature. However, the devices where the PureB layer is deposited for 20 min at 700°C show exponential increase of the resistance with decreasing $T^{-1/4}$ which characterizes variable range hopping conduction characteristic to amorphous materials [25]. The resistance with respect to $T^{-1/4}$ calculated at bias voltages of 0.1 V, 0.3 V and 0.5 V is shown in Fig. 6b. The measurements were performed for the devices B[6,700] and B[20,850]. For the device with 6-min PureB deposition it is suspected that the holes tunnel to the Al contact showing no change in the resistance for different bias voltages. Since VRH exhibits field dependence [26], the change in characteristics of thick PureB samples with bias could be due to VRH in the PureB layers. However, Schottky contacts can have similar temperature and bias dependence. Simulations of back-to-back Schottky contacts with a barrier of 4.25 eV to n-type bulk with doping of 10^{18} cm^{-3}, assuming the area of the device of 5000 µm^2 and a tunneling contact were performed in Sentaurus Device [27]. The work-functions define the slope of the resistance with respect to the temperature change. Simulation results are shown in Fig. 6b. For comparison, the analytical model for VRH is used to model temperature dependent resistance. Given that both Schottky contacts and the VRH mechanism show similar behavior with temperature, it could not be concluded with certainty that only the VRH or the Schottky resistance dominates the series resistance of the devices.

(a)



(b)

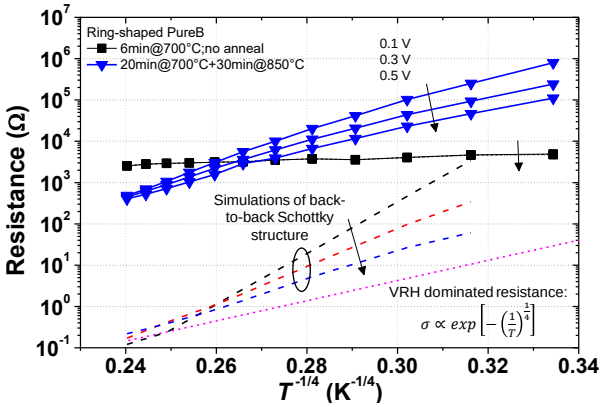


Figure 6. (a) Resistance at 0.1 V with respect to $T^{-1/4}$ for the PureB devices where the PureB layer is fabricated with various deposition and post-deposition fabrication steps. (b) Resistance with respect to $T^{-1/4}$ of the B[6,700] and B[20,850] devices. The resistance is calculated at voltages of 0.1 V, 0.3 V and 0.5 V. For comparison, simulations of a back-to-back Schottky structure and a VRH dominated resistance are shown.

IV. Discussion on the Origin of Non-Linear Behavior of Al-Contacted PureB Layers

For thick PureB layers the results show that the *I-V* characteristics change from almost ohmic behavior at room temperature to non-linear behavior at low temperatures. An explanation for this is offered by the rudimentary model of PureB-on-Si where Al forms a Schottky barrier to the PureB layer [20]. The band diagram in support of this model is made based on assumptions taken from [20] and is shown in Fig. 7. The thickness of the top layer was 5 nm, the IHL was modeled by a high fixed interface charge concentration, $N_I = 5\times10^{13}$ cm^{-2} at the interface between the Si top-layer and the bulk. The Al metal with work-function of 4.1 eV was assumed to form a Schottky contact to the top-layer with a barrier for holes. It is suspected that the holes from the IHL tunnel to the Al when the PureB/Si interface is brought close to the Al contact by a reduced thickness of the PureB layer. Thin PureB layers would thus form an ohmic contact. On the other hand, for thick PureB layers, tunneling of holes from the IHL to the Al contact would be suppressed at lower temperature. Both mechanisms, a change of the Schottky barrier tunneling with temperature or VRH, would result in non-linearities in the *I-V* characteristics as seen at low temperatures, and with

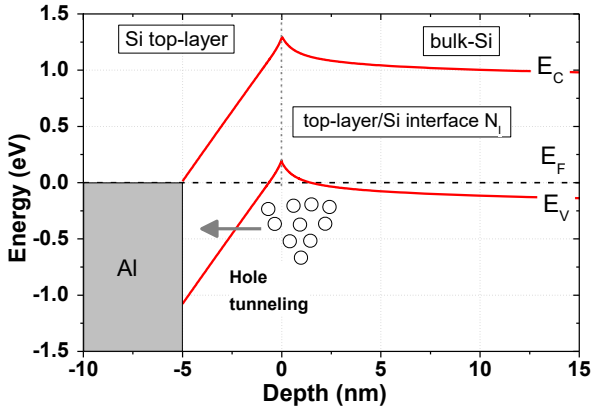


Figure 7. Band diagram of the Al-contacted Si top-layer on Si bulk with a thickness of the top-layer of 5 nm. The interface hole layer is simulated by assuming a fixed interface charge concentration of 5×10^{13} cm^{-2}.

the present measurements it is not possible to discern between the two.

Any further analysis is complicated since the PureB in ring-shaped structures was contacted by Al on either end of the IHL. It is assumed that contacts represent two back-to-back Schottky diodes with a resistor between, defined by the sheet resistance of the IHL, as shown in Fig. 8. To properly analyze such a structure, impedance spectroscopy could be used with an appropriate equivalent network [28], [29]. If a Schottky contact is formed, capacitive behavior of the Al-contacted PureB layers should become visible.

V. CONCLUSIONS

At room temperature, irrespective of the PureB thickness, the *I-V* characteristics are close to linear. It can be assumed that the Al contact to PureB is ohmic. Linear behavior is preserved even at cryogenic temperatures as low as 100 K for the samples with thin PureB layers or in cases where the PureB layer is completely removed. In contrast, ring-shaped structures with thicker PureB layers show non-linearities in *I-V* characteristics which are more pronounced when measurements are made at low temperatures. While VRH conduction in the PureB layer could well dominate the series resistance of the devices with the thicker PureB layers, similar temperature dependence would also be expected if the resistivity of the Schottky contact plays a role. In addition, tunneling of holes from the IHL to an Al Schottky contact would also explain the lower series resistance of devices with thin PureB layers that does not change with temperature. Likewise, both VRH and Schottky contacting could be responsible for the non-linear behavior observed for temperature dependent measurements of devices with the PureB layer deposited on p-type bulk Si. For this sample a much higher PureB resistivity is expected which may explain that non-linearities could be observed even at room temperature. The change of the tunneling with temperature is explained by the fact that the holes are tunneling from IHL to Al contact passing through PureB layer. Since the PureB layer should have an abundance of trap states, both VRH and direct tunneling of holes to the Al contact could support this behavior. This explanation is in accordance with the rudimentary model of the Al-contacted PureB-on-Si configuration proposed in [20]. Impedance spectroscopy should be performed to possibly confirm the assumption that a Schottky barrier is formed by Al deposition on PureB.

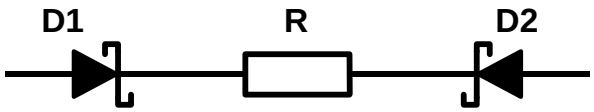


Figure 8. Back-to-back Schottky diode configuration representing the PureB contacted ring-shaped structure.

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Impact of TCAD Model Parameters on Optical and Electrical Characteristics of Radiation-Hard Photodiode in 0.35µm CMOS Technology

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***Abstract*—In this paper, a variability Design of Experiment (DoE) is performed on a radiation-hard photodiode structure in order to understand how the physical parameters of the device impact its spectral responsivity and dark current. The varied physical parameters describe the carrier mobility, lifetime, energy bandgap and recombination models. The electrical and optical performance of the device are simulated using TCAD software, as a function of varied physical parameters. The simulations are calibrated to the device measurements. The analysis of the design showed that the carrier lifetime is the most influencing parameter that impacts both the spectral responsivity and the dark current. Mobility parameters and Auger recombination parameters impact the spectral responsivity, while the energy bandgap at 340 K impacts the dark current. Finally, the model parameters that fit the measured dark current are obtained by the thorough variation simulations.**

Keywords—Image sensor, Ionizing radiation, Radiation hardness, TCAD software, Parameter variability, Screening, Design of Experiment, Spectral responsivity, Dark current

I. INTRODUCTION

Semiconductor detectors come in different varieties, like charge-coupled device (CCD) and CMOS image sensor (CIS), and generally consist of a sensing device and a readout circuit [1]. CIS are becoming more and more popular due to their wide application range, especially in terms of high-radiation environments. There are hybrid versions of a CIS, where the sensing device and the readout circuit are made on separated wafers and afterwards are bonded together. Due this processing, the hybrid CIS offers a large fill factor, and as the sensor and the readout circuit are independently optimized the other advantage is high radiation hardness. Their main disadvantage is the expensive and complex processing and production. On the other hand, the monolithic active pixel sensors (MAPS) are CMOS compatible which simplifies their production, as well as makes it cheaper. Their main disadvantage is the low operating voltage required for the CMOS readout circuit, and because of that the large depletion region is not achieved, thus reducing the charge collection efficiency and reducing the radiation hardness of the sensor. To overcome this issue, depleted MAPS (DMAPS) use the implementation of a high-resistivity starting material in order to get a large depletion region and increase the charge collection efficiency and radiation hardness [2] [3]. Overall, CIS are used in radiation environments, especially for medical purposes and space applications. In medical applications, specifically in the Computed Tomography (CT) scanner, X-rays are used during the scan. The X-rays cause ionization damage, creating positive traps in the oxide and interface states near the silicon/silicon-oxide interface. These defects impact the recombination rate and trapping of the charge carriers, thus reducing the spectral responsivity, increasing the dark current and degrading the overall performance of the sensor [4] [5]. High radiation hardness can also be achieved by using a special high-lifetime starting material, where the charge collection is dominated by diffusion due to the large diffusion length. As the depletion region area is small, the capacitance is reduced, but the collection speed is then limited because it is dominated by diffusion and not drift effects.

The goal of this paper is to calibrate the TCAD model parameters in simulations of a photodiode structure with high-lifetime epitaxial layer intended for the use in X-ray detectors. The photodiode's spectral responsivity and dark current are simulated as a function of varied recombination, mobility and energy bandgap parameters and are compared to the measurements. The main impact on recombination rate have carrier lifetimes and their impact on photodiode characteristic are examined by TCAD simulations [6]. Moreover, carrier mobility impacts the diffusion length which is a crucial parameter if the charge collection is dominated by diffusion. As the photodiode is implemented in the CT scanner, the range of the operating temperature of the device is between 27 °C and 67 °C, so the energy bandgap parameters are also varied in the statistical design.

II. SIMULATED PHODODIODE STRUCTURE AND PARAMETER VARIABILITY

The photoactive area of the photodiode is 565µm x 795µm, and consists of multiple n-well islands that act as the collection electrodes for the photo-generated charge.

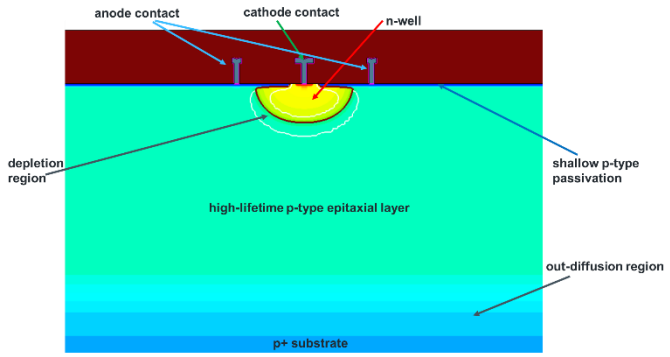

Fig. 1. Cross-section of the simulated photodiode under the reverse voltage of 1.25V. The photodiode consists of a small n-well island that is surrounded by shallow p-type passivation layer. It is positioned in the high-lifetime p-type epitaxial layer, which was thermally grown on top of the low resistivity p-type substrate material.

A. *Photodiode structure*

The photodiode is fabricated in an industry standard 350 nm high-voltage (HV) CMOS technology and simulated using TCAD software. The resulting 2D cross-section is shown in Fig. 1. Model parameters used in fabrication sequence simulations are calibrated with the actual process. The I-V and spectral responsivity characteristics of the photodiode structure are then analyzed by device simulations.

Fig. 2 presents the comparison of the measured and initially simulated I-V curve of the photodiode using default TCAD parameters. The dark current was normalized to 1 island and is below 1 pA. Fig. 3 presents the comparison between measured and simulated spectral responsivity curves.

B. *Parameter variability*

In order to calibrate the simulations with the measured data, variation of different physical parameters has been performed. The simulations of these varied parameters give information on how each parameter impacts the spectral responsivity and the dark current.

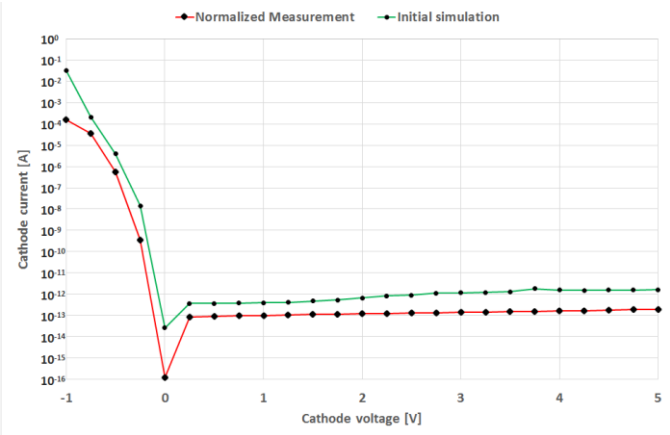

Fig. 2. Comparison of the normalized measurement and simulated I-V curve using default TCAD parameters of the photodiode structure. The normalization was done by dividing the measurement values by the total number of n-well islands used in the photodiode. The measurement was performed at 340 K and the operating voltage was 1.25V in reverse bias.

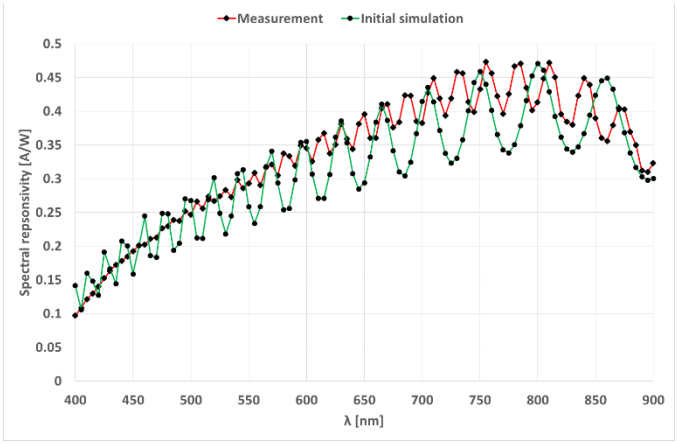

Fig. 3. Comparison of the measured and simulated spectral responsivity curves of the photodiode structure.

The energy bandgap is calculated in simulations according to:

$$E_g(T) = E_{g0} + \delta E_{g0} + \frac{\alpha T^2}{\beta + T} \qquad (1)$$

where T is temperature, E_{g0} is energy bandgap at 300 K and parameters $\alpha = 4.73 \cdot 10^{-4}$ eV/K and $\beta = 636$ K.

Doping dependent mobility of electrons is modeled by the Masetti model:

$$\mu_{dop} = \mu_{min1} + \frac{\mu_{const} - \mu_{min2}}{1 + \left(\frac{N_{A,0} + N_{D,0}}{C_r}\right)^{\alpha}} - \frac{\mu_1}{1 + \left(\frac{C_s}{N_{A,0} + N_{D,0}}\right)^{\beta}} \qquad (2)$$

where μ_{min1}, μ_{min2}, μ_1 are reference mobilities, C_r, C_s are reference doping concentrations, α, β are the exponents μ_{const} is the low-doping reference mobility and $N_{A,0}$ and $N_{D,0}$ are acceptor and donor concentrations [7].

SRH parameters are modeled by the Scharfetter relation:

$$\tau_{dop}(N_{A,0} + N_{D,0}) = \frac{\tau_{max}}{1 + \left(\frac{N_{A,0} + N_{D,0}}{N_{ref}}\right)^{\gamma}} \qquad (3)$$

where $N_{ref} = 10^{16}$ cm^{-3} is the reference doping profile and the exponent, $\gamma = 1$. As the electron effective mass is lower than the hole effective mass, electron mobility is higher than the hole mobility. Because of that, the diffusion length for electrons is larger than for holes. Also, the lifetime of electrons is higher than lifetime of holes [8]. In TCAD it was modeled so that hole lifetime is one third of the electron lifetime.

Auger recombination is modeled in TCAD by:

$$R^A_{net} = (C_n n + C_p p)(np - n^2_{i,eff}) \qquad (4)$$

where n, p are electron and hole concentrations respectively and the $n_{i,eff}$ is the effective intrinsic concentration. In the equation, parameters C_n and C_p are dependent on the Auger parameters and are calculated according to:

$$C_x(T) = \left(A_{A,x} + B_{A,n}\left(\frac{T}{T_0}\right) + C_{A,n}\left(\frac{T}{T_0}\right)^2\right)\left[1 + H_x exo\left(-\frac{x}{N_{0,x}}\right)\right] \qquad (5)$$

where *x* represents electrons (*n*) or holes (*p*) depending on whether electrons or holes are used.

In Table I, parameters with their initial values are shown. The parameters are placed in four groups, where each group describes different physical settings: energy bandgap, doping dependent mobility, Shockley-Read-Hall (SRH) recombination, Auger recombination. In addition to those parameters, as the photodiode is used in the CT scanner, where the operating temperature goes up to 67 °C (340 K), simulations are also performed at 320 K (spectral responsivity) and 340 K (spectral responsivity and dark current).

III. Design of Experiments and Results

In order to see the impact of the above mentioned parameters, the calibration methodology shown in Fig. 4 has been used. The block diagram of the calibration methodology consists of multiple steps. First, the parameters are varied in a wide range to see whether they impact the observed responses. Parameter screening is then performed, where these parameters are varied and sorted out according to the impact they have on photodiode electrical and optical characteristics. The analysis of the Design of Experiment (DoE) shows the variability of the simulated responses as a function of the varied parameters such that the simulations could be calibrated with the measurements.

Table I. Simulation input parameters and their initial values. Parameters are shown in 4 groups that describe energy bandgap, doping-dependent mobility, SRH recombination and Auger recombination settings.

Variability table		
Group	***Parameter***	***Value***
Energy bandgap	E_{g0}	1.16964 eV
Doping dependent mobility of electrons	μ_{min1}	52.2 cm²/Vs
	μ_{min2}	52.2 cm²/Vs
	μ_1	43.4 cm²/Vs
	C_r	$9.68 \cdot 10^{16}$ cm^{-3}
	C_s	$3.43 \cdot 10^{20}$ cm^{-3}
	α	0.68
	β	2
SRH recombination	τ_{maxE}	1 ms
	τ_{maxH}	one third of τ_{maxE}
Auger recombination	A_{AE}	$6.7 \cdot 10^{-32}$ cm^{6}s^{-1}
	A_{AH}	$7.2 \cdot 10^{-32}$ cm^{6}s^{-1}
	B_{AE}	$2.45 \cdot 10^{-31}$ cm^{6}s^{-1}
	B_{AH}	$4.5 \cdot 10^{-33}$ cm^{6}s^{-1}
	C_{AE}	$-2.2 \cdot 10^{-32}$ cm^{6}s^{-1}
	C_{AH}	$2.63 \cdot 10^{-32}$ cm^{6}s^{-1}
	H_{AE}	3.46667
	H_{AH}	8.25688
	N_{0E}	10^{18} cm^{-3}
	N_{0H}	10^{18} cm^{-3}

In the first set of simulations, a study of the impact of each parameter within their physically defined range of variations is performed. The study highlights the relative contribution of each parameter to the responses considered. As an example, the effect of varying the parameter α, ranging from 0.374 to 0.986, and implemented in the doping dependent mobility equation (2), is shown in Fig. 5. It can be seen that the SR curve decreases in values as the parameter increases, as it impacts the total doping concentration in the denominator of mobility equation. Basically, for larger α values, mobility is reduced, and therefore the diffusion constant of the carriers is also reduced. This means that the carriers recombine at shorter distance, and less charge is then collected by the collection electrode, which can be seen in reduced SR values. It can be noted that the variability of this parameter mostly influences lower and higher spectrum region. The absorption of the photons is determined by the absorption coefficient. For lower wavelengths, absorption of the photons is closer to the surface of the photodiode where the space charge region is placed. In that region, the doping levels are higher, either in n-well or in p-passivation region implying a smaller mobility and a higher impact of α for the same physical distance. For higher wavelengths, light is absorbed deeper in the structure, in the region with the out-diffusion from the substrate into the epitaxial layer. The absorption region is further away from the collection electrode, and because of that the diffusion length and hence the charge carriers are more likely to recombine before reaching the depletion region. Therefore, the mobility has a higher impact in the higher wavelength spectrum region (800-900 nm).

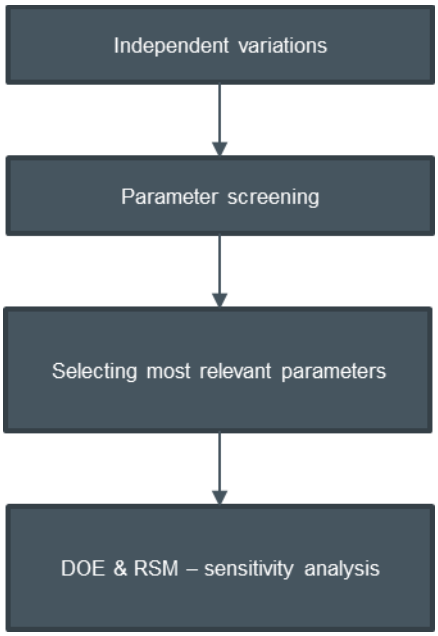

Fig. 4. Block diagram of the calibration methodology. Based on the DoE, Response Surface Model (RSM) is created which gives statistical parameter variability according to the quadratic relation of the input parameters.

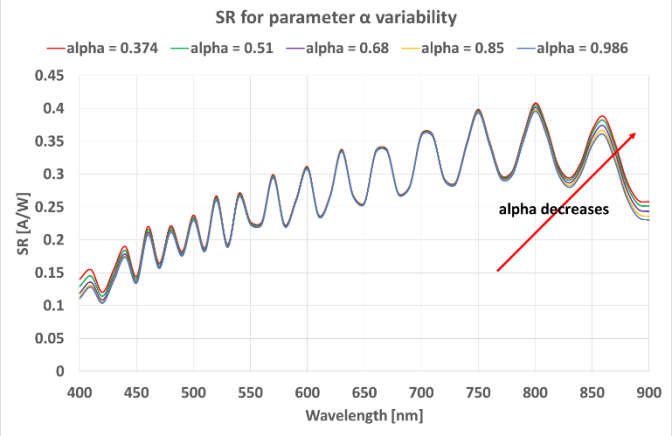

Fig. 5. Impact of different α values from equation (2) on the spectral responsivity simulation at 340 K. Parameter α is ranging from 0.374 to 0.986.

After the first set of simulations, a screening design using the L24 Plackett and Burman model [9] has been generated and simulated. The screening percentages of all input parameters are selected such that the parameter values are in physical range of their initial values. According to the Table II, each value was screened with the tolerances compared to the initial values. This screening model was then imported in TCAD software and was simulated [10]. Analysis of the screening model provided a Pareto graph shown in Fig. 6. It indicates the importance of the impact of each parameter on the spectral responsivity (at 320 K and 340 K, and at 500 nm and 900 nm) and the dark current (at 340 K and 1.25 V). It can be observed that for spectral responsivity, the largest effect comes from the lifetime, mobility and auger parameter variability, and for the dark current, the largest impact has the energy bandgap variation as well as the lifetime variations.

Table II. Screening percentage of all input parameters according to the parameter group.

Screening percentage			
Energy bandgap	***Doping dependent mobility of electrons***	***SRH recombination***	***Auger recombination***
+/- 1.50%	+/- 20%	+/- 5000%	+/- 20%

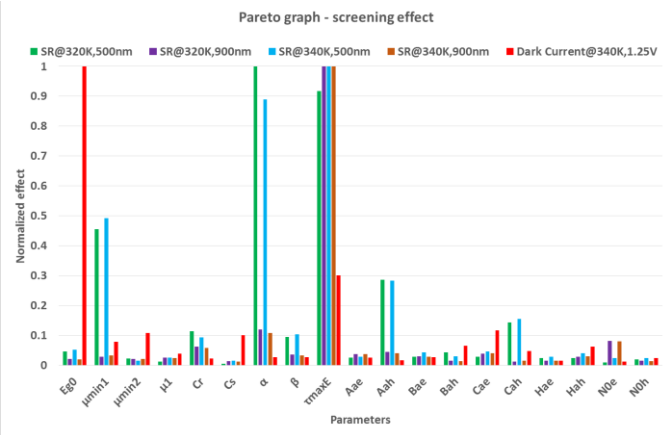

Fig. 6. Pareto graph for the screening analysis.

After the analysis, the parameters with the highest impact are selected. For the spectral responsivity, τ_{maxE}, α, μ_{min1}, A_{AH}, C_r and N_{0E} parameters were selected as the most important parameters and for the dark current, E_{g0} and τ_{maxE} were selected. The other parameters are neglected as they have a considerably smaller effect either on spectral responsivity or on dark current. According to a central composite full design (with face centered) a response surface model (RSM) was designed. It is designed by taking into account the screened values and also the initial value. The RSM gives information on how the observed responses behave according to a quadratic function of the most relevant parameters. The sensitivity analysis of each parameter is obtained by RSM techniques that deliver the variability of each response according to the variation of the input parameters within their range. After the sensitivity analysis, calibrated parameter values that achieve the best fitting of spectral responsivity have been extracted, and are shown in Table III. The variability of the spectral responsivity as a function of the variability of τ_{maxE}, at 340 K in comparison with the normalized measurement, is shown in Fig. 7. Lifetime has the highest impact in the higher wavelength spectrum region (800-900 nm), as it affects recombination rate and for lower lifetime, recombination increases, leading to the degradation in spectral responsivity. In general, the effect of other varied parameters is quite low, and additional calibration, where geometrical and physical parameters are adjusted, is needed [11]. The sensitivity analysis of RSM for the dark current is shown in Fig. 8. It can be noted that the calibrated curves match the measured curve quite accurately.

Table III. Calibrated parameter values for spectral responsivity simulation.

Parameter	***Initial value***	***Calibrated value***
μ_{min1}	52.2 cm^2/Vs	62.64 cm^2/Vs
C_r	$9.68 \cdot 10^{16}$ cm^{-3}	$11.6 \cdot 10^{16}$ cm^{-3}
α	0.68	0.544
τ_{maxE}	0.001 s	0.05 s
A_{AH}	$7.2 \cdot 10^{-32}$ $cm^6 s^{-1}$	$5.76 \cdot 10^{-32}$ $cm^6 s^{-1}$
N_{0E}	10^{18} cm^{-3}	$0.8 \cdot 10^{18}$ cm^{-3}

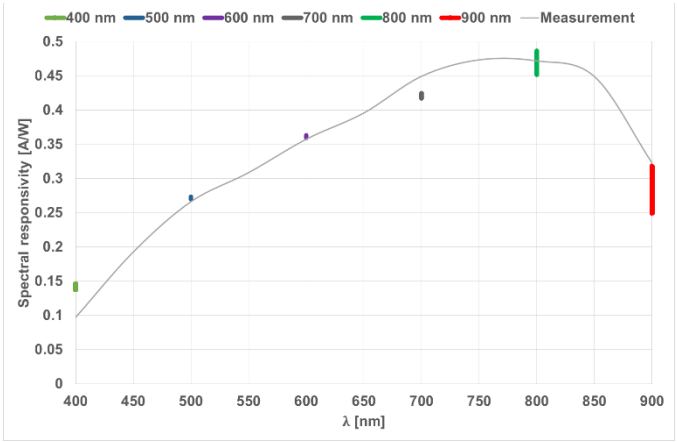

Fig. 7. Variation of spectral responsivity as a function of variability of the electron lifetime.

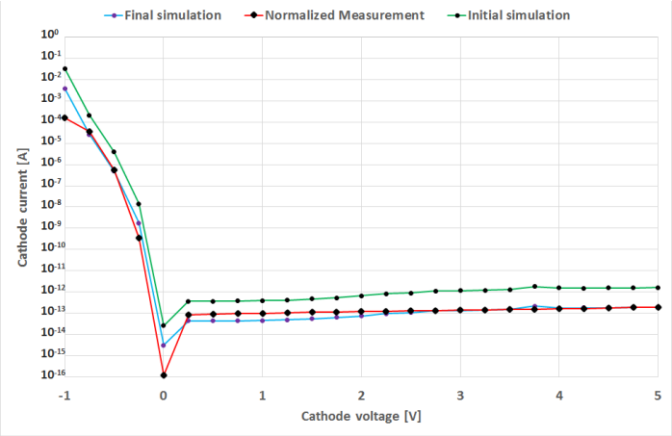

Fig. 8. Sensitivity analysis of dark current: comparison between measurement, initial simulation and final simulation with the calibrated parameters.

IV. Conclusion

A variability method is presented where parameters that describe energy bandgap, SRH recombination, carrier mobility and Auger recombination are varied in order to understand how each parameter impacts the spectral responsivity and the dark current of the examined photodiode. Analysis of the statistical methodology showed us that carrier lifetime and mobility have the highest impact on the spectral responsivity and that the measured dark current can be fitted only by adjusting the electron lifetime. The variability of spectral responsivity as a function of carrier lifetime variability showed the range of responsivity values around the calibrated point, which is determined by the calibrated lifetime value. As the other parameters have small effect on spectral responsivity, additional calibration where geometrical and physical parameters are adjusted, is needed to fully calibrate the spectral responsivity. Additionally, this study have shown which model parameters has the highest impact on I-V and optical responsivity characteristics of silicon photodiodes. It can give the guidelines to the designer to optimize the substrate material and those fabrication steps that can impact the most important parameters. Moreover, it also provides the information of which parameters must be calibrated most accurately during the simulations of such photodiodes.

Acknowledgment

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Simulation-based optimization of Ge-PIN-photodiodes with Al nanohole arrays for refractive index sensing

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***Abstract* - Biosensors based on propagating surface plasmon polaritons (SPPs) or localized surface plasmon polaritons can detect molecular binding events with high sensitivity via refractive index changes. In plasmonic nanohole arrays in thin metallic films, the transmission spectra can exhibit characteristic, asymmetric peaks (Fano resonances) that are particularly sensitive to refractive index changes. We integrated Al nanohole arrays into the metallization of vertical Ge-PIN-photodiodes and observed Fano resonances in the photocurrent generated in the Ge-PIN-photodiode, thus fabricating a compact refractive index sensor that can be directly integrated with signal conditioning and wireless transmission circuits. Here, we present simulation results for our devices using finite difference time domain (FDTD) method. We investigate the influence of nanohole array parameters such as hole diameter and array pitch on Ge-PIN-photodiode response. Furthermore, we show that Ge-PIN-photodiode property can be optimized by adjusting thicknesses of the Al layer as well as the semiconductor layers of the Ge-PIN-photodiode underneath. Here, the Al thickness particularly has a large influence on optical properties of our devices. We concluded that sensors consisting of Al nanohole arrays with Ge-PIN-photodiodes can achieve high sensitivities and promising applications in refractive index sensing.**

Keywords - photodetector; plasmonics; sensor;

I. INTRODUCTION

Integrated biosensors could pave the way for mobile and robust applications in medical diagnostics, food safety and security. Refractive index sensors can detect changes in the refractive index in the vicinity of the sensor surface induced by molecular binding events and can be used as biosensors with high sensitivities. Plasmonic nanohole arrays (NHAs), i.e. regular arrays of holes with subwavelength diameters in thin metallic films, have been investigated for refractive index sensing [1]–[3]. Surface plasmon resonances on NHA films can lead to extraordinary transmission at certain wavelengths, i.e. large peaks in the transmission spectra that often exhibit asymmetric line shapes (Fano resonances) [4],[5]. The peak of the Fano resonance is strongly influenced by change of refractive index.

Plasmonic structures can, in principle, be integrated with semiconductor devices such as photodiodes [6]. Our previous experimental results have shown that plasmonic NHAs structured in the metallization of vertical Ge-PIN-photodiodes lead to peaks in the responsivity (photocurrent divided by incident optical power) that can be attributed to extraordinary transmission through the NHAs [7]. The peaks show a strong shift as the refractive index of the surrounding dielectric is changed. Our device constitutes a promising step towards on-chip refractive index sensors that can be integrated with signal conditioning and wireless transmission circuits. A schematic figure as well as cross section of the semiconductor device layers, the metallic NHA and a SiO_2 layer acting as passivation between semiconductor and Al metallization is shown in Figure 1. Here, we present the results of detailed numerical calculations to investigate the influence of parameter changes on shape and peak of the resonances. We discuss the influence of array pitch Λ, hole diameter D, SiO_2 layer thickness d_{SiO2} and Al layer thickness d_{Al} on simulated responsivity spectra. Our aim is to identify relevant parameters for device optimization in order to enable the future development of highly sensitive, integrated refractive index sensors.

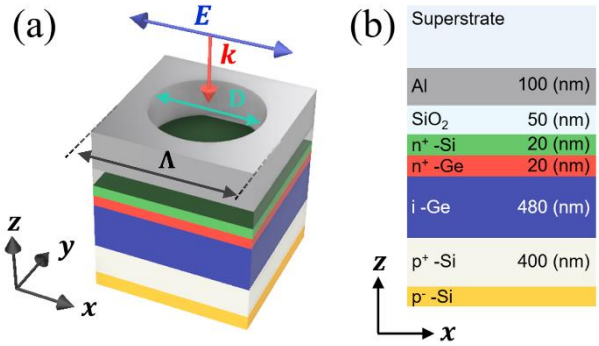

Figure 1. (a) Three-dimensional model of Ge-PIN-photodiode for FDTD simulation, (b) layer structure in *xz* plane

II. FDTD SIMULATION MODEL

FDTD methods are widely used to simulate optical properties [1],[2]. Here, we used the simulation software Lumerical [10] for all calculations. The three-dimensional simulation model is shown in Figure 1 (a). The incident wave is defined as plane wave, propagating along the *z* direction. The boundary conditions are set to Periodic Boundary Conditions (PBC) for the *x* and *y* directions and to Perfect Matched Layers (PLM) as absorber for the *z*

direction. The layer structure of Ge-PIN-photodiode is shown in Figure 1 (b).

Transmission monitors are placed within the *i*-Ge layer to calculate absorption in *i*-Ge, from which the device responsivity can be inferred. The transmission monitor gives the value of the optical power normalized to the power of the incident wave. The responsivity can be calculated using the following expression [10],

$$R = \frac{\frac{1}{2}\int\{Re(S_{\text{in}}) - Re(S_{\text{in}})\}dA}{\frac{hc}{\lambda}} \frac{Q}{P_{\text{source}}} \qquad (1).$$

S_{in} and S_{out} are the Poynting vectors above and below the *i*-Ge layer stack, h is Planck 's constant, c is the speed of light in free space, λ is the wavelength and Q is the elementary charge. The calculation is based on power losses in *i*-Ge layer caused by imaginary part of refractive index. The Ge permittivity was obtained from previous experimental characterizations of the material and used as input for the simulation.

III. RESULTS AND DISCUSSION

A. *Responsivity without nanohole arrays*

As a reference, we first calculated the absorption in the Ge layers in the absence of any metallization layer in order to be able to identify the influence of the nanohole array in subsequent simulations. The corresponding responsivity spectra in the wavelength range of 1100 nm to 1550 nm are shown in Figure 2. The sudden drop in responsivity for wavelengths around 1550 nm results from the material bandgap: for photons with energies above 0.8 eV, i.e. the energy of the direct transition in Ge, the absorption in the material is strongly reduced. The responsivity spectra show no dependence on the superstrate refractive index n_{Sup}, which is varied around 1.321, i.e. around the refractive index of water. The simulated responsivities are higher than the experimentally measured responsivities in our devices, as shown in Figure 2. This is due to the fact that a quantum efficiency of 1 is assumed in simulation. In experiment, factors such as absorption in the thin but highly n-doped Si- and Ge-layers (with $N_D = 1 \cdot 10^{20}$ cm^{-3} in both layers), which are not included in the simulation, contribute to a reduction in the measured responsivity compared to the simulated one. Finally, the simulated responsivity spectra show a drop at smaller wavelengths than the measured ones. This is a consequence of the residual strain in the Ge of the fabricated devices, which results in a slightly smaller energy of the direct transition compared to simulation.

B. *Refractive index of superstrate*

Responsivity spectra are strongly modified in the presence of nanohole arrays with an array pitch of 950 nm and hole diameters D = 540 nm (Figure 3). Extraordinary transmission through the nanohole arrays leads to the appearance of peaks in the responsivity spectra with asymmetric line shapes characteristic of Fano resonances. The peak wavelength shifts when the

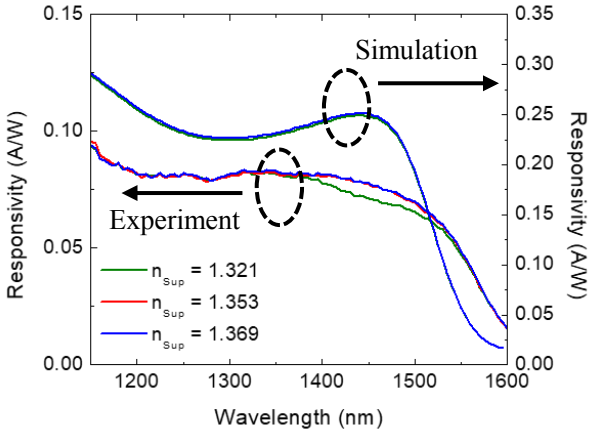

Figure 2. Responsivity spectra of Ge-PIN-photodiodes without nanohole arrays

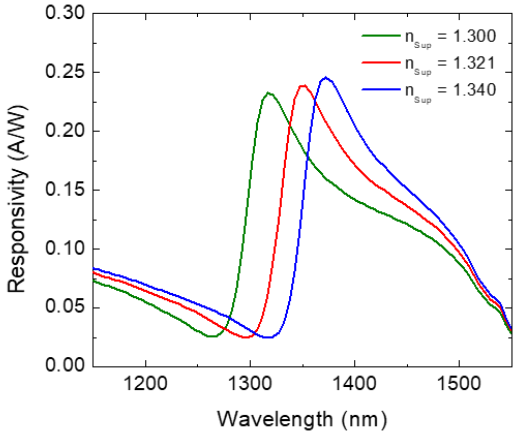

Figure 3. Responsivity with change of refractive index of superstrate, array pitch Λ = 950 nm, diameter D = 540 nm.

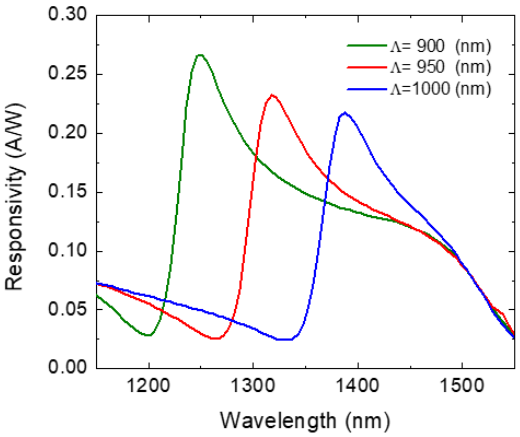

Figure 4. Responsivity with change of array pitch, refractive index n_{Sup} = 1.321, diameter D = 540 nm.

superstrate refractive index is changed: Figure 3 shows that the resonance peaks appear at 1297 nm, 1318 nm and 1338 nm as the superstrate refractive index changes from n_{Sup} = 1.32 to n_{Sup} = 1.34. For the following parameter variations, we keep the superstrate refractive index fixed at n_{Sup} = 1.321 (corresponding to DI water), i.e. we investigate the influence of parameter changes on device responsivity in the operating range around this value for the refractive index. For future applications, the operating range of the sensor can be adjusted e.g. by varying the array pitch and a parameter optimization should be performed specifically for the intended operating range.

The sensitivity S can be obtained using the peak shift of resonance $\Delta\lambda_{max}$ caused by difference of refractive indices Δn_{Sup}, defined by

$$S = \frac{\Delta\lambda_{max}}{\Delta n_{Sup}} \quad (2)$$

and is commonly used to characterize and compare refractive index sensors [1],[11].

In our case, the peak shift scales almost linearly with refractive index of superstrate, and the sensitivities extracted from the simulated responsivities are 977.17 nm/RIU and 1053.7 nm/RIU. These large sensitivities are beneficial for refractive index sensing applications.

C. Array pitch

The periodicity of the square NHAs strongly influences the peak position of the resonance and can be adjusted to define the operating wavelength in sensor applications. The simulated responsivity spectra show almost constant peak shifts from 1249 nm to 1318 nm and 1388 nm, for an array pitch of 900 nm, 950 nm and 1000 nm, respectively (Figure 4). These wavelengths are in good agreement with the analytical estimates of peak resonances at wavelengths λ_{max} as a result of the excitation of surface plasmon resonances (SPR) on the nanohole arrays according to [12],[13]

$$\lambda_{max} \approx \frac{\Lambda}{\sqrt{i^2+j^2}} \sqrt{\frac{\varepsilon_d \varepsilon_m}{\varepsilon_d+\varepsilon_m}} \quad (3).$$

Here, Λ is the array pitch of the NHAs, i and j are diffraction orders for x and y directions, and ε_d and ε_m are the permittivities of the dielectric and metallic material respectively.

D. Diameter of nanohole

Our simulations show that a variation of hole diameter has only a weak influence on the peak position in the responsivity spectra (Figure 5). However, the responsivity increases with increasing hole diameter, since a larger hole diameter can be expected to lead to an increase in overall transmission. Also, the peak can be seen to broaden slightly with increasing diameter. The hole diameter can, therefore, be chosen to obtain either narrower resonances or a higher device responsivity.

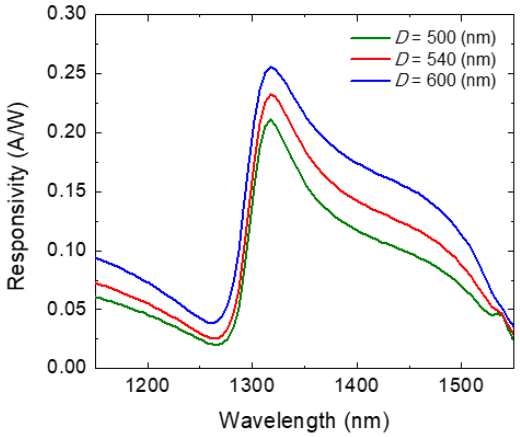

Figure 5. Responsivity with change of hole diameters, refractive index n_{Sup} = 1.321, array pitch Λ = 950 nm.

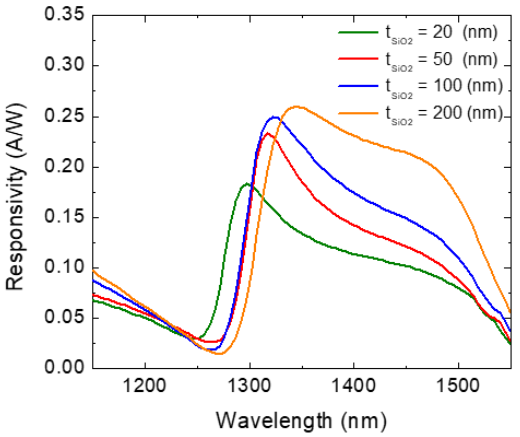

Figure 6. Responsivity with change of SiO_2 thickness, refractive index n_{Sup} = 1.321, array pitch Λ = 950 nm, diameter D = 540 nm.

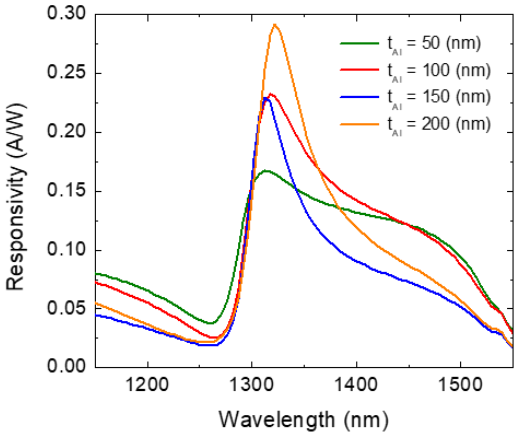

Figure 7. Responsivity with change of Al thickness, refractive index n_{Sup} = 1.321, array pitch Λ = 950 nm, diameter D = 540 nm

E. Thickness of SiO_2 layer

We expect the sensor responsivity to depend on the effective index of the medium in which the NHA is embedded, and this includes the device layer structure that supports the NHAs. The boundary surface between metal and dielectric is associated with excitation of surface plasmon resonances as well as the superstrate-faced side. Superstrate and substrate side can interact with each other by coupling of SPPs through the hole, which leads to an increased transmission. A change in SiO_2 thickness effectively shifts the refractive index on the substrate side to a lower refractive index. An increase in SiO_2 thickness can therefore be seen to increase the total responsivity (Figure 6), however, the resonance width also can be seen to increase strongly as the SiO_2 thickness exceeds 100 nm. This indicates that there is an optimal SiO_2 thickness that can be selected to provide a resonance shape that is optimal for sensing.

F. Thickness of Al layer

The thickness of the Al layer is also associated with the SPR interaction at the superstrate and the substrate sides. Figure 7 shows the simulated responsivity spectra as the thickness of the Al metallization layer d_{Al} is varied between 20 nm and 200 nm, while the thickness of SiO_2 is fixed at 50 nm. With increasing Al thickness, the resonance peak becomes more pronounced and the peak responsivity increases, indicating that the thickness of the Al layer can be adjusted to significantly improve sensing properties at a fixed resonance wavelength.

IV. Conclusion

We carried out extensive simulations using FDTD methods to investigate nanohole arrays in Al films on top of a vertical Ge-PIN-photodiode semiconductor layer structure for refractive index sensing. The simulation results clearly show that extraordinary transmission though the Al nanohole arrays can lead to sharp peaks that can be detected directly in responsivities of the Ge-PIN-photodiodes. Furthermore, we investigated how the array pitch Λ, the hole diameter D, the SiO_2 layer thickness d_{SiO2} and the Al layer thickness d_{Al} affect the simulated responsivity spectra. An optimized sensor should have both a high peak responsivity, thus requiring less input power from the external light source to generate photocurrent, and a narrow resonance peak, which makes it easier to quantify refractive index changes. Among the parameters investigated here, the thickness of the Al layer, thus, has the strongest potential to optimize the responsivity of the Ge-PIN-photodiode for refractive index sensing. We conclude that Ge-PIN-photodiodes are promising candidates for integrated refractive index sensing.

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Performance of $C_6H_8O_7$-treated and H- and Cl-passivated Ge-MOS-capacitances on Ge-Virtual-Substrate on Si(001)

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***Abstract* – As Moore's law is approaching its physical limitations, transistor concepts besides the classical Metal Oxide Semiconductor Field-Effect Transistor (MOSFET) have been invented. The Tunneling FET (TFET) is a promising candidate due to the theoretically predicted subthreshold swing below 60 mV/dec of this device concept. However, Si is not the substrate of choice for TFETs – the carrier mobility and the resulting on-currents are too low. Therefore, Germanium (Ge) is suggested as active material for p-channel TFET (p-TFET) as compound III/V-materials are suggested as n-TFET active material with a high-k material as Gate oxide. This development entails new issues in the manufacturing process. That is because the Ge/high-k-interface is not of natural high quality as the Si/SiO_2-interface, causing the Gate-MOS-capacitance to be the critical part of the TFET. New cleaning and passivation methods for the Ge surface are necessary. Nevertheless, Si will remain the substrate material of choice, what requires co-integration of those materials on Si. As a first attempt, we show Ge-MOS-capacitors with Al_2O_3 as Gate Oxide on Ge-Virtual-Substrate on Si(001) of good performance with hysteresis down to 0.6 V. We propose a combination of conventional and unconventional cleaning steps such as H_2O_2 and $C_6H_8O_7$ (Citric Acid) followed by H- and Cl-passivation. The discussed data are corrected for series resistance and – when possible – for parasitic capacitances that can be used as indicators for cleaning and passivation efficiencies.**

Keywords – Ge-TFET, Ge-MOSCAP, passivation.

I. INTRODUCTION

Due to its high hole mobility Germanium (Ge) is discussed as active material [1] for p-type Tunneling Field Effect Transistors (TFETs). As Silicon (Si), Ge is a group IV material on the periodic table and can therefore be integrated on a Si chip. However, new process development is necessary to fabricate Ge-devices successfully. With respect to transistors as TFETs, the most critical and crucial part in the process is the semiconductor surface treatment before Gate Oxide deposition [2]. Every trap or contamination at this interface will affect the device performance. For the best device performance, a perfectly clean and smooth semiconductor-oxide interface is needed. In contrast to Si, Ge does not offer a native oxide that can be used as Gate Oxide [3]. High-k materials as Aluminum Oxide (Al_2O_3) are commonly used. While for Si the well-known RCA cleaning leaves clean and smooth surfaces, no cleaning procedure exists that achieves comparable results for Ge. Standard wet chemical treatment that contains Hydrogen Peroxide (H_2O_2) cannot be applied on Ge since H_2O_2 oxidizes Ge. Combined with an aqueous solution that dissolves the formed oxide leads to significant material loss and a rough surface [4]. Another problem with standard wet chemical cleaning as Hydrofluoric Acid (HF), is that Germanium Dioxide (GeO_2) is indeed removed but a certain suboxide (GeO_x) remains. In order to achieve the best interface properties, however, all oxide residuals have to be removed. Surprisingly, [5] showed successful GeO_2 and GeO_x removal with 2.4 M aqueous Citric Acid (CA) treatment for 60 seconds at room temperature.

We propose a combination of CA cleaning with standard wet chemical treatments as H_2O_2, HF and Hydrogen Chloride (HCl). Since HF leaves and Hydrogen terminated (H-terminated) and (HCl) a Chlorine terminated (Cl-terminated) surface, these two treatments can also be considered a passivation technique [4]. Therefore, we oxidize the Ge-surface first with H_2O_2 to generate a sacrificial oxide that afterwards is completely removed with CA. Subsequently, the sample is either treated with aqueous HF (2.5 %) or HCl (30 %). In order to not impact the surface after cleaning and passivating no deionized (DI) water rinse is performed after CA and HF/HCl treatment.

The second part of this work is concerned with the correct interpretation of the acquired C-V data. We do not expect ideal C-V behavior for two reasons: Firstly, our Ge-active layer is grown on a VS-technology on Si resulting in reduced crystal quality compared to Czochralsky-grown Ge-wafers. Secondly, we use a simple and fast Metal-Oxide-Semiconductor-Capacitance (MOSCAP) process without mesa-etching but with back side contact. Fringing capacitances will impact the data and the whole stack has a certain series resistance (R_s) that might be high. Moreover, we do not expect to eliminate all parasitic capacitances (C_E) at the semiconductor interface. Accordingly, R_s and C_E have to be taken into account when modelling the equivalent circuit.

In this work we use the model for capacitance reconstruction from measured lossy MOS capacitance-voltage characteristic derived by [6] (see figure 1). In addition to the Si-model derived by Lehovec in [7] Rs

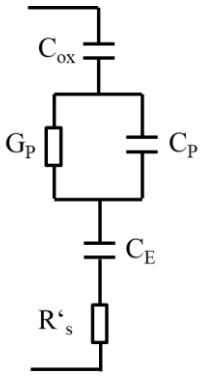

Figure 1. Aquivalent model for MOS-structures with lossy MOS C-V characteristics derived by [6]

and C_E caused by non-ideal semiconductor-oxide interface are considered. Therefore, the model enables us to calculate the intrinsic capacitance and conductance of MOSCAPs represented in the model by parallel capacitance (C_P) and parallel conductance (G_P), respectively. The model was also applied on MOSCAPs on VS with backside contact and therefore assumed to be suitable for our devices. However, the model is still derived for the Si-platform. We discuss its applicability to our MOSCAPs.

II. Experimental Procedure and Results

A. Material growth

One intrinsic Ge sample was grown by molecular beam epitaxy (MBE) on a six-inch p+ Boron (B) doped Si(001) substrate by using Ge-VS-technology. After heating the Si substrate up to T_{sub} = 330 °C, the Ge-VS layer with nominal dopant concentration $N_A = 10^{20}$ cm^{-3} and thickness of d_{VS} = 100 nm was deposited. Doping was realized using B and the dopant flux was pre-calibrated in Ge using four-point probe measurements. Ge grows lattice matched on Si only for the first monolayers. Therefore, the Ge film grown on top of the Si substrate is fully relaxed. This results in a bad crystal quality which is compensated for the Ge-surface by thermal annealing at 850 °C. The annealed surface functions as Ge-VS [8]. After annealing the active, intrinsic Ge-layer with nominal thickness of 300 nm was deposited at T_{sub} = 160 °C. The wafer was diced into 8 chips.

B. MOSCAP fabrication

For MOSCAP fabrication, a simple and fast process was used. First, the samples A, B, C, and D were cleaned and C and D passivated as shown in Table 1.
Sample A is only exposed to a H_2O_2 dip and functions as reference sample. A DI water rinse is only carried out after H_2O_2 dip. As well as after CA and passivation with HF or HCl, respectively, the sample is only shortly dipped in DI water to remove any visible residuals and blow dried with N_2. After cleaning and passivating the samples were directly loaded into the Atomic Layer Deposition (ALD) chamber with an additional test sample. A d_{ox} = 13.4 nm thick Al_2O_3 film was deposited at a process temperature of T_{ALD} = 300 °C. For sample A to D, oxide deposition was directly followed by 800 nm Aluminum (Al) gate electrode sputtering. The Si backside was cleaned by HF dip to remove the native SiO_2 and sputtered with a 1.4 µm thick backside contact. Lastly, the Gate electrode was structured by wet etching with Phosphoric Acid. Circuit Metal-Oxide-Semiconductor-Capacitance (MOSCAP) structures with an area of K1 = $6.4 \cdot 10^{-7}$ m^2 (K1-structures) were formed. The Al_2O_3 layer on the test sample was structured with Buffered-HF (BHF) in order to confirm d_{ox} with AFM. The oxide capacitance is calculated by

$$C_{ox} = \varepsilon_0 \cdot \varepsilon_{rel,Al2O3} \cdot A/d_{ox} \quad (1)$$

where ε_0 is the vacuum permittivity, $\varepsilon_{rel,Al2O3}$ is the relative permittivity of Al_2O_3 with a value of 8, K1 defines the area and d_{ox} is the thickness of the oxide The resulting oxide capacitance of a K1-structure is $C_{ox,K1}$ = 3.4 nF.

TABLE I. CLEANING AND PASSIVATION OF SAMPLES A-D

	A	B	C	D
H_2O_2 (20 s)	X	X	X	X
CA (60 s)		X	X	X
HF (10 min)			X	
HCl (10 min)				X

TABLE II. CLEANING OF AFM-SAMPLES E-H

	E	F	G	H
H_2O_2 (20 s)		X		X
CA (60 s)			X	X

C. AFM studies

In order to investigate the impact of the cleaning methods on the surface roughness, the samples E, F, G and H were exposed to the two different cleaning steps as shown in table 2.
Sample E is the untreated reference sample. AFM was immediately performed after cleaning on four spots on

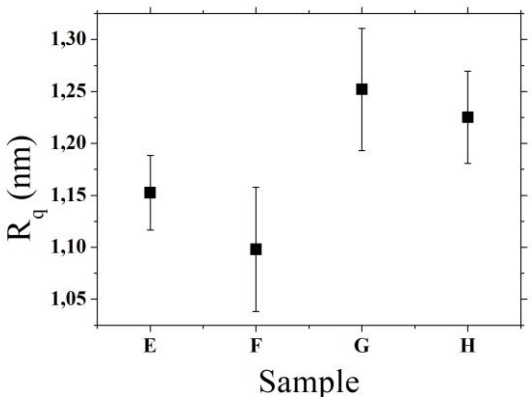

Figure 2. Comparison of surface roughness represented by mean value and standard deviation of amplitude parameter R_q of different surface cleaning steps

each sample. The amplitude parameter R_q was used to characterize the surface roughness. Figure 2 shows the mean value and standard deviation of R_q of each sample. The surface roughness of the untreated sample E can be reduced by a H_2O_2 dip (compare to sample F). Sample F exhibits the smallest surface roughness but also a large standard deviation. That means the surface roughness varies across the sample. CA increases the surface roughness from the virgin state and leads also to a higher standard deviation (sample G). By using H_2O_2 dip before CA (sample H), the surface roughness is indeed increased but the standard deviation is nearly constant compared to the initial state. Altogether, the mean value of the surface roughness does not change drastically. Considering the partially large standard deviations, it can be stated, that the cleaning steps have a negligible impact on the surface roughness.

D. Electrical characterization

C-V measurements were performed on K1-structures of each sample. The swept DC signal was superimposed with an AC signal of ΔV = 30 mV amplitude and frequency f = 500 kHz. On samples C and D, frequency dispersion was investigated additionally. The C-V

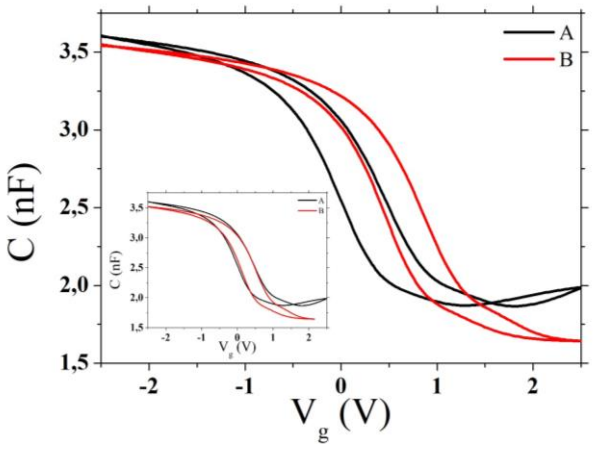

Figure 3. Comparison of C-V characteristics of K1-structures on samples A (black) and B (red) measured at f = 500 kHz, the inset shows the C-V characteristic of sample B corrected for the occurred flat band voltage shift compared to the C-V characteristic of sample A

measurements were carried out with Keithley 4200-SCS. Hysteresis h is extracted at $(C_{max} + C_{min})/2$. Figure 3 compares the C-V characteristics of K1-structures on samples A (black) and B (red) measured at f = 500 kHz.

Three main differences are observable when the sample is additionally cleaned with CA. First, the flat band voltage is shifted to higher voltages. This means that CA treatment leads to more positive charge at the oxide-semiconductor surface. However, the hysteresis reduces from h = 495 mV to h = 390 mV and the ratio $D_q = C_{max}/C_{min}$ has increased. Figure 4 shows the comparison of the reference sample A to samples C and D that were additionally treated with HF and HCl to create an H- and Cl-passivation, respectively.

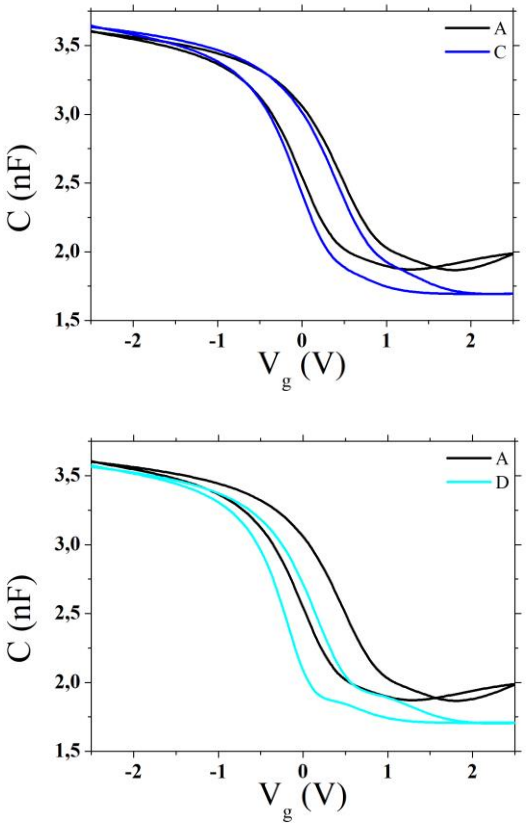

Figure 4. Comparison of C-V characteristics of K1-structures on samples A (black) and C (blue) measured at f = 500 kHz (topt) and comparison of C-V characteristics of K1-structures on samples A (black) and D (cyan) measured at f = 500 kHz (bottom)

Both passivation methods impact the C-V characteristics. It was found that the H-passivation on sample C (left) compensates the flat band voltage shift caused by CA treatment. However, the positive effect on the hysteresis is compensated too. Compared to reference sample A, the treatment of sample C has improved its C-V characteristics as it shows good saturation behavior in inversion and improved D_q. The Cl-passivation on sample D (right) also causes a flat band voltage shift to smaller voltages that even over-compensates the shift caused by CA treatment. Moreover, the hysteresis could be reduced to h = 350 mV and the C-V characteristic shows the same good saturation behavior in inversion. Looking at the figures of merit, the Cl-passivation in combination with H_2O_2 and CA cleaning seems to be the best surface treatment technique investigated in this work. However, the K1-structures on sample C show the most homogenous behavior across a large area (data not shown).

E. Data correction by using model for lossy C-V characteristics [6]

For all four samples, the measured capacitance in accumulation was larger than calculated C_{ox} which is in contradiction to theory. Therefore, a model for lossy C-V characteristics derived by [6] was applied to correct our data for series resistance and parasitic capacitance. We

observed an unexpected positive frequency dependence in accumulation, meaning the capacitance in accumulation increases with increasing frequency. This is in contradiction to theory [9]. It was found that it is not possible to calculate C_E by using this model when the C-V characteristics were measured at f = 500 kHz. For this reason, frequency dispersion was investigated on samples C and D from f = 5 kHz to f = 400 kHz. C_E can be calculated only for measurements with f < 400 kHz in our case. The reason for this is that only below this frequency (f < 400 kHz) the measured capacitance in accumulation becomes smaller than C_{ox}. This condition has to be meet for C_E calculation. Otherwise, C_E cannot be extracted and the C-V data connot be corrected. However, calculation of R_s is not bound to any conditions and can be calculated for all frequencies investigated Figure 5 shows the measured and corrected C-V data of sample D.

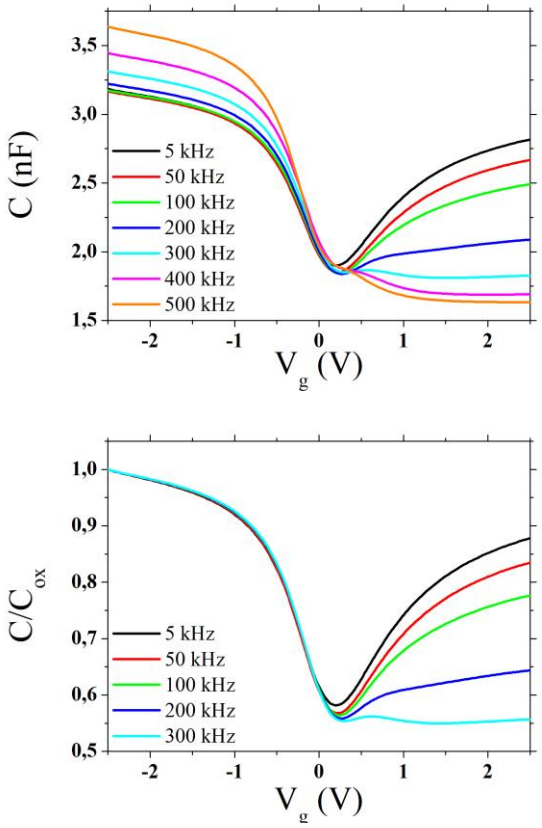

Figure 5. C-V characteristics of sample D at different frequency: Raw data (top) and corrected data (bottom)

Sample C exhibits the same behavior and the characteristics are not shown here. In inversion, we can observe the expected transition from high to low frequency measurement but the frequency dependence in accumulation is caused by parasitic effects as R_s and C_E. With the model proposed in [6], the frequency dependence can be corrected and the capacitance in accumulation normalizes to C_{ox}. Table 3 shows the calculated parasitic parameters. While R_s decreases with frequency, C_E increases with frequency after a local minimum at f = 50 kHz. With higher frequency, traps with energy level deep in the band gap cannot follow the AC signal anymore and are "frozen". This results in a constant charge that is located at the interface. The raw data shows a slight positive flat band voltage shift with increasing frequency. This indicates a positive parasitic capacitance and weak fermi-level pinning. We assume that the transition from weak to strong Fermi-level pinning occurs between f = 300 kHz and f = 400 kHz. For f > 300 kHz, the flat band voltage stops shifting and the capacitance in accumulation increases drastically.

TABLE III. PARASITIC PARAMETERS OF SAMPLE D

f (kHz)	5	50	100	200	300	400	500
R_s (Ω)	64,8	11,7	9,4	8,4	8,2	8,2	6,7
C_E (nF)	51,1	47,0	49,1	65,1	152,3	-	-

III. DISCUSSION

Using Ge as a device substrate fully integrated on Si presents two major challenges: The problematic semiconductor-oxide interface and the reduced crystal quality of Ge when grown by Ge-VS technology on Si compared to Ge Czochralski wafer material. In our case, we do not have to take the resulting parasitic capacitance into account, only, but also the trap density of the bulk material itself. It consists of three components: A hugh dislocation network inside to Ge-VS, threading dislocations starting at the surface of the Ge-VS penetrating the active Ge layer grown afterwards and point defects inside the active Ge layer, that originate from the MBE growth itself. The threading dislocation density in the active Ge layer is estimated to be in the order of 10^8 cm^{-3} from Transmission-Electron-Microscopy studies. However, the density defects inside the Ge-VS as well as the density of point defects inside the active Ge layer cannot be stated. To form better semiconductor-oxide interfaces, we combined conventional cleaning as H_2O_2-, HF- and HCl-treatment with an intermediate CA step. Compared to C-V characteristics of Ge-MOSCAPs that were treated with standard Si cleaning (H_2O_2 Dip and HF with DI water

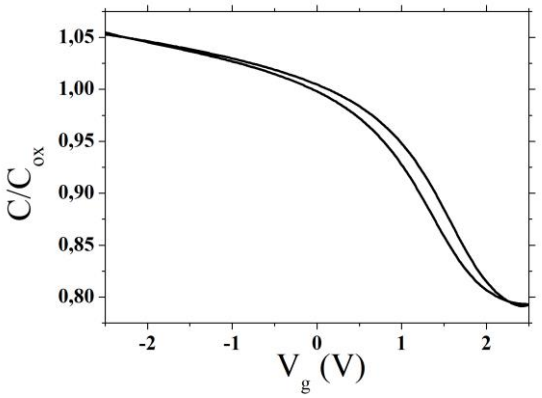

Figure 6. C-V characteristic of MOS-structure with standard HF treatment and and DI rinse

rinse, see figure 6), we achieved a clear improvement with our cleaning and passivating routine. Even though this structure shows very small h, this C-V behavior is not suitable for best TFET-performance since D_q = 1.33 is very low, the flat band voltage is shifted to very high voltage and shows bad saturation behavior in accumulation. We assume that the passivation has the highest impact on the C-V characteristics. Both passivation techniques improve the performance. Omitting DI rinse thereby was found to be very crucial for Ge-MOSCAP performance. The Cl-passivated structure shows the smallest h, while the overall performance of H-passivated structures is more constant and reproducible. Therefore, we prefer to apply H-passivation on our transistors.

We assume to observe fixed charges at the interface that are influenced by cleaning- and passivation-techniques since each combination of those causes a different flatband shift (see figures 3 and 4). From Al_2O_3-on-Si studies (data not shown) we found our Al_2O_3 to exhibit very small h down to a few Millivolts. Furthermore, these structures exhibit negative frequency dependence. Therefore, the parasitic effects do not originate from the bulk oxide, which can be assumed to be free of charge.

Since we observed abnormal frequency dependence in accumulation in this work, we need to correct our C-V data for parasitic effects. The model we used [6] is indeed derived for lossy oxides on a VS-technology, but not for Ge. However, it can be successfully applied on our data as long as the measured capacitance remains below C_{ox}. If this condition is met with the frequency dependence in accumulation, it can be corrected as well as the flat band voltage shift. The weakness of this way to correct C-V data is that C_{ox} has to be known precisely what strongly depends on d_{ox} estimation and ε_{rel}. Since we measured d_{ox} by AFM, the error caused by d_{ox} is assumed to be negligible.

We assume our VS to cause the abnormal positive frequency dependence in accumulation our raw data is showing. Since the VS exhibits a relatively high defect density it can be understood as another parasitic capacitance that impacts the measurement. Certainly, other groups have presented Ge MOSCAPs on VS that show negative frequency dependence in accumulation, however, with distinctly thicker VS-layers than we use. In [10], for instance, a VS of d_{VS} = 2.5 µm – 25 times thicker than our VS – was grown and negative frequency dependence was observed. Using a thicker VS-layer has two advantages: First, the defect density itself is reduced and second, the capacitance of the VS-layer is additionally reduced by the higher thickness. Therefore, the capacitance that results from the VS in [10] is considerably smaller than for our samples. Furthermore, our raw data does not show very large flat band voltage shift with frequency. Very likely, we almost observe strong Fermi-level pinning even for relatively low frequencies. We also observe frequency dependence in accumulation from very low frequency on. It is not as severe as for f > 300 kHz but still to be considered. This indicates still very high D_{it}.

IV. CONLUSION

Fabricating well behaving Ge-MOSCAPs remains challenging due to the non-ideal semiconductor-oxide interface. We were able to show clear improvement on our structures by combining CA treatment with conventual wet chemistry as H_2O_2, HF and HCl. Omitting DI rinse after CA, HF and HCl treatment was found to be very crucial to obtain good Ge-MOSCAP performance. The C-V data was corrected successfully as long as the measured capacitance does not exceed C_{ox}.

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Optical characterization of highly n-type doped $Ge_{0.95}Sn_{0.05}$ rod antennas on Si(001) substrates

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***Abstract* - Plasmonic excitations in metal nanostructures can be used to control and manipulate optical energy in the visible and infrared spectrum and have been used to enable biosensing, to enhance absorption and quantum yields for photovoltaics and to enhance the energy efficiency of light-emitting devices. For light at mid-infrared (MIR) wavelengths, metals become less suitable for plasmonic applications as a result of the high Drude losses. At those wavelengths, highly doped semiconductors are potential alternatives. The doped group IV alloy Ge_xSn_y has been shown to be particularly interesting. We present results on the fabrication and optical characterization of rod antennas fabricated from highly n-type doped $Ge_{0.95}Sn_{0.05}$ (n-Ge_xSn_y) on Si(001) substrates. Extinction spectra were obtained via Fourier Transform Infrared (FTIR) Spectroscopy. To verify the measurement results the behavior of the n-$Ge_{0.95}Sn_{0.05}$ rod antennas was simulated. The results show that the n-$Ge_{0.95}Sn_{0.05}$ rod antennas absorb MIR radiation through plasmonic excitation. Two different peaks could be observed in the extinction spectra of the n-$Ge_{0.95}Sn_{0.05}$ rod antennas and attributed to two locally separated plasmonic modes. One mode forms on the n-$Ge_{0.95}Sn_{0.05}$/Si interface of the n-$Ge_{0.95}Sn_{0.05}$ rod antennas, the other one forms at the n-$Ge_{0.95}Sn_{0.05}$/air interface. We discuss possible applications of this type of n-$Ge_{0.95}Sn_{0.05}$ rod antennas for MIR sensing.**

Keywords – GeSn, Plasmonic, Infrared-detection.

I. INTRODUCTION

Controlling and manipulating optical energy using plasmonic excitations has been used e.g. to enhance the performance of optical devices [1], to increase spatial resolution for optical microscopy [2] and to enable biosensing [3, 4]. In metallic nanoparticles, localized surface plasmon resonances (LSPR) can result from the interaction of incident light with free electrons in the metallic nanoparticle. LSPR can be excited if the dimension of the metallic nanoparticle is smaller than the wavelength of the impinging light, forming collectively oscillating but non-propagating electrons on the surface of the metal structure. This leads to strong enhancement of the electromagnetic fields around the structures. They are often referred to as plasmonic antennas. The wavelength dependence of the antenna resonances strongly depends on the surrounding dielectric material and the geometry of the antenna itself.

Metals such as Au or Ag are well suited for plasmonic applications involving light at visible or near-infrared wavelengths. At longer wavelengths, the high Drude damping limits the usefulness of metals for plasmonic applications. At these wavelengths, doped semiconductors have been proposed as alternative materials [5, 6]. Using doped group-IV semiconductors has the additional benefit of easy integration onto the complementary metal-oxide-semiconductor (CMOS) platform. The dielectric function of highly doped semiconductors is often well approximated by Drude terms of the form

$$\varepsilon(\omega) = \varepsilon_\infty\left(1-\left(\frac{\omega_p^2\tau^2}{1+\omega^2\tau^2}\right)\right)+i\frac{\varepsilon_\infty\omega_p^2\tau}{\omega\left(1+\omega^2\tau^2\right)} \quad (1)$$

with the high frequency dielectric constant ε_∞, the plasma frequency ω_p and the relaxation time τ. The plasma frequency is related to the material parameters dopant concentration N_D and effective mass m^* via

$$\omega_p = \sqrt{\frac{N_D e^2}{m^* \varepsilon_\infty \varepsilon_0}} \quad (2)$$

where ε_0 is the free space permittivity. Increasing the plasma frequency by increasing dopant concentration N_D or lowering the effective mass m^* lowers the crossover wavelength λ_c at which the real part of the permittivity becomes negative. For wavelengths above λ_c, the material is suitable for plasmonic applications.

The Drude model has been shown to be a good representation of the permittivities of e.g. highly n-doped Ge and GeSn [7, 8] For p-doped materials, intervalence band transitions can lead to modifications of the permittivity that make those materials less suitable for plasmonic applications [8]. Among the elemental group-IV semiconductors, Ge is potentially more suitable for plasmonic applications than Si because of the lower effective mass for electrons in Ge [8]. Alloying Ge with Sn can lower the conduction band effective mass further [7]. However, doping GeSn using molecular beam epitaxy (MBE) is difficult: Phosphorous (P) as dopant leads to memory effects in the chamber, and Antimony (Sb) is susceptible to segregation [9].

This work reports on the optical characterization of highly n-type doped $Ge_{0.95}Sn_{0.05}$ rod antennas on Si(001) substrates. To verify the potential of this alloy for

plasmonic applications it is necessary to characterize the optical properties of plasmonic structures made from this material. Here, we report on the experimental characterization of the optical behavior of the rod antennas in the mid-infrared (MIR) region via Fourier Transform Infra-Red (FTIR) spectroscopy.

II. Experimental Section

A. Material growth

Two doped GeSn samples were grown by molecular beam epitaxy (MBE) on four inch Si (001) substrates. After deposition of a 50 nm Si layer at a substrate temperature of 600 °C, $Ge_{0.95}Sn_{0.05}$ films with nominal dopant concentrations $N_D = 10^{20}$ cm^{-3} and thicknesses of 1 µm (sample A) and 300 nm (sample B) were deposited at substrate temperatures of 160 °C. The thickness of sample A was chosen to exceed the expected penetration depth for electromagnetic fields at the projected operating wavelength in the material [8]. Doping was realized using Sb, and the dopant flux was pre-calibrated in Si using four point probe measurements.

B. Structuring

Sample A was used to fabricate rod antennas as follows: 100 nm SiO_2 were deposited via plasma-enhanced chemical vapor deposition on top of the $Ge_{0.95}Sn_{0.05}$ layer to act as a hard mask. Hard mask structuring was carried out using e-beam lithography and dry etching in a reactive ion etching system. The structure was then transferred to the $Ge_{0.95}Sn_{0.05}$ films using an inductively coupled plasma reactive ion etching system (ICP-RIE). The remaining SiO_2 was removed by wet-etching using buffered hydrofluoric acid.

Three different sizes and three different densities of rod antennas were fabricated in arrays of 400 x 400 μm^2 size. Figure 1 shows the schematic geometry as well as a scanning electron microscopy image of the fabricated antennas. Antenna geometries and lattice pitches are shown in Table 1.

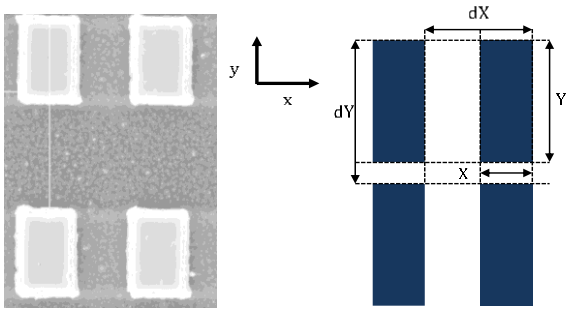

Figure 1. SEM image and dimensioning of the rod antennas

TABLE I. DIMENSIONS OF THE ROD ANTENNAS

	P1	P2	P3	P4	P5
X (µm)	1.2	1.2	1.2	1.2	1.2
Y (µm)	1.8	2	2.4	1.8	1.8
dX (µm)	2.2	2.2	2.2	3.2	4.2
dY (µm)	3.8	4	4.4	4.8	5.8

C. Measurements

Dopant concentrations were extracted from low-temperature Hall measurements on van-der-Pauw structures at a sample temperature of ~ 40 K.

Optical characterization in the spectral range up to 16 µm wavelength was carried out using Fourier Transform Infrared Spectroscopy (FTIR). The extinction spectra were extracted from transmission measurements, using a 140 µm aperture, as follows:

$$E = 1 - T_A/T_B. \quad (3)$$

Here, E is the extinction, T_A is the transmission measured in the presence of the rod antenna array and T_B is the reference transmission measured through the Si substrate.

III. Results

A. Dopant concentrations

For Sample A (Sample B) we obtained a dopant concentration of $1.2 \cdot 10^{20}$ cm^{-3} ($5 \cdot 10^{19}$ cm^{-3}). Using a conductivity effective mass $m^* = 0.0661$ m_0 [10], where m_0 is the electron mass, we can estimate a crossover wavelength of $\lambda_c \sim 3.7$ µm for sample A. Although both samples were grown at nominally identical growth conditions, Hall measurements show markedly different dopant concentrations for both samples. For sample B, the dopant concentration extracted from Hall measurements at low temperatures shows good agreement with the value obtained from ellipsometry characterization [8]. One possible explanation is dopant segregation, which leads to a larger dopant incorporation with increasing film thickness.

B. Extinction spectra

We used rod antennas fabricated from Sample A to investigate the extinction spectra. The extinction spectra of the P1 rod antennas for two perpendicular polarizations of the incident light are shown in Figure 2. The dashed line shows the extinction for polarization along the X-axis of the antennas. The solid line shows the same for polarization along the Y-axis. Both spectra show two peaks in the investigated wavelength range. The spectral positions of the peaks depend on the polarization of the light. The extinction spectra for all fabricated antenna geometries are compared in Figures 3 and 4. When the antenna geometry remains unchanged but the antenna density is reduced (P1, P4, P5, Figure 3), the position of the peak around 14 µm remains unchanged whereas the peak at low wavelengths is washed out. This can be a consequence of the low signal intensity at low antenna densities: Reducing antenna density leads to an overall drop in the magnitude of the extinction.

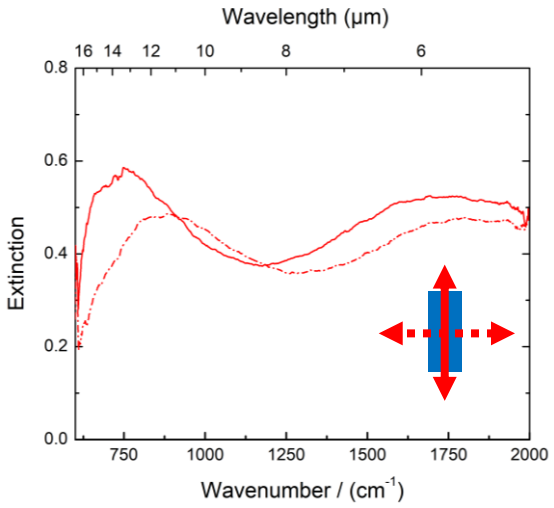

Figure 2. Extinction spectra of the P1 rod antenna for 0° (solid line) and 90° (dashed line) polarized light, Sample A

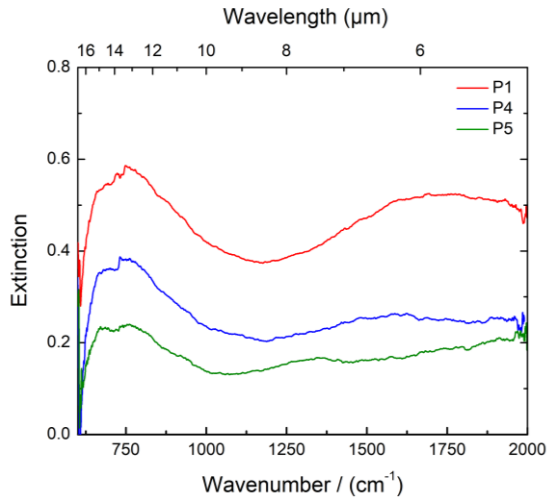

Figure 3. Extinction spectra of the P1 (red), P4 (blue), P5 (green) rod antenna for 0° polarized light, Sample A

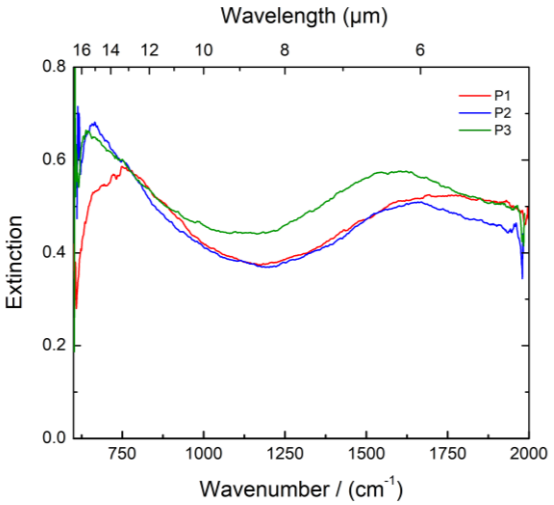

Figure 4. Extinction spectra of the P1 (red), P2 (blue), P3 (green) rod antenna for 0° polarized light, Sample A

When the antenna geometry is changed, i.e. the antenna length is increased (P1, P2, P3), the peak at high wavelengths shifts outside of the measurable spectral range towards longer wavelengths (Figure 4). A similar shift towards longer wavelengths can be observed for the peak in the 6-7 μm wavelength range.

C. *Simulation*

Simulations were performed with the CST MICROWAVE STUDIO® time domain solver. A 3D model of a P1 rod antenna array with dimensions identical to the fabricated structures ($Ge_{0.95}Sn_{0.05}$ with a thickness of 1 μm and lateral dimensions as reported in Table I) was used for the simulation. The sample permittivity was approximated by a Drude form using our experimentally determined dopant concentration and a conductivity effective mass $m^* = 0.0661\ m_0$. The substrate was assumed as a perfect loss free material with a relative permittivity of $\varepsilon_{rel} = 11.67$. A wavelength range from 33.3 μm to 3.3 μm was investigated in simulation. Nonidealities of our fabrication process such as sidewall roughness as well as rounded edges are not reproduced in simulation. While our simulation predicts the occurrence of two main peaks in the extinction spectra, we are unable to reproduce the exact wavelength dependence obtained from experimental measurements. Cross sectional field intensity maps of the antennas and the substrate at wavelengths of 13 μm and 4 μm are shown in Figure 5 (a) and (b), respectively, and reveal the existence of two antenna resonances that are also present as peaks in the simulated extinction spectra. One mode manifests itself via local field-enhancement (hotspots) at the GeSn/substrate interface. The other mode is accompanied by local field-enhancement at the upper antenna edges. We note that qualitatively, the experimentally observed shift of the resonance wavelength towards longer wavelengths with increasing antenna length is reproduced in simulation.

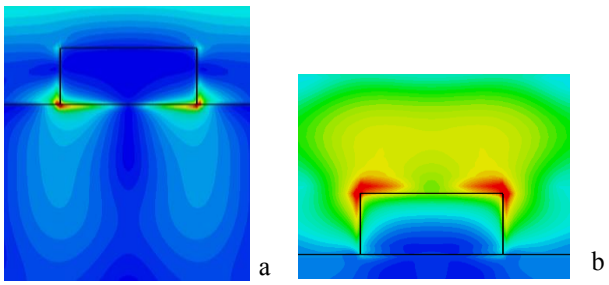

Figure 5. Cross sectional field intensity maps for 0° polarized light at wavelengths (a) 13 μm and (b) 4 μm

IV. Discussion

The polarization and geometry dependence of the extinction peaks indicate that they can be attributed to the rod antennas. The peaks shift to longer wavelengths with increasing antenna length but are not significantly influenced by antenna density. This is consistent with the

interpretation that the peaks in the spectra result from the excitation of plasmonic modes in the antennas: The wavelengths at which plasmonic modes can be resonantly excited increase with increasing antenna length. In prior experiments on antennas fabricated from highly doped Ge layers [11], the double peak structure in the extinction spectra was also observed and attributed to the existence of two distinct modes at the antenna/substrate and at the antenna/air interface. In comparison, the separation between the two peaks in terms of wavenumber is much larger in our experimental spectra. We interpret this to be a result of dopant segregation: in our case, the doping concentration in the $Ge_{0.95}Sn_{0.05}$ layer is lower at the $Ge_{0.95}Sn_{0.05}$/Si interface than in the topmost part of the $Ge_{0.95}Sn_{0.05}$ layer. This is also corroborated by our Hall measurement data, in which the thinner layer shows a lower dopant concentration. In our antennas, this means that the antenna/substrate mode and the antenna/air mode are effectively excited in parts of the $Ge_{0.95}Sn_{0.05}$ layer with markedly different dopant concentrations. This could also explain the difficulties in reconciling simulation results with experiment.

One possible application of our plasmonic antennas is the enhancement of MIR detection: local field enhancement can be used e.g. to boost detection efficiency in the spectroscopy of chemical substances. However, designing $Ge_{0.95}Sn_{0.05}$ antennas for such applications is likely to require a more precise control over the dopant distribution within the antennas.

V. CONLUSION

Our experimental results indicate that we have successfully observed plasmonic excitations in rod antennas fabricated from highly n-type doped $Ge_{0.95}Sn_{0.05}$. Our results indicate that two different and locally separated LSPR modes can be obtained. The LSPR modes can be used to obtain electrical field enhancement either at the antenna/substrate or at the antenna/air interface. However, we also find evidence for inhomogeneous doping in our structures, indicating that further investigations of n-type doping of GeSn alloys are required to tailor the material for application needs.

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Transition metal polysulfides and their potential applications

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***Abstract* – Low-dimensional transition metal polysulfides are an interesting family of compounds, which have in common the presence of disulfide groups S–S. This feature dictates their unusual chemistry and electrochemistry. We have optimized synthetic procedures and systematically studied sulfides of IV-VI groups, such as TiS_3, ZrS_3, VS_4, NbS_3, CrS_3 etc. in their bulk and nanosized forms. The nanosized samples were prepared by liquid-phase exfoliation of the bulk counterparts. Our preliminary studies show the promise of such materials for a variety of applications, including transistors, Li-ion batteries, and photocatalysis.**

Keywords – transition metal polysulfides; low-dimensional materials; photocatalysis; electrodes; transistors.

I. INTRODUCTION

Transition metal polysulfides (TMPSs) are well-known for their unusual physical and electronic properties. The Peierls instability and charge density waves observed in such materials have been studied intensively since 1960s [1]. However, during the last decade, TMPSs have seen renewed interest due to the new synthetic possibilities that allowed obtaining nano-structured samples [2-9]. Quasi-1D transition metal trichalcogenides are nowadays considered as candidates for next generation electronics and optoelectronics [8]. At the same time, new application areas are being uncovered for them [10-21], and the development of characterization tools now allows better tuning of the sample's properties. In this paper, our aim is to outline and discuss our results on the emerging applications of TMPSs in the general context of their structure and the accumulated literature data.

Basically, TMPSs comprise a wide number of compounds containing pairs or chains of sulfur atoms. One of the most common examples is pyrite FeS_2, in which formal oxidation states are described as $Fe^{2+}S_2^{2-}$. We are more interested in low-dimensional TMPSs, which are sulfides of group IV (titanium, zirconium, and hafnium), group V (vanadium, niobium, and tantalum) and group VI (chromium, molybdenum, and tungsten) (Fig. 1). These materials have van der Waals-bonded chain- or layer-type structures. Sulfur atoms may be bound in pairs fully or partially. For example, in transition metal trisulfides, such as TiS_3, ZrS_3, NbS_3 etc. ($M^{4+}S^{2-}(S_2)^{2-}$) (Fig. 1 c) sulfur exists in two non-equivalent forms: (i) "common" sulfide ions S^{2-} and (ii) disulfide groups $(S_2)^{2-}$. In patronite VS_4, all S atoms exist as pairs (Fig. 1 a). The S–S and metal-metal bond lengths influence strongly the electrical and optical properties of TMPSs [8]. Many of them are semiconducting. TiS_3 monolayer is predicted to be a direct band gap semiconductor with a gap of ~ 1 eV and a rather high carrier mobility [9]. ZrS_3 is a wide-band gap semiconductor with band gap of 2.0 – 2.8 eV [12, 22], which corresponds to shorter wavelengths of visible light. Energy band positions of TMPSs are shown to be suitable for photocatalytic dye degradation [15-17], photocatalytic disinfection [18] and several photoelectrochemical processes, such as hydrogen evolution reaction (HER) [10, 12, 19], and electrocatalytic oxygen evolution reaction (OER) [14]. Moreover, the paired S–S atoms may play the role of catalytically active sites of water splitting [14, 23].

In this relation, the presence of S–S pairs in the TMPSs also endows them with some unusual chemical features. For example, the disulfide group is shown to participate in the electrochemical processes occurring in rechargeable lithium ion batteries with TMPSs cathodes [13]. The reversible transformation of S–S pairs into usual sulfide groups S^{2-} adds to the increased capacities of such cathodes: $S_2^{2-} + 2e^- = 2S^{2-}$. In the result, the achieved capacities are often above 200 – 300 $mA{\cdot}h{\cdot}g^{-1}$, which is rarely attained by widely used oxide cathodes. On the other hand, the S–S groups govern the surface properties

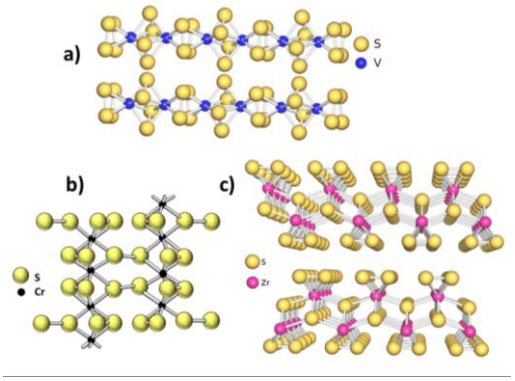

Figure 1. Crystal structures of the representative transition metal polysulfides with low-dimensional structures: a) VS_4 (quasi-1D structure, isolated chains) and c) ZrS_3 (1D/2D structure composed of chains extended along *b* axis and covalently bonded into layers within the *ab* plane); b) amorphous CrS_3 (interconnected chains) according to EXAFS data.

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of TMPSs, as we have shown by growing Ag_2S phase on VS_4 [24], which is not typical for common sulfide surfaces devoid of disulfide fragments, such as MoS_2. These examples show that the unique properties of sulfur pairs S–S in many ways predetermine the properties and potential applications of TMPSs.

Here, we report synthesis and systematic investigation of the properties of a series of polysulfide samples with chained or layered structures, including TiS_3, ZrS_3, VS_4, NbS_3, CrS_3. The samples show promise for diverse applications, such as thin-film transistors, lithium ion battery electrodes, and photocatalysis.

II. EXPERIMENTAL PART

A. *Synthesis and exfoliation*

One series of the starting TMPSs were crystalline species (TiS_3, ZrS_3, VS_4, NbS_3) while one sample was amorphous (CrS_3).

The syntheses of the crystalline TMPSs were carried out using the high temperature ampoule method, starting from high purity sulfur and the corresponding metals, according to the well-known procedures. The elements were taken in stoichiometric amounts, with a slight excess of sulfur (less than 1%). For example, to synthesize ZrS_3, Zr and S were vacuum-sealed in a quartz ampoule, the ampoule heated up to 500°C for 15 h and kept at 500°C for 150 h. After the ampoule was opened, excess sulfur was removed in vacuum at 200°C.

The amorphous CrS_3, $MoS_{4.7}$, WS_5 were prepared from 15-20 excess of sulfur and metal hexacarbonyls $M(CO)_6$ in boiling 1,2-dichlorobenzole at 180°C. Excess sulfur and unreacted $M(CO)_6$ were removed in dynamic vacuum at 150-200°C.

Bulk powdered samples were sonicated in ultrasonic baths (Elmasonic S40 ultrasonic bath, ultrasound power 120 W) in various organic media, as we have previously described [2-6]. This led to the formation of homogenous colloidal dispersions. In order to remove large and non-exfoliated particles, the dispersions were centrifuged at 2600 rpm for 30 mins. X-ray powder diffractogramms both for crystalline and dispersed zirconium trisulfide are in accord to the ZrS_3 calculated pattern (Fig. 2).

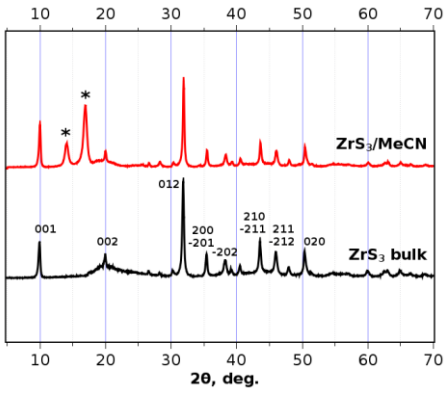

Figure 2. X-ray powder diffractogramms of the crystalline ZrS_3 (lower line), and exfoliated particles of ZrS_3 from colloidal dispersion ZrS_3/acetonitrile (upper line). Reflexions from filtrating membrane marked with asterisk.

Here NbS_3 was tested as a material for thin film transistor application, ZrS_3 as a catalyst for dye photodegradation, and the series VS_4, NbS_3, TiS_3, CrS_3 for cathode materials in lithium batteries.

B. *Characterization*

Electrical properties of thin films:

A NbS_3 film of 0.5 – 1 μm in thickness was deposited from ethanol/water colloidal dispersion by spraying onto a SiO_2/Si substrate in transistor configuration with the use of the Si substrate as a gate. Two planar contacts (a drain and a source) were connected to the $NbS_3/SiO_2/Si$, and the third contact was attached to the silicon substrate [2].

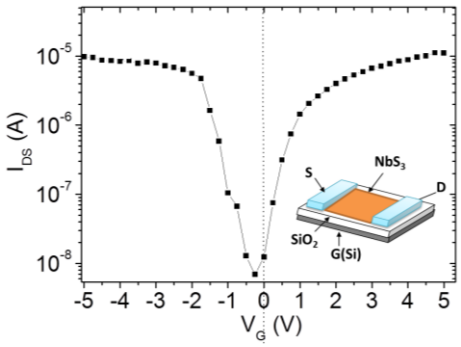

Figure 3. The drain current I_{DS} (V_G) characteristics for NbS_3 films obtained from an ethanol/water colloid solution. Drain–source voltage V_{DS} was 0.5 V. The inset shows the device configuration.

Electrochemical testing:

To prepare the working cathode, polysulfide powders were mixed with conductive carbon material, polyvinylidene fluoride (PVDF) in dimethyl sulfoxide (DMSO). The electrochemical measurements were performed at a current density of 200 $mA \cdot g^{-1}$ in a CR2032 coin cells with a lithium (Li/Al) counter electrode, a Celgard® membrane separator and an electrolyte consisting of a 1M $LiPF_6$ solution in a 1:1 mixture of ethyl carbonate/diethyl carbonate.

Dye degradation:

14 mg of ZrS_3 powder was placed into 80 ml of 0.022 mM methyl orange water solution and irradiated with near-UV light. The concentration of methyl orange was monitored by UV/vis spectroscopy.

III. RESULTS AND DISCUSSION

TMPSs were obtained in bulk form from elements and then exfoliated into nanoribbons through sonication. This approach is well-established for various layered materials, including graphene and MoS_2 [25]. Colloid dispersions may then be easily processed into thin films, either by filtration or by spraying. The resulting bulk and film samples were screened for a range of applications, some examples of which we present below.

First, we report current–voltage characteristics of the NbS_3 thin films (Fig. 3) [2]. The dependence of the drain current I_{DS} (V_{DS}) was linear and demonstrated the ohmic behavior of the contacts. The sheet resistivity was $3.5 \cdot 10^6$ Ohm/□. The current in the $NbS_3/SiO_2/Si$ films was measured as a function of gate voltage V_G, and from this, the carrier mobility was calculated. The mobility of electrons and holes was estimated as 1200 – 2400 $cm^2 \cdot V^{-1} \cdot s^{-1}$.

Next, TMPSs were tested as components of Li-ion battery cathodes (Fig. 4). The ability of van der Waals bound compounds to host ions in the interlayer space is well-known, but in case of polysulfides, they carry an additional advantage for lithium storage, which is their anionic redox chemistry related to the $(S–S)^{2-}/S^{2-}$

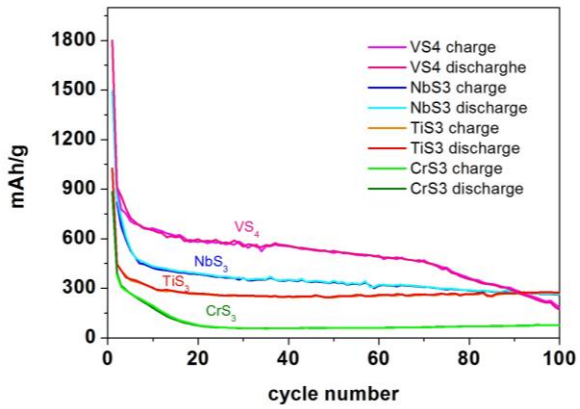

Figure 4. Discharge and charge capacities of transition metal polysulfide-based cathodes of Li-ion batteries as a function of cycle number (cathode composition: TMPS/conductive graphitic material/PVDF, current density 200 mA/g).

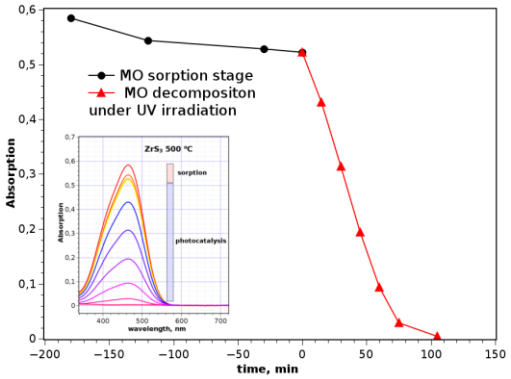

Figure 5. Photocatalytic decomposing of methyl orange using ZrS_3 as a photocatalyst under near-UV light irradiation. Before irradiation, the mixture was stirred in the darkness for 180 mins to establish adsorption-desorption equilibrium between the dye and the ZrS_3 surface (shown as negative times). Inset shows the changes of UV-vis spectra with time.

transformations [13]. The initial discharge and charge capacities of polysulfide-based cathodes were very high, that is, close to or even over 1000 $mA \cdot h \cdot g^{-1}$. For example, for TiS_3, these values were equal to 1026 and 448 $mA \cdot h \cdot g^{-1}$, for NbS_3 – 1492 and 821 $mA \cdot h \cdot g^{-1}$, and for VS_4 – 1799 and 918 $mA \cdot h \cdot g^{-1}$. The Coulombic efficiency in the first cycle is low, however, it should be noted that the testing was conducted under a very high current. After approximately 20 – 30 cycles, the capacities have settled at a level of around 250 $mA \cdot h \cdot g^{-1}$ for TiS_3, 250 $mA \cdot h \cdot g^{-1}$ for NbS_3, and 550 $mA \cdot h \cdot g^{-1}$ for VS_4 and kept at this level for up to 100 cycles, with somewhat faster fading for the latter one. These values of capacity and high cyclability exceed the characteristics of the best oxide electrodes used presently [21].

One more example of the practical potential of TMPSs is their activity as photocatalysts in dye degradation. Fig. 5 shows a kinetic curve of the sorption in the dark (-180 – 0 mins) and photocatalytic decomposition of methyl orange (0 – 120 mins) in presence of the ZrS_3 photocatalyst. During the first 3 hours of the experiment, 10% of the dye was adsorbed on the catalysts' surface. Total decomposition of methyl orange is achieved in 120 mins. A related process of photocatalytic water splitting with TMPS-based catalysts was recently demonstrated in several literature references (Fig. 6) [10, 12, 14, 19].

IV. Conlusion

Transition metal polysulfides may be prepared by simple synthetic procedure from elements. The combination of their characteristics, such as crystal structures, band gap widths, energy level positions and the presence of S–S pairs make this family of compounds a very promising field to explore. Our preliminary studies revealed the possibilities to process TMPSs into thin-film transistors, incorporate them into battery electrodes with great cyclability and increased capacity, and use them directly as effective photocatalysts for dye decomposition. Research on their activity for hydrogen evolution is underway. These early results show that TMPSs hold

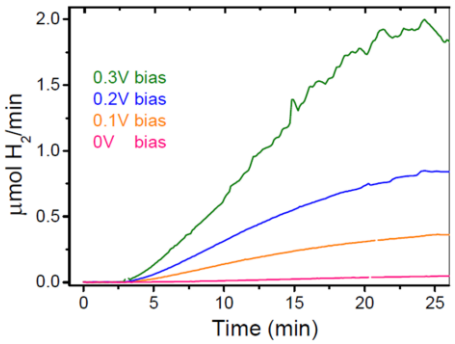

Figure 6. Hydrogen evolution flow by using TiS_3 nanoribbons at different bias potentials (vs. Ag/AgCl) [10].

strong development potential for a variety of practical fields and are worth further active investigation.

Acknowledgment

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Possibility of developing coplanar isolator via deposited YIG thin films

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***Abstract* - The transmission coefficients of nonreciprocal coplanar waveguide are measured in the X-frequency band. The experimental results are compared to the simulated results obtained by HFSS for different magnetic field intensities. The isolator with a coplanar waveguide structure has been made on 12.3 µm-thick thin film YIG, the non-reciprocal effect (S_{21} - S_{12}) can reach 2 dB at 9 GHz for an applied field of 280 mT.**

Keywords* - *Microwave device, isolator, coplanar waveguide

I. INTRODUCTION

Magnetic materials present some interests in RF applications; in particular, yttrium iron garnet (YIG) is studied for the realization of microwaves applications like isolators [1-2] and circulators [3-4]. This material presents sharp ferromagnetic resonance, low magnetic and dielectric losses at the application frequency. The integration of microwave components needs to use YIG magnetic thin films, which is deposited on different substrates using various techniques like radio frequency sputtering [5-6], chemical vapor deposition [7] and pulsed laser deposition [8].

Isolators are mainly used for decoupling. The problem that power reflecting back to generators may lead to nonlinear effects such as the instability and frequency shifting [9]. To avoid this, an isolator between the generator and the load could be applied in order to attenuate only the reflected wave and hence protect the generator [10]. Fading due to obstacles, for example, snow accumulation on the reflector of an antenna is a challenging problem in satellite communication in northern countries such as Finland [11]. Hence the transmitter is affected by impedance variations of the antenna. This can be avoided by employing an isolator between transmitter and the antenna. Besides, in applications where cascade amplifiers are used, the change of one stage's input impedance could affect others [9]. The solution is to use isolators between different amplifiers stages, then they can be adjusted without interacting with the others.

The coplanar waveguide (CPW) with ferrite material was first developed in 1969 by Wen [12]; the non-reciprocal effect is based on the gyromagnetic resonance. In the latter work, the isolation performance is about 37 dB with important insertion losses. The main obstacle to the use of this structure is the magnetic material which is in the form of rods, located in the slots between the conductors at the air-dielectric interface. An alternative to this problem is to make vacuum deposition of magnetic materials in thin layers. The CPW technology is widely used in microwave integrated circuits (MICs) and in monolithic microwave integrated circuits (MMICs) [13-14].

Different studies use 1000 µm-thick YIG substrate for the realization of a coplanar isolator [1], [15]. Most of them obtain a high isolation and important insertion losses. A thin YIG film based on coplanar isolator was presented by S. Capraro et al [16]. A non-reciprocal effect of 0.3 dB was detected at 9 GHz for 2.5 µm YIG thin film. But these experimental results were not compared to the simulations of S-parameters of CPW with YIG thin film.

In this article, the experimental results of a nonreciprocal coplanar waveguide using 12.3 µm thin-film YIG are presented. An external transverse magnetic field has been applied on the device, to stimulate the nonreciprocal effect, which is defined by the difference between the forward direction (S_{21} or insertion loss) and the reverse direction (S_{12} or isolation). A comparison between experimental results and simulation results are shown. In particular, the transmission parameters are measured and simulated.

II. COPLANAR WAVEGUIDE FERRIMAGNETIC RESONANT ISOLATOR

The behavior of magnetic materials in RF devices is widely understood using the Polder permeability tensor to describe the interaction of the ferrite material with RF excitation fields [17-18]. For a given external constant magnetic field H_a (figure 1), a ferrite with a saturation magnetization *Ms* the imaginary part of the permeability is the RF absorption mechanism in the isolator.

As shown in figure 1, the coplanar isolator consists of a YIG thin magnetic film deposited on the surface of an alumina dielectric substrate. The ground and signal metallization are added on the surface of YIG film by using a lift-off process. The thickness of the gold signal line and the ground planes is around 600 nm. The length of the device is 2.3 cm. The major geometric parameters of the device are given below.

The transmission characteristics of the device are analyzed by using a 65 GHz vector network analyzer (VNA) and a probing system (figure 2). The manual probe

tester is a Süss Microtec PM5 model. The probes are Picoprobe coplanar GSG probes. The HF cables and the VNA are respectively V-type Anritsu semi-rigid cables and model A37397 Anritsu vector network analyzer.

TABLE I. DESIGN SPECIFICATIONS FOR COPLANAR ISOLATOR

Design parameters	Dimensions
Substrate	d = 10 mm, h_S = 0.635 mm
Ferrite material	h_F = 12.3 µm
Signal line	s = 0.3 mm
Slots	w = 0.3 mm

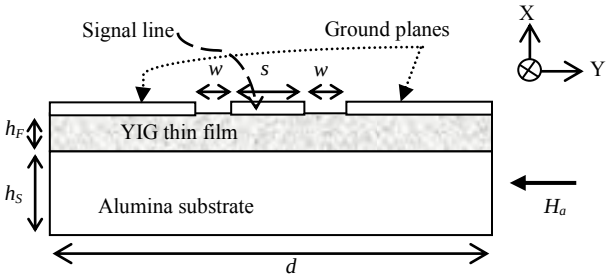
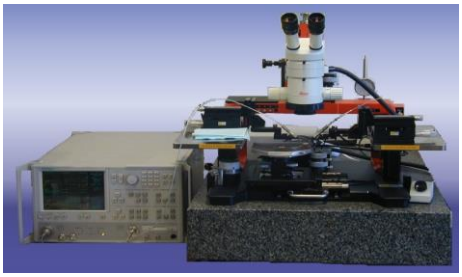
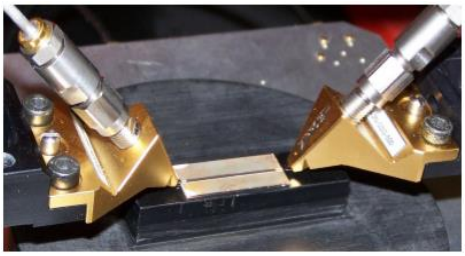


Fig. 1. Coplanar isolator structure



(a)



(b)

Fig. 2. Measurement system (a) Vector network analyzer (VNA) and probe system (b) Demonstrator under test

A. *Experimental results*

Using materials magnetic is important for obtaining non-reciprocal effects. Thus, a post-deposition thermal annealing of YIG thin films is necessary to obtain magnetic properties. These characteristics are closed to those of YIG bulk. The saturation magnetization ($\mu_0 M_s$) measured by VSM (Vibrating Sample Magnetometer) of the YIG thin film deposited on alumina substrate is about 169 mT.

In order to obtain the S-parameters, the coplanar isolator was connected to a vector network analyzer. The transmission coefficients for the two directions of propagation, S_{21} (insertion loss) and S_{12} (isolation), are shown in figure 3 for different transverse magnetic fields. The gyromagnetic resonance phenomenon is observed when an external field is applied, and the resonance frequency is close to 9 GHz for 280 mT dc applied field intensity. The difference (S_{21} - S_{12}) represents the non-reciprocal effect (NRE) and reached 2 dB for higher magnetic field. According to figure 4, the NRE increases linearly from 0.3 to 2 dB for an applied field between 23 and 280 mT.

Additionally, figure 3 shows that the measured resonance frequency depends on the applied field. However, for a ferrite sample the gyromagnetic resonance frequency is given by the Kittel's equation [19]. Since the demagnetization factors could be ignored when the device is transversely biased, so, according this equation, the resonance frequency (f_r) could be written in terms of the applied bias field (H_a) and saturation magnetization (M_s) as

$$f_r = \mu_0 \gamma / 2\pi \left[H_a (H_a + M_s) \right]^{1/2} \quad (1)$$

Here γ is the gyromagnetic ratio (γ = 28 GHz/T) which is the ratio of the spin magnetic moment to the spin angular momentum as expressed by

$$\gamma = m/s \quad (2)$$

where m is the magnetic dipole moment of an electron due to its spin, and s is the spin angular momentum of an electron.

The measured resonance frequencies are then compared with the calculated ones. As shown in figure 5, the two results are in agreement.

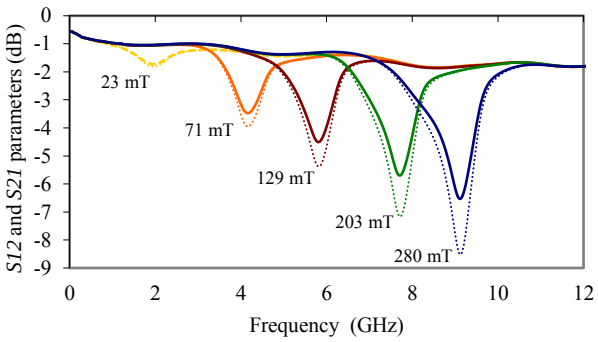


Fig. 3. Transmission parameters *S12* (dashed line) and *S21* (solid line) versus frequency for different applied fields

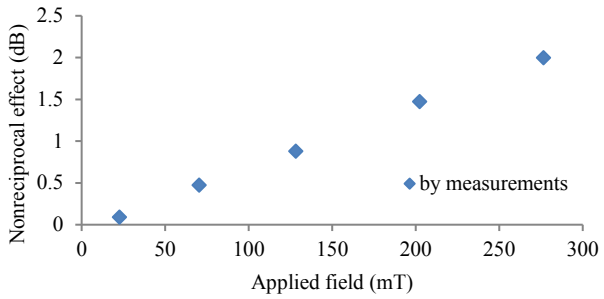


Fig. 4. Non-reciprocal effect versus applied field

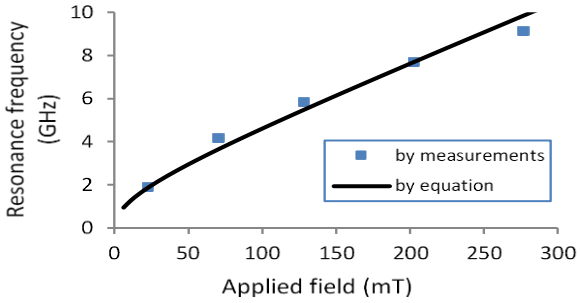


Fig. 5. Resonance frequencies versus applied field

High-frequency electromagnetic field simulation based on 3D-FEM (Finite Element Method) simulator (HFSS by ANSOFT) is used to analyze the transmission characteristics of the isolator with CPW. The physical parameters are set as follows:

- Saturation magnetization (M_S) = 169 mT.
- Relative dielectric constant (ε_r) = 15.
- Dielectric loss tangent ($tang\delta$) = 2.10^{-4}.
- Electric conductivity of the gold signal line (σ) = 41×10^6 S/m.

For simulation, HFSS uses the internal static magnetic-field (H_0) instead of the external applied field (H_a) and it assumed here to be uniformly applied to the YIG thin film. The field H_0 is expressed by

$$\overrightarrow{H_0} = \overrightarrow{H_a} - N\,\vec{M} \qquad (3)$$

where N is the demagnetization factor and M is the magnetization.

The simulated structure of the device is shown in figure 6 and the design parameters of the isolator are given in table 1. In order to obtain the S-parameters, the transmission characteristics of the model are analyzed by assigning excitations to the isolator structure. These excitations include wave ports assigned to each end face of the model's two CPW isolator sections.

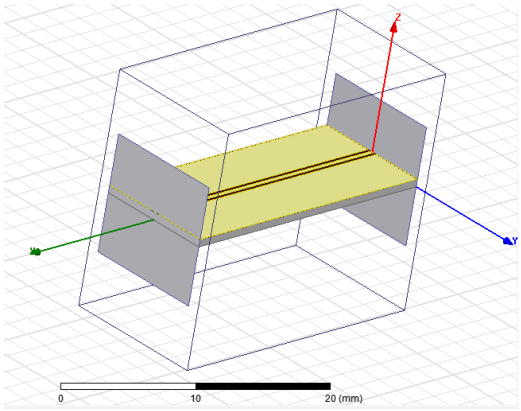


Fig. 6. CPW isolator structure simulated by HFSS

After simulations and convergence of the solution, the transmission parameters (S_{12} and S_{21}) versus frequency are plotted. Figure 7 shows the comparison of simulated and measured S-parameters when the ferrite is biased transversely with an internal magnetic field H_0 = 254 mT for simulations, and an external magnetic field H_a = 280 mT for measurements. It is noted a good agreement between measurements and HFSS/Designer 3D simulations of S_{12} and S_{21} parameters, except that the simulated bandwidth is lower than the measured one. In addition, the simulated nonreciprocal effects are compared to the measurement results for different magnetic field intensities, as shown in figure 8. In general, the simulated NRE meet the measured ones, except that there is a difference in amplitude between the two results, which varies from 0.2 to 0.6 dB depending on the intensity of the field. A difference in bandwidth is also observed. This is probably due to the non-uniform magnetic bias fields. Besides, the internal magnetic field is relatively different to the external applied field. This variation can be explained by equation (3) and the non-uniform external field applied to the YIG thin film.

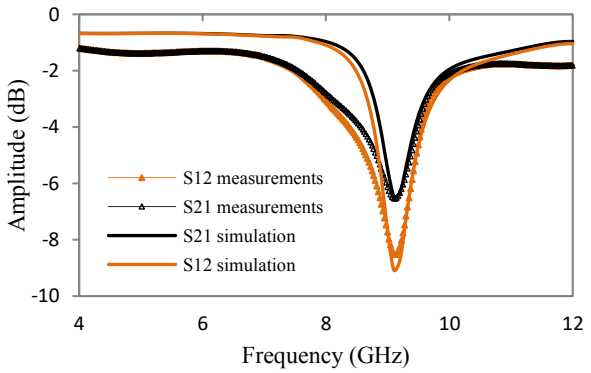


Fig. 7. Isolator S-parameters obtained in simulation and measurements

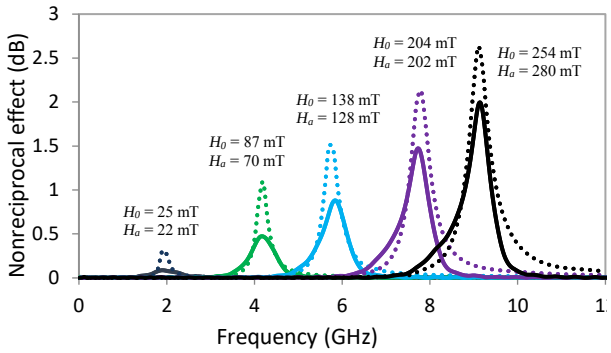


Fig. 8. Non-reciprocal effects obtained in simulation (dashed line) and measurements (solid line) for different applied fields. For simulation, the applied field is the internal field (H_0) for HFSS.

III. CONCLUSION

In this article, an integration compatible CPW isolator via deposited YIG thin films on alumina substrate is realized. An external transverse magnetic field (0 – 280 mT) is applied to the structure. The transmission coefficients of this structure have been experimentally measured and simulated. The experimental results have a good agreement with simulated results in terms of transmissions S_{12} and S_{21}. The isolator made with 12.3 µm-thick thin film YIG permits to obtain 2 dB of non-reciprocal effect for an applied field of 280 mT. To increase this effect, two methods are envisaged: the deposition of thicker magnetic films and the use of metamaterial.

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Analysis and modeling of capacitive electrodes for insulin dose detection

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***Abstract* - In this paper, a three-dimensional physical model for the capacitive measurement in an insulin pen used by diabetic persons has been developed. To this purpose, ANSYS Maxwell 3D software has been used to faithfully model an insulin pen and numerically assess the electrode capacitance. A configuration with four electrodes, of given dimensions for their thickness and length, has been chosen for the cap. Consequently, information on the capacitance values between face-to-face electrodes has been obtained. This model can be used to predict the value of the electrode capacitance in many different situations imagined by the designer.**

Keywords – insulin pen; capacitive measurement; dose detection; electrode profile; 3D model

I. INTRODUCTION

Nowadays, one of the ten most common health diseases is the diabetes. The diabetes falls into the endocrine diseases category and it is a long-term condition that causes high blood sugar levels. In 2014, it was estimated that 422 million people were affected by diabetes [1]. There are two types of diabetes. Type 1 Diabetes is when the pancreas does not produce insulin at all while Type 2 Diabetes occurs when the body does not produce enough insulin or the insulin produced is not properly used. The first type of diabetes affects 10% and the other 90% of people with diabetes. Unfortunately, diabetes may produce blindness, limb amputation, kidney failure, stroke or heart attack [2].

In order to allow for optimal body functioning in patients with diabetes, the blood sugar (glucose) must be monitored closely. With respect to the treatment of this disease, we mention that the Type 1 diabetes is treated with insulin (hormone produced by the pancreas), while Type 2 Diabetes can be treated with non-insulin as well as insulin medication and dietary optimization. The purpose of the medication for Type 2 diabetes is to decrease the levels of glucose, by increasing the sensitivity to insulin, decreasing the absorption of carbohydrates from the digestive system and increasing the elimination of glucose.

There are different means to deliver the insulin such as prefilled (disposable) pens, insulin pumps and syringes. The insulin pen is a medical device which is used to inject insulin in the patients suffering from diabetes. Insulin pens are preferred to vials or syringes, as they provide easy administration and control of the dosage. As the needles of the insulin pens are thinner and shorter than those of the syringes, they provide a less painful injection. Also, the prefilled pens are disposable. In 2016, there were around 8 million users of insulin pens in the top five European countries with the Germany insulin market generating more than 1.5 billion USD in 2016. Among the major players and producers of insulin pens we can mention the top companies such as Novo Nordisk, Eli Lilly, Sanofi, Owen Mumford and Ypsomed. The US insulin pen market is still difficult to fully enter, as insulin syringes use is still prevalent here.

The measurement of the insulin dosage in the insulin pen can be made via capacitive measurements [3]. Capacitive sensing is a proximity sensing technology. The operating principle is based either on the change in the geometry (distance) or capacitance variation in the presence of conductive or dielectric materials. Capacitive sensors have been used with success in the past, in various applications, such as self-calibration water level measurement [4] and monitoring [5], ice growth measurement [6].

Before developing a new prototype, a valuable asset to use in the behavior predicament and performance assessment is the use of three-dimensional physical models. Such models have been successfully used by the first author for the complete characterization and design optimization of magnetic sensors, based on Hall Effect [7-9].

The work in the present paper is intended to provide the analysis and modeling of capacitive electrodes in an insulin pen. To this purpose, both an analytical model and three-dimensional physical model in ANSYS software have been developed. The paper is organized as follows. The second part introduces the device, by giving precise dimensions of all the layers present in the pen (insulin, air, plastic, copper electrodes, etc.) while the third part presents the analytical model of the electrode capacitance. The fourth part is devoted to presenting the simulation results and to interpret them. Finally, the paper concludes in the fifth section.

II. DEVICE PRESENTATION

A. Insulin pen

The insulin pens have many obvious advantages for patients, as they are very dainty to carry and much easier to use as there are no complex instructions to follow in order to use them properly. They provide an accurate information on the dosage and give confidence to the patients that they have administered themselves the right amount of insulin. In a study in 2010 [10], there has been shown that patients favour the prefilled disposable pens to the refillable alternatives. This is because the first category of pens are smaller and lighter and there is no need to introduce a fresh insulin container each time. Some refillable pens provide

however half-unit increments and a memory function. Depending on the country, the pen typically requires a prescription. Each patient will choose the right type of insulin pen in accordance with their own preferences regarding insulin administration needs and lifestyle.

B. Capacitive measurement

There are several physical methods used to measure the volume in the insulin pen, such as optical method, mass method and capacitive method [3].

As already mentioned in the introductory part, the mechanism of providing and recording the right dose for the insulin administration is based in this work on capacitive measurement. This method has been chosen for its power consumption integration potential and the advantage of non-contact measurement. Moreover, the capacitive method is preferred because it is not vulnerable to dirt, scratches and optically opaque structures. By using capacitive method, the volume is measured by relying on the change in electric permittivity of the different materials. Any change in the volume of material (water, insulin or air) is possible to be recorded by a change in their electric permittivity. A variation of the capacitance will then be observed, when a certain insulin dose will be administered.

We emphasize that in this paper we shall use the term "insulin" in the sense of "insulin solution", i.e. aqueous salt solution containing insulin.

C. Maxwell electrostatic regime

To model and numerically evaluate the main parameters of the insulin pen, the ANSYS software has been employed. For the correct electrode capacitance simulation, ANSYS Maxwell electrostatic regime has been used. Electromagnetic field problems are managed by the Maxwell simulator, by solving Maxwell's equations in a finite region of space with appropriate boundary conditions. The solution of the problem can also take into account various user-specified initial conditions in order to obtain a solution which is guaranteed to be unique. To perform an electrostatic analysis, the electric solution type must be chosen [11].

D. Three-dimensional model

This section is devoted to presenting the three-dimensional model of the insulin pen, as it has been developed using the ANSYS simulator. The insulin pen has two main components, the cap and the body of the pen.

The cap on its own is important as it is here that the electrodes used for capacitive sensing are placed. Therefore, we shall start off by giving below, in Figure 1, the three-dimensional model of the cap itself in the shape of a cylinder. Later on in this article we will present the whole model of the insulin pen.

We can see that the cap itself (in light blue) is actually made of plastic, whereas the electrodes (in orange) are made of copper. The electrodes [12] have been named from A to D, in a clock-wise direction on the cylinder. It is important to also mention that we can see the electrodes ending with a smaller portion, which hardly contributes to the capacitance value but serves to give place for the addition of the needle. In order to properly handle the boundary simulations, a vacuum box (in red), with dimensions 222.024 mm * 27.600 mm, has been added around the structure. Already in Figure 1, we can see, in the most inner part of this structure, the insulin ampoule (in glass) and a lid at the bottom.

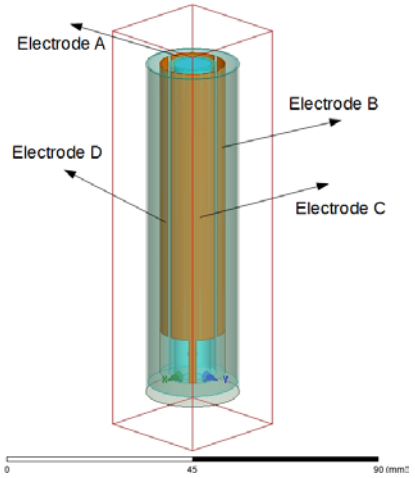


Figure 1. Three-dimensional physical model of the insulin pen cap alone, placed in vacuum, as modeled in ANSYS

The dimensions of the cap have been chosen in order to fit real insulin pens found on the market (for example the one from Eli Lilly). All the geometrical parameters of the insulin cap are summarized in Table I.

TABLE I. GEOMETRICAL PARAMETERS

Thickness of the electrode	$t_{electrode} = 50 \cdot 10^{-6}$ m
Length of the electrode	$l_{electrode} = 69 \cdot 10^{-3}$ m
Smaller part of the electrode	$l_{s,electrode} = 11 \cdot 10^{-3}$ m
Electrode inter-distance	$d_{inter-electrode} = 10^{-3}$ m
Radius of the cylinder on which electrodes lie	$R_{\text{sensor}} = 8 \cdot 10^{-3}$m

Further on, we shall present the full system of the insulin pen. The three-dimensional physical model developed in this work can be seen in Figure 2.

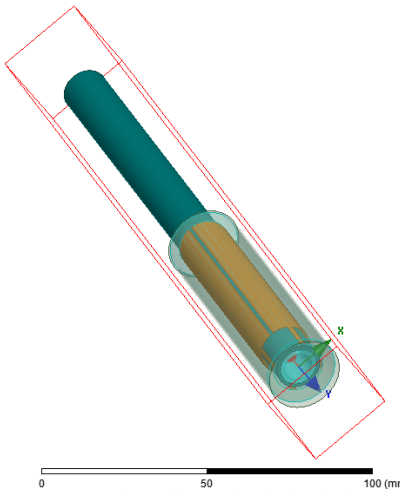
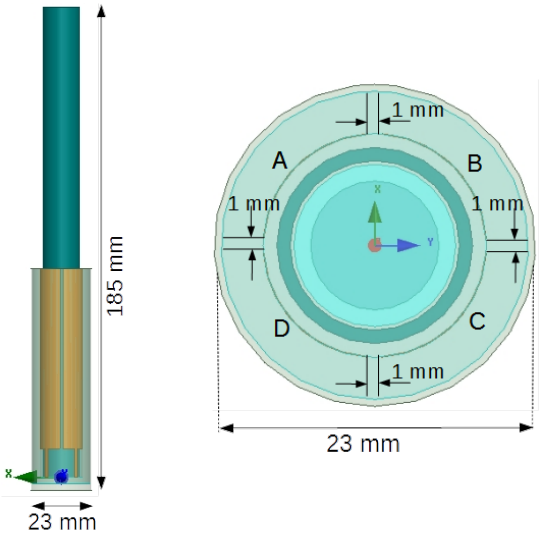


Figure 2. Three-dimensional physical model of the full insulin pen, placed in vacuum, as modeled in ANSYS

Figure 3 introduces other views of the insulin pen and its dimensions, as well as a profile cut in xOy plane. The insulin pen is 185 mm long and 14 mm wide, while the diameter of the cap is 23 mm, respectively. There is 1 mm (arc of circle small enough to be approximated by a straight line) between two successive electrodes. The electrodes introduced in Figure 1 and denoted by A, B, C and D letters are situated in the cap of the full insulin pen.



(a) (b)

Figure 3. Two views of the physical model of the full insulin pen

III. Analytical Model

As already mentioned, the whole principle of the correct volume and therefore insulin dose measurement relies on the correct evaluation of the electrode capacitance. Let us now briefly remember the definition of the capacitance [13]. As we know, the capacitance is defined as the ratio of charge Q to the voltage V:

$$C = \frac{Q}{V} \tag{1}$$

with V defined as line integral of the electric field E:

$$V = \int_0^d E(z)dz \tag{2}$$

The equation for the capacitance C between two parallel plates (planar capacitor) found at a distance d is the following:

$$C = \varepsilon \frac{A}{d} = \varepsilon_0 \varepsilon_r \frac{A}{d} \tag{3}$$

where A is the area of overlap of the two plates, in square meters, ε is the absolute electric permittivity of dielectric, ε_0 is the electric permittivity of free space ($\varepsilon_0 \approx 8.854\times10^{-12}$ F·m^{-1}) and ε_r is the relative electric permittivity of the material which is found between the plates. For example, in the case of vacuum, ε_r=1. Obviously, the unit for the capacitance C is F (farads).

An analytical model has been developed which will provide a formula for the evaluation of the electrode capacitance by taking into account all the media (air, plastic, glass, insulin) present in the insulin pen and their layout. The media present in the insulin pen cap, between two electrodes, as we look at the pen in a transversal cross section through the cap, can be seen in details in Figure 4.

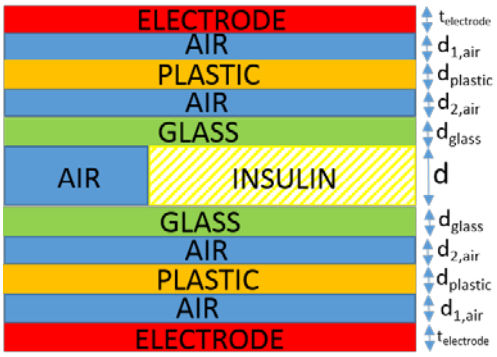


Figure 4. Physical media between two electrodes, in a transversal cross section of the insulin pen cap

I mention that the analytical model proposed in this paper is different from the one in [3], as it has more layers, more analytical steps and also provides the numerical values for all layers dimensions. In current analytical model, the glass, plastic and air layers have now a correct double contribution to the total capacitance, from each side of the insulin ampoule. This fact is also reflected in both Figures 4-5 and actual capacitance equations (Eqs. 4-5).

In Table II are presented the numerical values of the thicknesses of each of the media found in the insulin pen.

TABLE II. Media Thicknesses

Type	Notation	Numerical value
Thickness of first air layer	$d_{1,\,air}$	$1 \cdot 10^{-3}$ m
Thickness of plastic	$d_{plastic}$	$0.95 \cdot 10^{-3}$ m
Thickness of second air layer	$d_{2,\,air}$	$0.25 \cdot 10^{-3}$ m
Thickness of glass	d_{glass}	$1.2 \cdot 10^{-3}$ m
Width of insulin ampoule	d	$9.2 \cdot 10^{-3}$ m

Figure 5 presents the equivalent capacitance circuit, which will be used to calculate the sense capacitance $C_{A\text{-}C}$ between electrodes A and C as presented in Figure 3 (b).

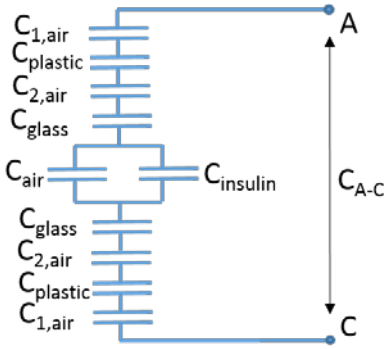


Figure 5. Equivalent capacitance circuit

By looking at the equivalent capacitance circuit in Figure 5, corresponding to the whole insulin pen, we provide an analytical expression of the total capacitance between two opposite contacts (for example A and C). The capacitance between these two electrodes is visually depicted in Figure 6. We mention that this capacitance is the sense capacitance itself, with no parasitic capacitances taken into account.

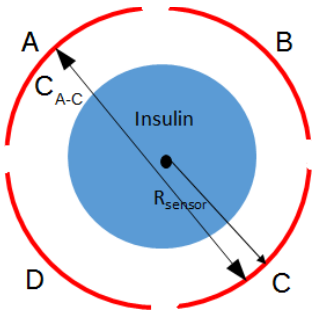


Figure 6. Evaluation of $C_{A\text{-}C}$ between A and C opposite electrodes

Therefore, the total capacitance C found between two opposite sense electrodes (for example A and C), according to the model developed in this paper is given by the following formula:

$$\frac{1}{C_{A-C}} = \frac{1}{C_{1,air}} + \frac{1}{C_{plastic}} + \frac{1}{C_{2,air}} + \frac{1}{C_{glass}} + \frac{1}{C_{air}+C_{insulin}} + \frac{1}{C_{glass}} + \frac{1}{C_{2,air}} + \frac{1}{C_{plastic}} + \frac{1}{C_{1,air}} \quad (4)$$

where $C_{1,air}$ and $C_{2,air}$ are the capacities of the air outside of the ampoule and C_{air} is the capacity of the air inside the ampoule, respectively. Further on, we have:

$$\frac{1}{C_{A-C}} = \frac{2}{C_{1,air}} + \frac{2}{C_{plastic}} + \frac{2}{C_{2,air}} + \frac{2}{C_{glass}} + \frac{1}{C_{air}+C_{insulin}} \quad (5)$$

with the following formulae holding for the individual capacitances:

$$C_{1,air} = \frac{\varepsilon_{air}A}{d_{1,air}}$$

$$C_{plastic} = \frac{\varepsilon_{plastic}A}{d_{plastic}}$$

$$C_{2,air} = \frac{\varepsilon_{air}A}{d_{2,air}} \quad (6\text{-}11)$$

$$C_{glass} = \frac{\varepsilon_{glass}A}{d_{glass}}$$

$$C_{air} = \frac{\varepsilon_{air}A_1}{d}$$

$$C_{insulin} = \frac{\varepsilon_{insulin}A_2}{d}$$

In Eqs. (6-9), A is the area of the sense electrode, which is given by the following expression:

$$A = Ll_{electrode} = R_{sensor}\theta l_{electrode} \quad (12)$$

with L the length of the arc of circle of the electrode and θ the angle describing the arc of circle.

We mention that in our four electrode cap model, the angle θ describing the cylinder electrodes, in radians, will have the value of $3\pi/8$.

At this point it is important mentioning that in order to be able to apply the classical formula for the capacitance value in Eq. (3), which is only valid for planar parallel plates, we will approximate the area A of the cylinder electrode with a planar area but of the same surface, as in Eq. (12). The smaller the angle θ is, the better the approximation. The latter can be viewed as "small electrodes approximation". Also, we must consider the average distance d, which will be explained in details further on. Under these circumstances we can apply the formula in Eq. (3) to find the capacitance.

It is still possible to express the distance between the plates as a function of the horizontal position. In this way it will be more accurate since the plates are not parallel but have a semicircle shape. In Figure 7, there is the depiction of two plates with arc of circle shape. It is the distance between them, on Oy axis, that we will take the average of. In this way, we can make the transition of the cylindrical plate capacitor into planar capacitor with the plate area equal with the area of the cylinder plate (Eq. 12) but with the distance between the plates equal to $d_{average}$ for the planar capacitor.

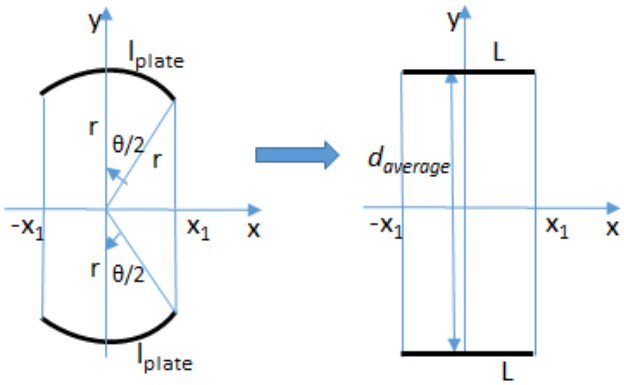


Figure 7. Transition from cylinder plate capacitor to planar capacitor

To do this, an average value of diameter has been calculated and it can be substituted with the $2r$ regarding the distance between the two plates. All the other 'r' in the equation need to remain as they are because they intervene in the area of each plate (actually this 'r' is the same as R_{sensor} in Eq. (12)). We will work in polar coordinates x and y, where:

$$x = rsin\frac{\theta}{2}, y = rcos\frac{\theta}{2} \quad (13)$$

Obviously, we have

$$x^2 + y^2 = r^2 \quad (14)$$

We are interested now to express y as a function of x, as it follows

$$y = \sqrt{r^2 - x^2} = f(x) \quad (15)$$

The average value of the function f=f(x) is the following:

$$f_{average} = \frac{1}{b-a}\int_a^b f(x)dx \quad (16)$$

Further on:

$$d_{average} = 2\frac{1}{2x_1}\int_{-x_1}^{x_1}\sqrt{r^2-x^2}\,dx = \frac{1}{x_1}\int_{-x_1}^{x_1}\sqrt{r^2-x^2}\,dx \quad (17)$$

$$\int\sqrt{r^2-x^2}\,dx = \frac{1}{2}\left[\left(x\sqrt{r^2-x^2} + r^2\sin^{-1}\frac{x}{r}\right)\right] \quad (18)$$

$$d_{average} = \frac{1}{2x_1}\left[r^2\sin^{-1}\left(\frac{x_1}{r}\right) - r^2\sin^{-1}\left(\frac{-x_1}{r}\right)\right] \quad (19)$$

By doing the computations, we further obtain:

$$\frac{1}{C_{A-C}} = \frac{1}{A}\left(\frac{2d_{1,air}}{\varepsilon_{air}} + \frac{2d_{plastic}}{\varepsilon_{plastic}} + \frac{2d_{2,air}}{\varepsilon_{air}} + \frac{2d_{glass}}{\varepsilon_{glass}}\right) + \frac{1}{C_p} \quad (20)$$

where

$$C_p = \frac{\varepsilon_{air}A_1}{d_{average}} + \frac{\varepsilon_{insulin}A_2}{d_{average}} \quad (21)$$

$$C_p = \frac{\varepsilon_{air}k_1A}{d_{average}} + \frac{\varepsilon_{insulin}k_2A}{d_{average}} = \frac{A}{d_{average}}(\varepsilon_{air}k_1 + \varepsilon_{insulin}(1-k_1)) \quad (22)$$

Additionally $k_1 = \frac{x}{l}$, with x being the length occupied by air and l length of the glass insulin ampoule. This can also be seen in Figure 8. We mention that in this case the total length of the electrodes coincides with the length of the insulin ampoule.

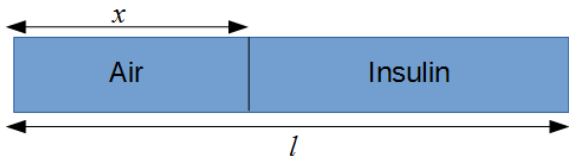


Figure 8. Air and insulin volumes in the insulin ampoule

Finally, the expression for the sense capacitance between two opposite electrode A and C is given below:

$$C_{A-C} = \frac{A}{\frac{2d_{1air}}{\varepsilon_{air}} + \frac{2d_{plastic}}{\varepsilon_{plastic}} + \frac{2d_{2air}}{\varepsilon_{air}} + \frac{2d_{glass}}{\varepsilon_{glass}} + \frac{d_{average}}{\varepsilon_{air}k_1 + \varepsilon_{insulin}(1-k_1)}} \quad (23)$$

The permittivity of free space (absolute) and relative electric permittivity are written in Table III. We mention that the relative electric permittivity of insulin is considered in this work to be 81, as it is not pure insulin, but a solution highly diluted in water.

TABLE III. ELECTRIC PERMITTIVITY OF MEDIA

Name	Symbol	Numerical value
Permittivity of free space (absolute)	ε_0	$8.854 \cdot 10^{-12}$ F/m
Relative electric permittivity of air	$\varepsilon_{r,air}$	1
Relative electric permittivity of plastic	$\varepsilon_{r,plastic}$	3.18
Relative electric permittivity of glass	$\varepsilon_{r,glass}$	4.7
Relative electric permittivity of insulin	$\varepsilon_{r,insulin}$	81

IV. RESULTS AND DISCUSSION

After carefully producing the three-dimensional precise geometry of the insulin pen, we have proceeded to do the simulations in ANSYS Maxwell 3D, under electrostatic regime. A simulation was launched in order to numerically estimate the values of the capacitance found between two electrodes. A polarization scheme as below has been used.

TABLE IV. POLARIZATION SCHEME (2 VS. 2 BIAS)

Electrodes	**Excitation type**
A and B (connected)	Voltage, 1 V
C and D (connected)	Voltage, 0 V

In Figure 9, one can see the variation of the capacitance (simulated and analytical results) versus k_1. The values chosen for k_1 are related to nine injection scenarios ranging from 0% to 100% air content (insulin discharge). We can see the values of the capacitance in the order of a few pFs. More precisely $C_{AB\text{-}CD}$= 7.82 pF, for full insulin pen case (simulation results). We must point that in Figure 9 we have considered the Eq. (23) from the analytical model for $\theta = 3\pi/4$. Due to the fact that the analytical model only refers to the cap itself, an offset (parasitic) capacitance coming from the rest of the full system in the value of 5 pF has been added. This value has been obtained through simulation on the complete insulin system minus the cap.

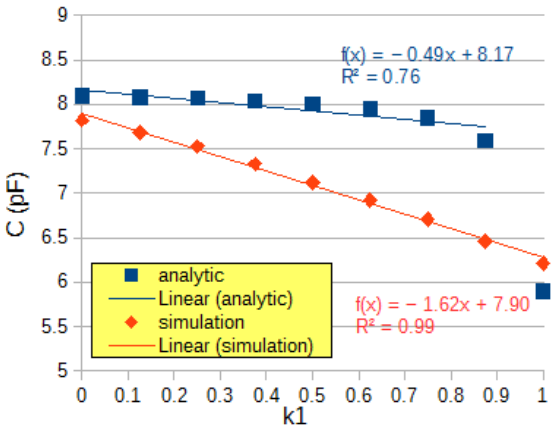


Figure 9. Electrode capacitance (2 vs. 2 bias) versus k_1

The simulated curve in Figure 9 has been fitted with a straight line of expression y=-1.62x+7.90. Alternatively, the analytical model provides a linear behavior in the $k_1 \in$ [0, 0.875] interval, y=-0.49x+8.17 (the end points can be considered end of the interval errors). In this way, the behavior of the injection has been proven to be linear, as desired.

In Figure 10, another polarization scheme (1 vs. 3, with 1V on electrode A and 0V on electrodes B, C and D) has been studied with the 3D model. We see a 15% decrease in the capacitance with respect to 2 vs. 2 polarization scheme.

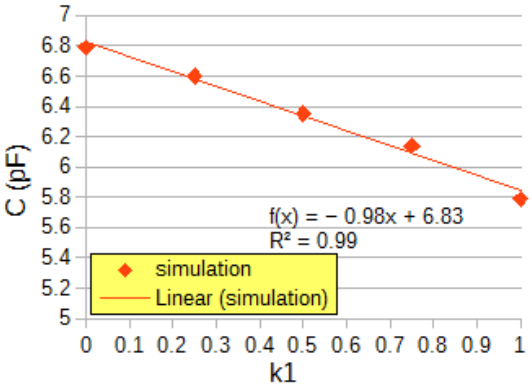


Figure 10. Electrode capacitance (1 vs. 3 bias) versus k_1

In Figure 11, three inter-electrode distances from 1 to 3 mm have been considered, in 2 vs. 2 polarization scheme. We observe that there is a capacitance drop by 1 pF (more abrupt) when going from 1 to 2 mm and by 0.7 pF from 2 to 3 mm, respectively.

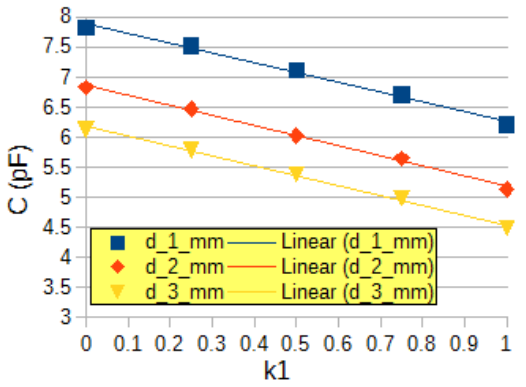


Figure 11. Electrode capacitance (2 vs. 2 bias) versus k_1

The obtained results for the capacitance are also in agreement with experimental results presented in the literature [3]. We mention that experimental results of the authors are ongoing at the time of writing this paper, as fabricated electrodes are being expected to be ready soon.

V. Conclusions and Future Perspectives

The work in this paper was intended to model and analyze the electrode capacitances in an insulin pen, for insulin administration to diabetic patients. To this purpose, a three-dimensional model of the full insulin pen containing all the media inside (air, plastic, glass, insulin) with precise dimensions has been proposed. The model is developed in ANSYS software and the electrode sense capacitance is calculated in an electrostatic regime in Maxwell 3D. A complete analytical model for the determination of the electrode capacitance between two opposite electrodes has been also conceived and included in this paper.

Numerical results of the electrode capacitance, for an insulin pen configuration with four electrodes have been obtained. The variation of the sense capacitance for different insulin injection scenarios, polarization schemes and inter-electrode distance has been given. The linear behaviour of the injection has been proven. The sense capacitance is in the order of a few pFs, with the capacitance between AB and CD electrodes $C_{AB\text{-}CD}$= 7.82 pF, for simulated full insulin pen case.

As future directions related to this project we mention performing the experimental results to evaluate the capacitance on various electrode types.

Acknowledgment

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Analysis of GaN MagFETs Compatible with RF Power Technology

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***Abstract* - The three-dimensional simulations, calibration, measured currents and calculated relative sensitivities of the first-ever fabricated double-drain gallium nitride (GaN) magnetic field effect transistor (MagFET) are given in this work. The MagFETs are GaN high electron mobility transistors (HEMTs) capable of operating under harsh environments. Geometrical and operational analysis are carried out on MagFETs using commercial simulation software Silvaco. The analysis shows promising relative sensitivities of 6.84%T^{-1} and 5.04%T^{-1} at ambient temperatures of 400 K and 500 K, respectively. In addition, the relative sensitivity of fabricated device is improved from 12%T^{-1} to 24%T^{-1} at 300 K by optimising device geometrical parameters.**

***Keywords* - GaN; HEMT; MagFET**

I. INTRODUCTION

In modern power electronics, additional circuitries are added to sense the current passing through the components and to provide system safety. It is a major advantage if the sensor can operate close to the analysed systems under high temperatures and high radiations and provide accurate outputs.

Most of the sensor technologies available in the market are silicon based. Compound semiconductors such as GaN are better candidates for operation under harsh environment. GaN-based devices have proven to be a promising replacement for silicon technology in RF and power applications [1], [2]. The large bandgap, good thermal conductivity, and polarization properties provide various advantageous over the conventional semiconductors. Due to significant interest in electrical and thermal properties of GaN material, commercialization of nitride-based devices is emerging quickly.

It is known that magnetic fields deflect the moving charge in semiconductors and the inversion layer of metal oxide semiconductor field effect transistors (MOSFETs) as reported in previous works [3], [4]. The magnetic field effects in the electronic device can be detected by sensing contacts across the device measuring Hall voltage or by split contacts measuring current imbalance, for instance.

In order to detect the current imbalance resulting from magnetic field, the drain contact is divided into two individual contacts held at the same potential and separated by a distance (see Fig.1). Ideally, under no magnetic fields, corner contacts on the device with the same length and width will receive equal current flow. In this case, the current difference will be zero and consequently the sensitivity. In the presence of magnetic fields, applied perpendicular to the device surface, the charged carriers are deflected as a result of the Lorentz force. This imbalance can be measured on contacts and the relative sensitivity of the double-drain sensor is calculated by the following equation [5]:

$$S_r[\%T^{-1}] = \frac{|I_{D1}-I_{D2}|}{(I_{D1}+I_{D2})\times|B|} \times 100\% \quad (1)$$

where I_{D1} and I_{D2} are the currents from drain 1 and drain 2 contacts, respectively, in the presence of magnetic field (B). The relative sensitivity of split-current sensors may show poor values as the current imbalance is small compared to device total current. Higher sensitivities can be achieved by adding a 3rd drain [6] and modifying the magnitude of the current flowing through it. The sensitivity is also a function of geometric parameters as seen in the following equation [7]:

$$S_r = G\mu^* \frac{L}{W} \quad (2)$$

where G is the geometrical correction factor, μ^* is the Hall mobility, L is the device length and W is the device width. The Hall electron mobility reads:

$$\mu_n^* = r_n \mu_n \quad (3)$$

where r_n is Hall electron scattering factor and μ_n is effective electron mobility. Furthermore, the current deflection (d) is a function of [8]:

$$d = f(L, \mu_n, B, T) \quad (4)$$

where L is the device length, μ_n is the electron mobility, B is the applied magnetic field and T is the temperature. To increase the current deflection and relative sensitivity, a

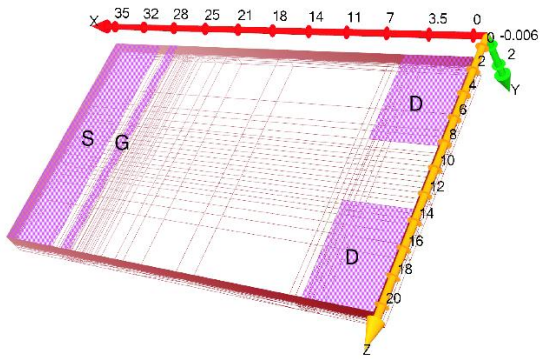

Fig. 1. 3D simulated GaN MagFET showing mesh profile at the device surface and dimensions (in microns) of fabricated device.

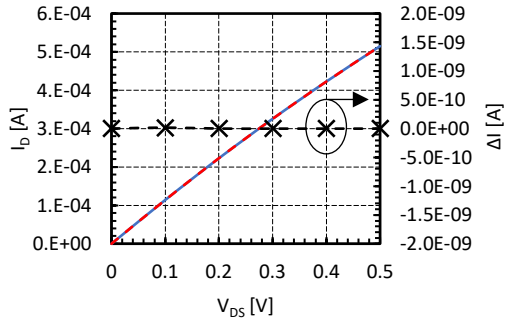

Fig. 2. Simulated drain currents (overlaid) of GaN MagFET (I_D) against drain to source voltage (V_{DS}) at V_{GS}=0V and 300 K. The current imbalance (ΔI) is nearly zero in absence of magnetic field (B=0 T).

longer sensor, higher electron mobility, larger magnetic field and lower operational temperature are required. Two-dimensional electron gas (2DEG) channel of GaN hetero-structure fulfils the requirement for high mobility.

The magnetic sensors are integrated with other electronics in the same IC batch to detect magnetic fields in the range of few milli-Tesla.

In this paper, we present simulation, calibration, analysis and optimisation of first-ever fabricated double-drain GaN magnetic sensors. The relative sensitivities and current differences are computed for different geometrical parameters, ambient temperatures and biasing conditions. The simulations are carried out to optimise the GaN device relative sensitivity for integration with a coil to be placed on top of the sensor in micro-meter distance. The current to be sensed flows through the coil producing the magnetic field invoking current imbalance in the GaN device.

II. Device Structure and Simulation Models

The simulated unintentionally doped (UID) gated sensor is GaN/$Al_xGa_{1-x}N$/GaN hetero-structure similar to GaN high electron mobility transistors (HEMTs) on silicon substrate. The mole fraction is x=0.25. The cap, the barrier, and the buffer thicknesses are 2 nm, 25 nm and 2 µm, respectively. The simulated sensor has a source length of L_S=5.5 µm, drain length of L_D=5.5 µm, source width of W_S=20 µm, source to drain distance of L_{SD}=24 µm, source to gate distance of L_{GS}=1.0 µm and gate to drain distance of L_{GD}=22 µm. The gate contact length is L_G=1.0 µm. The length and width of fabricated/simulated sensors are L=35 µm and W=20 µm, respectively. The separation between two drain contacts is L_{DD}=5 µm. The SiN passivation thickness is t_{SiN}=10 nm.

The spontaneous and piezoelectric polarizations are active in all simulations and the electron sheet density is set to 9.5×10^{12} cm^{-2} via polarization adjustments. The unintentional impurities resulting from epitaxial growth are added to the model in GaN:UID buffer at E_C-E_T=0.11 eV and E_C-E_T=3.28 eV [9]. Nitride parameters used in this paper are extracted from the literature [10]. The Shockley-Read-Hall (SRH) and Fermi-Dirac statistics are activated for all simulations. Nitride mobility models for low and high electric fields are employed in 3D simulations. The mobility is considered as effective to account for scattering mechanisms in fabricated device. Self-heating effects are neglected.

The Lorentz force and magnetic effects are modelled using 3D MAGNETIC module of Silvaco atlas. The GaN Hall scattering factor is extracted from the literature [11] and is set to be r = 1.1 in simulations. The magnetic field (B) is applied perpendicular to the surface in units of Tesla.

III. GaN MagFET Simulation and Measurement Results

The GaN split-current magnetic sensor with two drains is presented in Fig. 1. The drain contacts have the same length and width to avoid undesirable current offset in the absence of magnetic field.

Fig. 2 shows the output characteristics of the GaN split current sensor in the absence of magnetic field at 300 K. The current flows equally into two drains and the current imbalance (ΔI) is nearly zero for V_{DS}=0V to V_{DS}=0.5V at V_{GS}=0V. The negligible current offset is important to ensure accuracy of simulation results since poor meshing may cause current deflection in absence of magnetic fields.

Fig. 3 is the simulated current imbalance for various applied magnetic fields at V_{GS}=0V, V_{DS}=0.5V and 300 K. The measurements were carried out on 60 fabricated devices and standard deviation resulting from imperfection

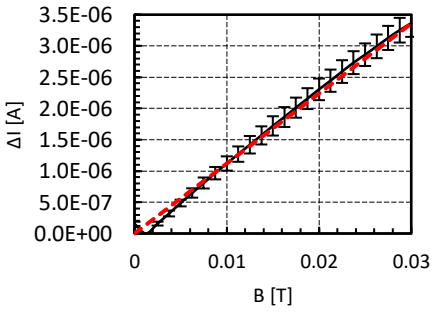

Fig. 3. Simulated current difference (ΔI) of GaN MagFET (dashes) from B=0 T to B=0.03 T in steps of 0.01 T at V_{DS}=0.5V, V_{GS}=0V and 300 K against measured current imbalance (line) in fabricated GaN sensors. The errors bars are calculated standard deviation from 60 fabricated devices. The calculated relative sensitivty is S_r=12%T^{-1}.

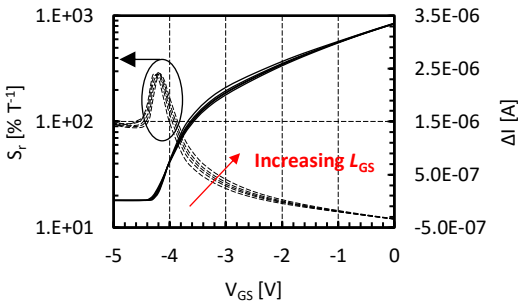

Fig. 4. Simulated relative sensitivities (S_r) (dashes) and current difference (ΔI) (lines) of GaN MagFETs for different gate to source spacings of 1.0 μm to 5.0 μm in steps of 1.0 μm where gate length and source to drain spacing is kept constant (L_G=1.0 μm and L_{SD}=24 μm) at B=0.03 T, V_{DS}=0.5V, and 300 K.

in fabrication process, geometrical errors and non-uniformity in material resistivity and thickness have been presented with bars. The current difference obtained from simulations has been calibrated to experimental data showing a good agreement.

Fig. 4 is the predicted current imbalance and relative sensitivities for various gate to source spacing of L_{GS}=1.0 μm to L_{GS}=5.0 μm in steps of 1.0 μm. Gate length and source to drain spacing are kept constant at L_G=1.0 μm, L_{SD}=24 μm, respectively. Due to reduction in total current [12] of the device and increase in the Lorentz force between gate and drain resulting from this scaling, simulation results show increase in relative sensitivities. This effect is more pronounced at low gate biases. It needs to be mentioned that keeping the device length constant and scaling up the gate to source distance may trigger impact ionisation at lower biasing conditions [13].

Fig. 5 is the simulated differential current and relative sensitivities for different gate lengths of L_G=1.0 μm to L_G=5.0 μm in steps of 1.0 μm where gate to source and source to drain spacings are kept constant at L_{GS}=1.0 μm and L_{SD}=24 μm, respectively. Scaling up the gate length reduces the device total current [12]. Consequently, improvement in relative sensitivity is observed. In addition, increase in the electric field resulting from this scaling between gate and drain is also predicted.

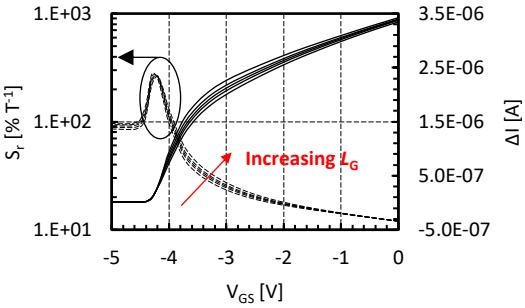

Fig. 5. Simulated relative sensitivities (S_r) (dashes) and current difference (ΔI) (lines) of GaN MagFETs for different gate lengths of 1.0 to 5.0 μm in steps of 1.0 μm where the gate to source and source to drain spacings are kept constant (L_{GS}=1.0 μm and L_{SD}=24 μm) at B=0.03 T, V_{DS}=0.5V, and 300 K.

Fig. 6 is the simulated current difference and calculated relative sensitivities at V_{DS}=0.5V, 300 K and various ambient temperatures. The simulation predicts promising relative sensitivities of S_r=6.84%T^{-1} and S_r=5.04%T^{-1} at high temperatures of 400 and 500 K compared to S_r=12%T^{-1} at 300 K. The degradation is due to electron mobility and velocity reduction [14], [15]. Moreover, threshold voltage shift is also observed from TCAD results due to trap states at the device surface [16].

Fig. 7 is the comparison between the optimised device (L=65 μm, W=20 μm, L_S=5.5 μm, W_S=5.0 μm, L_{DD}=5 μm, L_G=5.0 μm and L_{GD}=10 μm) against the sensor with L=35 μm, W=20 μm, L_S=5.5 μm, W_S=20 μm, L_{DD}=5 μm, L_G=1.0 μm and L_{GD}=22 μm. An increase in sensitivity (from S_r=12%T^{-1} to S_r=24%T^{-1}) is predicted at V_{GS}=0V for the optimised GaN magnetic sensor. The increase in relative sensitivity at V_{GS}=0V is mainly due to increase of source to drain resistance and reduction of total current, while at low gate biases is also due to increase in current imbalance resulting from a larger Lorentz force.

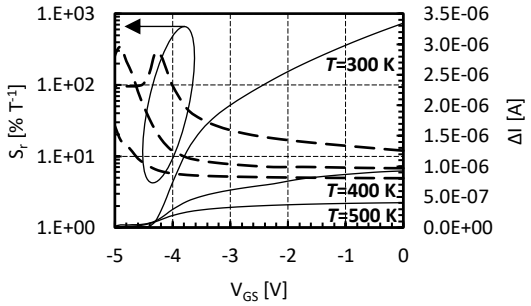

Fig. 6. Simulated relative sensitivity (S_r) (dashes) and current difference (ΔI) (lines) of GaN MagFET for different ambient temperatures of T=300 K, T=400 K and T=500 K at V_{DS}=0.5V and B=0.03 T.

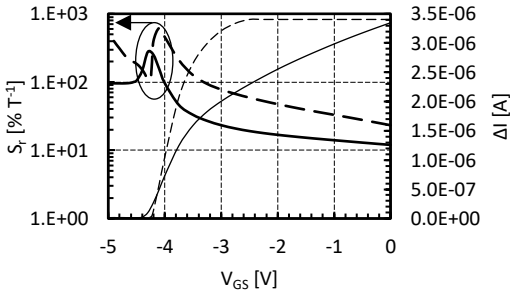

Fig. 7. Simulated relative sensitivity (S_r) (dash) and current difference (ΔI) (dash) of optimised GaN MagFET (L=65 μm, W=20 μm, L_S=5.5 μm, W_S=5.0 μm, L_{DD}=5 μm, L_G=5.0 μm and L_{GD}=10 μm) against previously simulated GaN MagFET relative sensitivity (line) and current difference (line) with L=35 μm, W=20 μm, L_S=5.5 μm, W_S=20 μm, L_{DD}=5 μm, L_G=1.0 μm and L_{GD}=22 μm at V_{DS}=0.5V and 300 K.

IV. CONCLUSION

Three-dimensional simulations have been employed to study relative sensitivities, the main figure of merit of magnetic sensors. Simulated current difference was calibrated against measured data to validate simulations obtained from Silvaco software. Geometrical analysis was carried out on GaN split-current magnetic sensor demonstrating increase in relative sensitivities with scaling up the gate length and source to gate spacing. We also presented an optimised device predicting an increase in relative sensitivity from S_r=12%T^{-1} to S_r=24%T^{-1} at V_{GS}=0V, V_{DS}=0.5V and 300 K. In addition, three dimensional simulations were carried out to study the relative sensitivities at 300 K, 400 K and 500 K ambient temperatures predicting a promising operation of GaN split-current sensors under harsh environment.

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Simulation Study of a Deep-Trench LDMOS with Bilateral Super-Junction Drift Regions

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***Abstract* - An improved structure of the Deep-Trench Lateral Double-diffused Metal-Oxide-Semiconductor transistor (DT-LDMOS) is proposed and studied. The most improvement is that a well-known concept of super-junction is simultaneously applied to the bilateral drift regions beside the deep-trench. Thus, in comparison with the conventional device, the Figure of Merit (FOM, which equals $BV^2/R_{on,\,sp}$) of the proposed one is increased by about 35.6%, which means a significant reduction of conduction loss is achieved. Another improvement is that the device substrate is changed from silicon-on-insulator to ordinary bulk silicon. Therefore, the highest lattice temperature in a heat dissipation test is reduced from about 373 K for the conventional device to about 312 K for the proposed one, which means a better heat dissipation performance is obtained. All in all, the proposed device not only attains a remarkable improvement in electric characteristics, but also possesses an enhanced reliability. It is believed to be a promising device for the monolithic power ICs with enhanced performance.**

Keywords* - *power electronics; power device; LDMOS; deep-trench; super-junction.

I. INTRODUCTION

The development of power electronics is closely related to the evolution of power devices [1]. Especially in a monolithic high-voltage ICs, power switches are critical to the chip performance. These switches are mostly the Lateral Double-diffused Metal-Oxide-Semiconductor (LDMOS) transistors, which consume large chip area [2]. Recently, a LDMOS based on a technology of Deep-Trench (DT) has gained increasing attention [3], [4]. This device uses a deep and narrow trench filled with dielectric, substituting the traditional semiconductor of silicon, to sustain most of the surface voltage. Since the critical electric-field of dielectric is much higher than that of silicon, the device width can be greatly curtailed.

In the past five years, studies on developing the DT-LDMOS were actively carried out [5-11]. The common idea of them is to improve the distribution of electric-field in the drift region. Undoubtedly, the most effective approach to address that, as is well-known, should be the technique of Super-Junction (SJ), which is regarded as a breakthrough to the "silicon limit" [12-17]. However, although there have been many DT-LDMOS devices improved by SJ, the improvements are always limited to be implemented in the drift region on only one side of the DT. Besides, in the prior art, Silicon-On-Insulator (SOI) is commonly used to eliminate the impact of substrate on surface electric-field distribution. The oxide layer in SOI would heavily hinder the heat powered by the device itself from diffusing to a heat sink at the bottom.

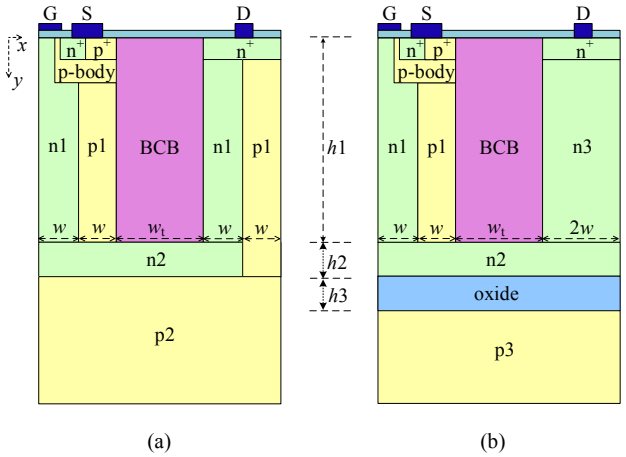

Figure 1. Cross section views of the (a) proposed and (b) conventional DT-LDMOS devices. There are two structural distinctions, i.e., the right drift regions, and the substrates. Just one cell of each device is displayed here, and the actual device consists of plenty of symmetrical cells in parallel. To analyze the characteristics of the total device, the boundary condition of reflection symmetry is applied at the left and right edges of the cell structure in the simulation.

To address the above issues, an improved DT-LDMOS is proposed in this paper. By applying SJ to the bilateral drift regions on both sides of the DT, the proposed device achieves a significantly improved trade-off between the breakdown voltage (BV) and the specific on-resistance ($R_{on,\,sp}$). Moreover, through adopting the ordinary bulk silicon as substrate, not only is the cost economized, but also the reliability concerned about heat dissipation is strengthened. Therefore, the proposal is deemed to be promising for the monolithic power ICs with improved performance and efficiency. The theory and performance of the proposed device will be expounded in the following.

II. STRUCTURE AND MECHANISM

Fig. 1(a) and (b) depict the cross section views of the proposed and conventional devices, respectively. In these figures, just one cell structure of each device is displayed. It is widely known that an actual device should consist of

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plenty of symmetrical cells in parallel. Therefore, to analyze the characteristics of the total device, a boundary condition of reflection symmetry, which is applied at the left and right edges of the cell structure, is used in all of the following simulations [18]. Additionally, in the actual device, there should be a junction termination at the edge of the outermost one of the parallel cells [19]. If the device is applied in monolithic ICs, this termination will act as an isolation between the high-voltage power devices and the low-voltage integrated circuits.

There are numerous similarities between the two devices. Specifically speaking, at the bottom, both the substrates of p2 and p3 are connected to the ground as well as 0 V. On the surface, there are three coplanar electrodes, which are named as Gate (G), Source (S) and Drain (D) from left to right, respectively. G is connected to a low-voltage control signal switching within the range of ± 10 V. S is always connected to 0 V. D is connected to the highest reverse voltage through a resistance or an inductive load. Between S and D, there is a narrow DT filled with a dielectric of BenzoCycloButene (BCB) which has a low permittivity and a high critical electric-field. When the device is off, the DT sustains most of the reverse voltage between S and D. And due to the critical electric-field as high as 5.3 MV/cm in BCB [20], the device width could be pretty small. Besides, on the left side of the DT, there is a drift region in a typical form of SJ, which consists of an n^- pillar (n1) and a p^- pillar (p1). Through a proper design, as well as making the doping dose of n1 and p1 be equal, the electric flux emitted by the depleted n1 can be fully absorbed by the depleted p1 when the device is off, even though the two pillars are heavily doped. In this case, the SJ drift region can act as an intrinsic region to sustain a reverse voltage as high as possible and, meanwhile, presents an ultra-low on-resistance. The drift region in this situation is referred to "charge-balanced".

There are also two discernible distinctions between the two devices. First, as shown in Fig. 1(b), the right drift region in the conventional device is a common n-type layer (n3). However, in the proposed one as shown in Fig. 1(a), this region is improved to have the same SJ form as the left. According to the charge-balanced principle mentioned above, the trade-off between the BV and $R_{on, sp}$ can be further improved by this modification. Moreover, the additional SJ drift region located on the right side of the proposed device has a negligible effect on the dynamic electric characteristics, which will be demonstrated in part IV. The second structural improvement is the alteration of the substrate. In the conventional device, the material of SOI is utilized as substrate to protect the electric-field distribution in the drift regions. However, the oxide layer in SOI will hinder the heat produced by device operations from diffusing to the packaging metal at the bottom. This is dangerous for power device which is continuously working in the case of high-voltage and/or large-current. Hence, to improve the performance of heat dissipation, the substrate is replaced by ordinary bulk silicon in the proposed device. In conclusion, the above structural changes can contribute to the improvements on the trade-off between the BV and $R_{on, sp}$, and improve the heat dissipation reliability as well.

III. Simulation and Optimization

Both of the devices shown in Fig. 1 are optimized by using the simulation tool of MEDICI. Simulation models include CONSRH, CONMOB, FLDMOB, SRFMOB2, and IMPACT.I. In the turn-off process, the impact ionization rate (α) increases along with the drain voltage. When the integral of α equals 1, the device is broken and the drain voltage at this time is the BV. In the on-state, when the gate voltage and the drain voltage are fixed at 10 V and 0.5 V, respectively, the on-resistance multiplied by the device width of 13 μm is $R_{on, sp}$. More details of the simulation methods can be found in [18].

Before the simulation, several justifiable settings of the device size are assigned. In detail, the pillar width (w) is set to 2 μm, and the DT depth (h_1) is set to 25 μm. The thickness of n2 (h_2) is set to 2 μm, and the thickness of the oxide in the conventional device (h_3) is set to 3 μm. Besides, the thickness of the substrates of p2 and p3 are set to be sufficient for accurate simulations. In other words, p2 and p3 are thick enough to avoid being completely depleted at the highest reverse voltage. In the proposed device, from the bottom up, the key parameters need to be optimized include the doping concentrations of p2 (N_{p2}) and n2 (N_{n2}), the DT width (w_t), and the doping concentrations of n1 (N_{n1}) and p1 (N_{p1}), respectively. The processes of optimization for the proposed device will be performed in this order.

To shield the complex interplay among the parameters, some necessary assumptions are made. For instance, to analyze the influence of N_{p2} on BV without disturbances, we set the DT to have a sufficient width of 10 μm, and set the drift regions consisting of n1 and p1 to be intrinsic to approach the ideal charge-balanced status even without lateral electric-field between the pillars. It should be indicated that whether the drift region is SJ or not, the narrow DT would act as a capacitor and induce charges in the silicon nearby it. Hence, a p^- pillar and an n^- pillar both with a variation vertical doping should be assigned to the left and the right nearby the DT, respectively. Namely, the left p1 and the right n1 or n3 should be always doped. Because the concept of variation vertical doping in such a device is not the issue studied in this paper, it will be ignored and not be reiterated below.

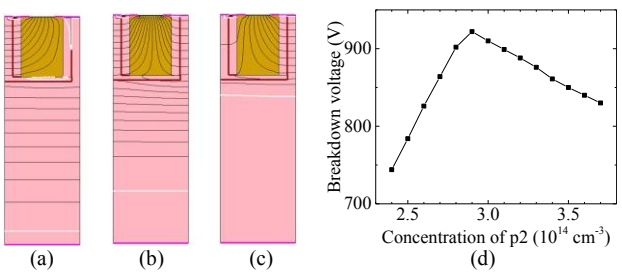


Figure 2. Optimization of N_{p2} for the proposed device. When N_{p2} is set to 1×10^{14} cm^{-3}, 2.9×10^{14} cm^{-3} and 2.4×10^{15} cm^{-3}, the BV is 491 V, 922 V and 551 V, respectively, and the potential distribution at the moment of breakdown is shown as (a), (b) and (c), respectively. In these figures of potential distribution, the black contours are 50 V/div, and the white lines are the edges of depleted regions. (d) BV vs. N_{p2}, @ w_t = 10 μm; $N_{n2} = 8\times10^{15}$ cm^{-3}; n1 and p1 are intrinsic. Taking into account the simulation results, a value of 2.9×10^{14} cm^{-3} is selected for N_{p2}.

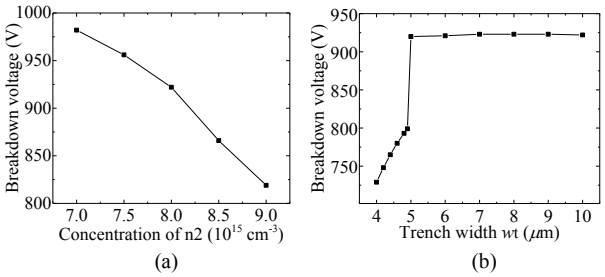


Figure 3. (a) Influence of N_{n2} on BV for the proposed device, @ w_t = 10 μm; N_{p2} = 2.9×10^{14} cm^{-3}; n1 and p1 are intrinsic. (b) Effect of w_t on BV for the proposed device, @ N_{p2} = 2.9×10^{14} cm^{-3}; N_{n2} = 8×10^{15} cm^{-3}; n1 and p1 are intrinsic.

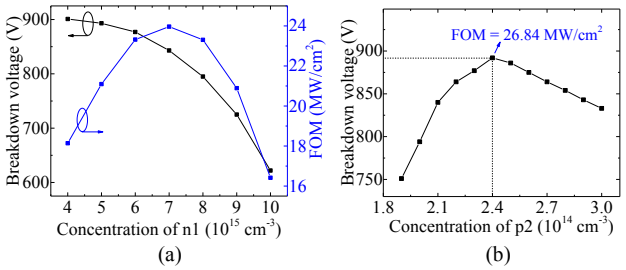


Figure 5. (a) Impact of N_{n1} on BV (the left axis) and on FOM (the right axis) for the proposed device, @ N_{p2} = 2.9×10^{14} cm^{-3}; N_{n2} = 8×10^{15} cm^{-3}; w_t = 5 μm. (b) Fine-tuning optimization of N_{p2} for the proposed device, @ N_{n2} = 8×10^{15} cm^{-3}; w_t = 5 μm; N_{n1} = 7×10^{15} cm^{-3}.

In the proposed device, if N_{p2} is too large or too small, the BV will be impaired. This is because when the device is turning off, the potential of S and G maintains 0 V, and the potential of D is increased gradually. If N_{p2} is quite large, according to Poisson's equation, a heavily doped substrate will provide plentiful charges to deplete n2 completely at a low reverse voltage, and then the potential of n2 will be clamped. As a result, the highest reverse voltage is sustained mainly by the right drift region and, therefore, the BV is reduced, as demonstrated by Fig. 2(c). Otherwise, if N_{p2} is quite small, the reverse voltage will be sustained mainly by the left drift region, and the BV will be reduced as well, as illustrated in Fig. 2(a). Based on the simulation results as shown in Fig. 2(d), a value of 2.9×10^{14} cm^{-3} is selected for N_{p2}.

With the optimized N_{p2} and the same assumptions that w_t = 10 μm and that the drift regions are intrinsic, the impact of N_{n2} on BV is analyzed. As shown in Fig. 3(a), the BV is increased along with the decrease of N_{n2}. However, since n2 is the current-conductive layer, the decreased N_{n2} will result in an increased $R_{on,\ sp}$. For a comprehensive consideration of the trade-off between the BV and $R_{on,\ sp}$, a value of 8×10^{15} cm^{-3} is chosen for N_{n2}.

Fig. 3(b) displays the effect of w_t on BV, when both of N_{p2} and N_{n2} are optimized, and the drift regions are still intrinsic. It is noted that when w_t is reduced to be less than 5 μm, the BV is sharply decreased. This is because when the DT is so narrow, the lateral electric-field in it is enormous. According to the equation of continuity of electric flux, this electric-field is decreased proportionally into the silicon nearby the dielectric, where the reducing factor is equal to the relative permittivity of silicon divided by that of the dielectric. However, although the electric-field is decreased, it is still larger than the critical electric-field of silicon, and can lead to breakdown. Otherwise, when w_t is larger than 5 μm, the breakdown will mainly be decided by the electric-field distribution in bulk silicon. Since n2 has a heavy doping, the voltage drop across it is small, and most of the reverse voltage is sustained by the bilateral SJ drift regions. Therefore, further increase of w_t will barely benefit the BV, but only increases the cell pitch and raises $R_{on,\ sp}$. Based on above, a value of 5 μm is chosen for w_t. In this case, the aspect ratio of the DT is (5:1). We conducted an experiment to confirm this aspect ratio is feasible. As illustrated in Fig. 4, an aspect ratio of (27.44 μm: 5.52 μm) which approximates to the required one is obtained.

After N_{p2}, N_{n2} and w_t were optimized, the influence of N_{n1} and N_{p1} is analyzed. According to the charge-balanced concept, N_{n1} should equal N_{p1}. Meanwhile, an increased N_{n1} contributes to a smaller $R_{on,\ sp}$, but deteriorates the BV, due to the enhanced electric-field between n1 and p1, as indicated in Fig. 5(a). The main purpose of this work is to improve the trade-off between the BV and $R_{on,\ sp}$, so a well-known "Figure of Merit" (FOM) is introduced as "FOM = (BV^2 / $R_{on,\ sp}$)" [7]. Depending on the simulation results, the optimized N_{n1} as well as the one associated with the highest FOM is found to be 7×10^{15} cm^{-3}.

Since each of the above steps is based on some assumptions and actually there is a complex interplay among them, a fine-tuning of N_{p2} is supplemented, as shown in Fig. 5(b). Finally, the optimized structure for the proposed device gains a FOM of about 26.84 MW/cm^2 with a BV of about 892 V.

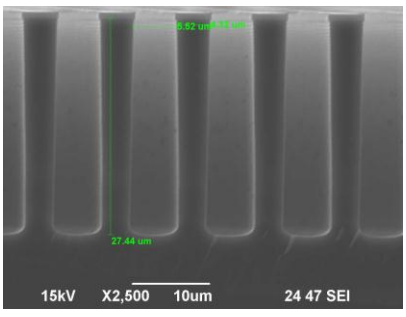


Figure 4. Scanning Electron Microscope photo of the deep-trenches. The DT is etched by using an Inductively Coupled Plasma (ICP) technique. The aspect ratio obtained in the experiment is about (27.44 μm : 5.52 μm), which is approximate to the required value of 5:1.

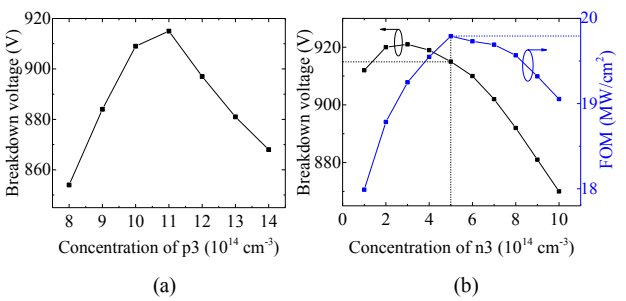


Figure 6. Opitimaztion for the conventional device. (a) Impact of N_{p3} on BV, @ N_{n1} = 7×10^{15} cm^{-3}; N_{n2} = 8×10^{15} cm^{-3}; w_t = 5 μm. (b) Effects of N_{n3} on BV (the left axis) and on FOM (the right axis), @ N_{n1} = 7×10^{15} cm^{-3}; N_{n2} = 8×10^{15} cm^{-3}; w_t = 5 μm.

TABLE I. OPTIMIZED PARAMETERS

Parameter	*Value*
Doping concentration of n1 (N_{n1})	7.0×10^{15} cm^{-3}
Doping concentration of n2 (N_{n2})	8.0×10^{15} cm^{-3}
Doping concentration of n3 (N_{n3})	5.0×10^{14} cm^{-3}
Doping concentration of p1 (N_{p1})	7.0×10^{15} cm^{-3}
Doping concentration of p2 (N_{p2})	2.9×10^{14} cm^{-3}
Doping concentration of p3 (N_{p3})	1.1×10^{15} cm^{-3}
Width of the deep-trench (w_t)	5.0 μm

The conventional device is optimized as consistently as the proposed one. The optimization process is concisely presented in Fig. 6. As mentioned, the structural distinctions between the conventional and the proposed devices are the right drift region and the substrate. Therefore, it can be concluded from Fig. 6 that, when the doping concentration of p3 (N_{p3}) equals 1.1×10^{15} cm^{-3} and the doping concentration of n3 (N_{n3}) is 5×10^{14} cm^{-3}, the conventional device is optimized, and achieves a FOM of about 19.79 MW/cm^2 with a BV of about 915 V.

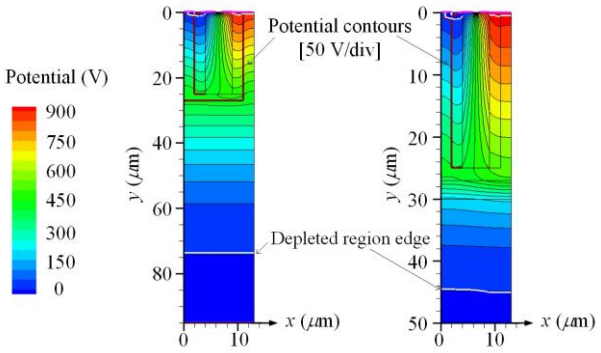
The optimized parameters are listed in Table I. It should be explained that all of them can be fabricated in reality. For example, for the proposed device, N_{p2} of 2.9×10^{14} cm^{-3} can be realized by using an epitaxial silicon wafer which is doped by boron and with the resistivity of about 46 Ω·cm. Based on this wafer, series of epitaxies and ion implantations are performed to form n2 and the pillars of n1 and p1. After that, a deep-trench is etched and filled by the chemical vapor deposition (CVD). At last, after some basic common CMOS processes, the proposed device can be fabricated. All of the above processes have been commonly adopted to fabricate SJ or DT devices in industry. Besides, the material of BCB is also a feasible dielectric for power devices. Its properties and characteristics have been studied by many previous studies. For example, the filling process for it and the influence of the interface between the BCB and silicon have been experimentally studied in [21]. Hence, it is a reasonable inference that the proposal is feasible.

IV. CHARACTERISTICS AND COMPARISON

To compare the device characteristics, such as the static and dynamic electric characteristics, we substitute the optimized parameters into a series of simulations. The comparison results are expounded as following:

A. Static electric characteristic

Since the drift region of n2 is heavily doped, the voltage drop across it is small, and most of the reverse voltage is sustained by the SJ drift regions beside the DT. As shown in Fig. 7, at an approximate reverse voltage of about 900 V, the two devices both present uniform distribution of potential contours in the right drift region. However, it should be pointed out that in the conventional device, N_{n3} is only about 5×10^{14} cm^{-3}. In other words, it achieves the BV of about 915 V through sacrificing the other performance as well as increasing the $R_{on,\ sp}$.



(a) (b)

Figure 7. Potential distribution at the moment of breakdown for the (a) proposed and (b) conventional devices. In the right drift region of them, the potential contours are both distributed uniformly. But the doping concentrations there have a great different. N_{n1} for the proposed device is over tenfold larger than N_{n3} for the conventional one.

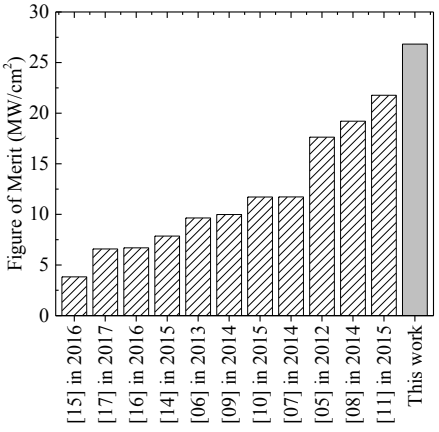


Figure 8. Comparison of the FOM performance between some recently reported LDMOS and the proposed device, where the FOM achieved in this work is the highest.

Therefore, the FOM for it is just about 19.79 MW/cm^2. For the proposed device, N_{n1} has reached 7×10^{15} cm^{-3}. Meanwhile, due to the application of charge-balanced, the breakdown voltage still achieves 892 V. Therefore, the FOM of the proposed device is enhanced to about 26.84 MW/cm^2, which is increased by 35.6% in comparison with that of the conventional one.

Fig. 8 exhibits the FOM performance of numerous LDMOS published recently, including the DT-LDMOS improved by some other techniques [5]-[11] and the devices of lateral SJ LDMOS [14]-[17]. Evidently, due to a further application of SJ, i. e., due to the addition of the right SJ drift region, the proposed device achieves a higher FOM than those in the prior art.

More specifically, as shown in Fig. 9, the relationship between the BV and $R_{on,\ sp}$ of DT-LDMOS is further improved by this work. The curve marked with "silicon limit" was proposed by B.J. Baliga in 1989, and has been broken through by X.B. Chen with his patent of super-junction [12]. However, since SJ has not been perfectly applied to a LDMOS yet, this "silicon limit" continues to be applicable for most of the LDMOS. Taking advantage

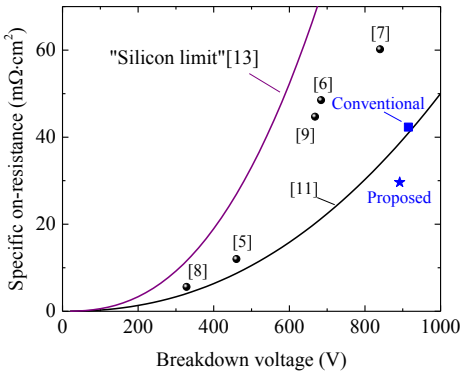


Figure 9. Comparison of the BV ~ $R_{on,\ sp}$ relationship between some recently published DT-LDMOS and the devices studied in this work, where the relationship achieved in the proposed device is optimum.

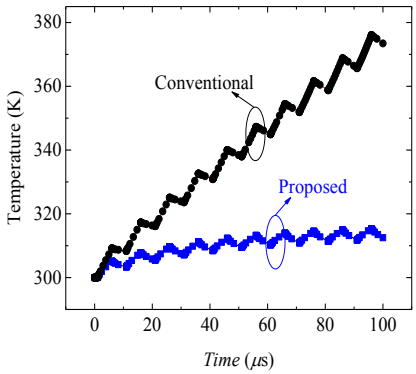


Figure 11. Highest lattice temperature extracted from the heat dissipation testing, where a thermal resistance is assumed at the device bottom, and the devices are repeatedly switching in a high-power case .

of the DT, the referenced structures of DT-LDMOS, especially the latest published one with a variable-*k* dielectric trench and the conventional device simulated in this work, all achieve a lower $R_{on,\ sp}$ than that in the "silicon limit" at the same BV. In other words, these devices all overcome the "silicon limit". Nevertheless, in comparison with them, the proposed device achieves a much better trade-off between the BV and $R_{on,\ sp}$, which means the static electric characteristic of DT-LDMOS is optimized to a new level.

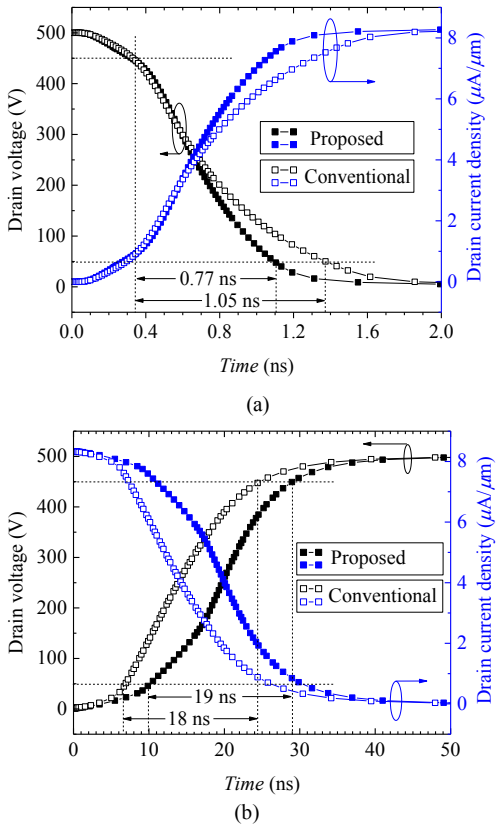


Figure 10. Comparisons of the (a) turn-on and (b) turn-off processes, where the two devices are both connected to a DC bus-voltage (V_{DD}) of 500 V with the same resistance load. The control signal as well as the gate voltage triggers the device at the time of 0 ns. The turn-on time and turn-off time are computed as the time for output voltage varying from 90% to 10% and from 10% to 90% of V_{DD}, respectively.

B. Dynamic electric characteristic

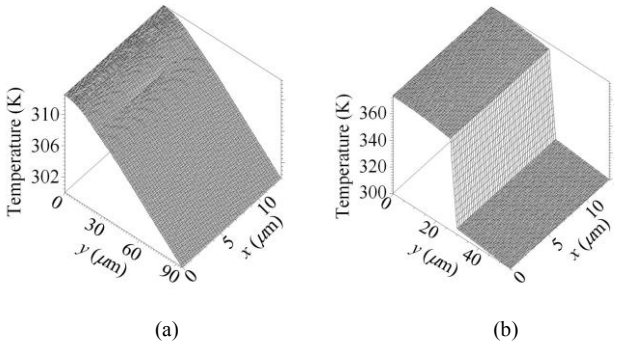
According to the simulation results as shown in Fig. 10, the turn-on time for the conventional and proposed devices is 1.05 ns and 0.77 ns, and the turn-off time for them is 18 ns and 19 ns, respectively. The comparison reveals the structural changes proposed in this paper have a negligible effect on the dynamic electric characteristics.

Actually, influence of a SJ drift region on switching performance is usually referred to a turn-off delay time. At the beginning of turn-off, charges are gradually taken away from the drift region. n1 and p1 with a depleted region between them are acting as a differential capacitance (C_{SJ}). Since the depleted region has a large area, and is thin at this moment, C_{SJ} is tremendous. The device should charge C_{SJ} first and, therefore, there is a delay time before the reverse voltage is rapidly increased. The standard calculation of turn-off time is to compute the time for output voltage varying from 10% to 90% of the highest reverse voltage, and it can be observed from Fig. 10(b) that, the incipient reverse voltage during the delay time (from 0 ns to about 10 ns) is small. Therefore, the delay time caused by the SJ drift region affects neither the power loss nor the turn-off time. As a result, although there is larger turn-off delay time for the proposed device, due to the additional SJ drift region on the right, the switching performance is actually not affected.

C. Heat dissipation characteristics

Since the surface of power devices is covered by packaging adiabatic materials, the dissipation of the heat powered by the devices themselves mainly relies on a heat sink at the bottom. However, in the conventional device as shown in Fig. 1(b), the oxide layer in SOI obviously hinders heat from flowing to the bottom and, therefore, leads to a threat to the device reliability. To cope with that, we change the substrate in the proposed device to ordinary bulk silicon, as shown in Fig. 1(a).

To illustrate the advantage of this modification, a simulation of heat dissipation testing is performed. In the testing, the ambient temperature is set to 300 K. The thermal conductivity of the oxide and BCB are assumed according to the references [18], [20]. The thermal boundary conditions for this non-isothermal simulation include a finite thermal resistance between the device and a heat sink. This thermal resistance is assumed to be 2028



(a) (b)

Figure 12. Comparison of the 3-D temperature distributions between the (a) proposed and (b) conventional devices. The distributions are both extracted at the tenth circle in the high-power heat dissipation test.

K·μm/W and is located at the bottom of the device, which is defined according to the realistic application of an 8-lead standard Small Outline Package (SOIC-8) with a chip area of about 4 mm^2. Under these conditions, both the proposed and conventional devices are forced to work in a high-power situation, i.e., they are connected to a 400 V bus-voltage with an on-state current of 14 A, and repeatedly switch in a frequency of 100 kHz.

In Fig. 11, it can be seen that during the testing, the highest lattice temperature for the conventional device is continuously increased, while that for the proposed device gradually reaches a stabilization. After ten circles, as well as at the time of 100 μs, the highest lattice temperature for the conventional device is raised to about 373 K, while that for the proposed device is only about 312 K. This can be intuitively observed by the temperature distribution at this time. Evidently, as shown in Fig. 12, the oxide layer in the conventional device badly hinders the heat dissipation, and in the proposed device, the heat can swimmingly flow to the heat sink at the bottom, which makes the device more reliable.

V. CONLUSION

In this paper, an improved structure of DT-LDMOS is proposed and studied by simulations. Through the application of the bilateral SJ drift regions and the modification of the substrate, the proposed device not only achieves a significant improvement in electric characteristics, but also possesses an enhanced heat dissipation reliability.

The simulation results demonstrate the advantages of the proposal. In comparison with the optimized conventional device with the same size and having the approximate BV of about 900 V, the FOM of the proposed one is significantly increased by about 35.6%. Moreover, the highest lattice temperature extracted from a high-power testing is reduced from about 373 K for the conventional device to about 312 K for the proposed one.

All of these results make our proposal promising and interesting for the monolithic power ICs. In the future, we will continue the study. For example, it is meaningful to fabricate the proposed device, and to experimentally study if such a proposal would be more resistive to the heat-induced changes in characteristics than the prior art.

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Simulation Study on the High-*k* SJ-VDMOS with Gradient Side-Wall

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***Abstract* - The influences of gradient side-walls in a High-*k* Super Junction Vertical Double-Diffused Metal-Oxide-Semiconductor (High-*k* SJ-VDMOS) and in an ordinary Super Junction VDMOS (SJ-VDMOS) are studied and compared according to the analysis and simulations. The two devices show the same steady on-state current density for different side-wall gradient, but their breakdown voltages (V_b) acutely vary and, therefore, their FOM (Figure of Merit, which is equal to the square of V_b divided by the specific on-resistance) are varied. The study indicates that, the V_b of the device with more lightly doped pillars will be less impacted by the side-wall gradient, and the one having the pillars with unequal areas will be more impacted. Moreover, it is also demonstrated that, an appropriate positive side-wall gradient (namely, the Hk-pillar is wider at the top than at the bottom) would significantly benefit the V_b and FOM. The comparisons between the High-*k* SJ-VDMOS and the ordinary SJ-VDMOS prove the former is more resistive to the side wall gradient deviation. Meanwhile, these study results are believed to be a useful and helpful reference to improve the High-*k* SJ-VDMOS.**

Keywords* - *New Electronic Materials and Applications, Power Electronics, Power Semiconductor Devices

I. INTRODUCTION

As one of the most popular power semiconductor devices, the Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) has been widely used in computers, televisions, cell phones, and so on [1]. This device has the advantages of convenient voltage control and fast switching speed. Especially for the trench Vertical Double-Diffused MOSFET (VDMOS), there is a large current density when the device is in the on-state. However, for the application utilized in a higher voltage, the specific on-resistance (R_{on}) of it will inevitably be increased along with the V_b [2]. Therefore, the power loss in this case will be increased. The contradictory relationship between the V_b and R_{on} always limited the development of power MOSFET, which is called "silicon limit" traditionally.

As is well known, the technique of Super Junction (SJ) breaks through the "silicon limit" [3, 4]. Fig. 1a shows a typical structure of the SJ-VDMOS. By introducing a P-type doped silicon pillar (P-pillar) to compensate the N-type doped one (N-pillar), the doping concentration of the N-pillar can be increased, and the R_{on} can be decreased under the same condition of V_b. A method to fabricate such a SJ structure is normally the technology of multiple epitaxies and subsequent ion implantations [5,6]. However, this method uses a complex process and consumes a large cost. Another method is first etching a deep trench and then filling it with the oppositely doped silicon [7, 8]. The latter method is easier for controlling and fabricating in comparison with the former. However, whether using the former or the latter method, the electric characteristics of the SJ structure in Fig. 1a is very sensitive to the charge imbalance. If the doping dose of the N-pillar is not equal to that of the P-pillar, the redundant charges after a compensation between them will greatly impact the distribution of electric field, which makes the device be

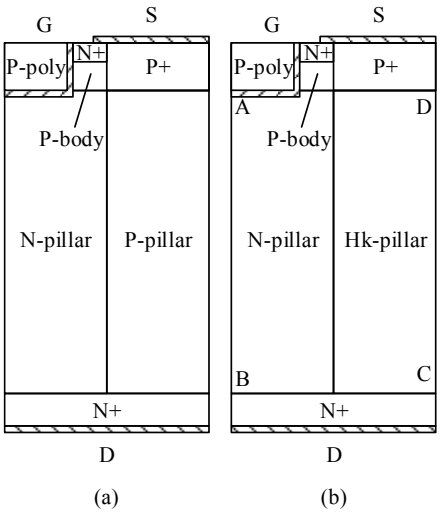

Figure 1. Schematic diagrams of (a) SJ-VDMOS and (b) High-*k* SJ-VDMOS, both with vertical side wall.

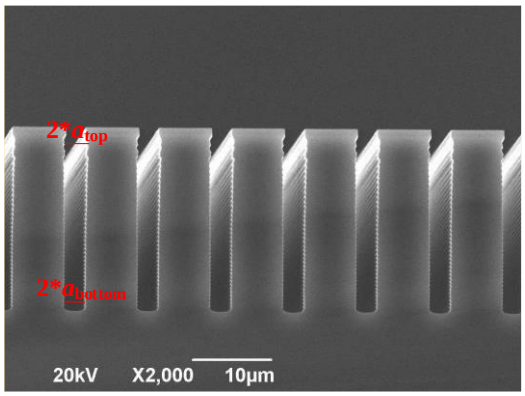

Figure 2. Cross-section of the etched trench.

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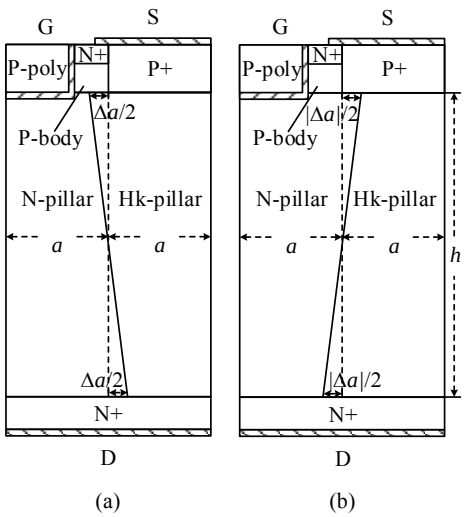


Figure 3. Schematic diagrams of High-*k* SJ-VDMOS (a) with positive gradient, $\Delta a > 0$ and (b) with negative gradient, $\Delta a < 0$.

easier to be broken [9, 10].

Actually, it is very difficult to get the identical doping doses for the two pillars in Fig. 1a. In order to address this, a SJ-VDMOS of High permittivity (High-*k* SJ-VDMOS) has been proposed [11, 12], which is shown in Fig. 1b. The fabrication of the High-*k* SJ-VDMOS can be briefly illustrated as below. At first, a deep trench is etched on the substrate, then it is filled by some High-*k* material like $PbZr_xTi_{1-x}O_3$ (PZT). The filling method can be the radio frequency magnetron sputtering [13]. After that, a polysilicon layer or just metal can be deposited on the top of the device. Then, smoothing the surface, and obtaining the P-body and the N+ by implantation and diffusion. The gate can be implemented just by a normal process. When the High-*k* SJ-VDMOS is off, the electric displacement lines flow to the top P+ region through the High-*k* material pillar (Hk-pillar). If the permittivity of the High-*k* material is high enough, the electric displacement lines emitted by the N-pillar can be laterally and fully absorbed by the Hk-pillar. As a result, a vertically uniform distribution of the electric field can be obtained in the drift region. The theory of the High-*k* SJ-VDMOS to get the improved trade-off relationship between the V_b and R_{on} is similar to that of an ordinary SJ-VDMOS. However, because the Hk device doesn't use the approach of doping to compensate the pillars, it is obviously more resistive to the influence of charge imbalance.

Table I. THE PARAMETERS OF HIGH-*K* SJ-VDMOS AND SJ-VDMOS

Parameters of half cell	**Units**	**SJ-VDMOS**	**High-*k* SJ-VDMOS**
Width of N-pillar and P/Hk-pillar (a)	μm	2	2
Relative Permittivity of Hk-pillar (ε_{Hk})	-	-	1000
Depth of the pillars (h)	μm	20	20
Doping concentration of N-pillar and P-pillar ($N_{pillars}$)	cm^{-3}	1E16	1E16
Breakdown voltage (V_b) (vertical trench)	V	301	293
Conduction voltage (V_c) (V_g=10 V I_d=100 A/cm^2)	V	7.3	6.7
Figure Of Merit (FOM)	kW/cm^2	12411	12813

Note: In this paper, the breakdown voltage is obtained when the impact ionization integral of the carriers equals 1. The conduction voltage is the voltage drop on the device when the conduction current density I_d is 100 A/cm^2 and meanwhile the voltage of gate V_g is 10 V. The conduction current density is calculated by the conduction current divided by the cell area. The specific on-resistance is calculated by the conduction voltage V_c divided by I_d=100 A/cm^2. FOM is defined as $(V_b)^2/R_{on}$, [14].

In this study, more and further analysis and comparisons between the High-*k* SJ-VDMOS and the conventional SJ-VDMOS is performed. For instance, in actual process of etching a deep trench, it is nearly impossible to obtain an absolutely vertical trench with large aspect ratio. The gradient of the trench side-wall could have a great influence on the static performances for both of the two devices. Especially, with an appropriate positive gradient, better characteristics for High-*k* SJ-VDMOS can be obtained.

II. SIMULATION AND ANALYSIS

A. *Static performance of the High-k SJ-VDMOS and SJ-VDMOS with the gradient side wall*

The depth of the etched trench shown in Fig. 2 is h = 20 μm. The width of it at the top is $2*a_{top}$ = 3 μm, and the width at the bottom is $2*a_{bottom}$ = 2.6 μm. Therefore, the deviation value of the side wall in this trench is $\Delta a = a_{top} - a_{bottom}$ = 0.2 μm, and the gradient of it is 90°+arctan ($\Delta a/h$) = 90.57° approximately.

Based on the angle obtained above, the variation range of the gradient is chosen to be 90°±2° in the simulation. The current fabrication capability of etching a trench is totally within this range. Therefore, the range of the deviation value (Δa) is -0.7~+0.7 μm for a trench with depth of 20 μm. If $\Delta a > 0$, the gradient is called positive, and negative if $\Delta a < 0$, as is shown in Fig. 3. Meanwhile, it should be noted that no matter Δa, the P/Hk-pillar at the top have the same width with the N-pillar at the bottom in this section. Hence, the areas of the pillars are same. That is, for the SJ-VDMOS, the doping doses of the pillars are identical and the charge balance is satisfied.

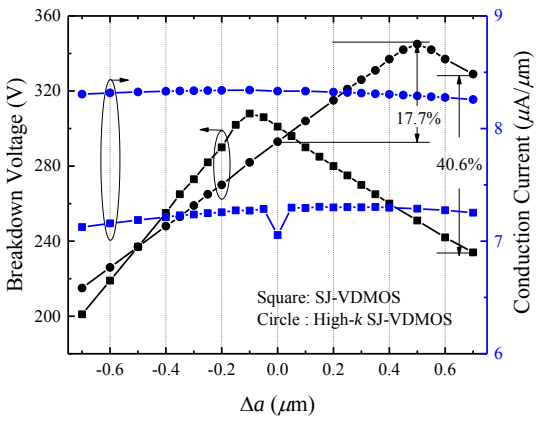


Figure 4. Breakdown voltages and conduction currents of High-*k* SJ-VDMOS and SJ-VDMOS when V_g=10 V and V_d=1 V, $N_{pillars}$=1E16 cm^{-3}

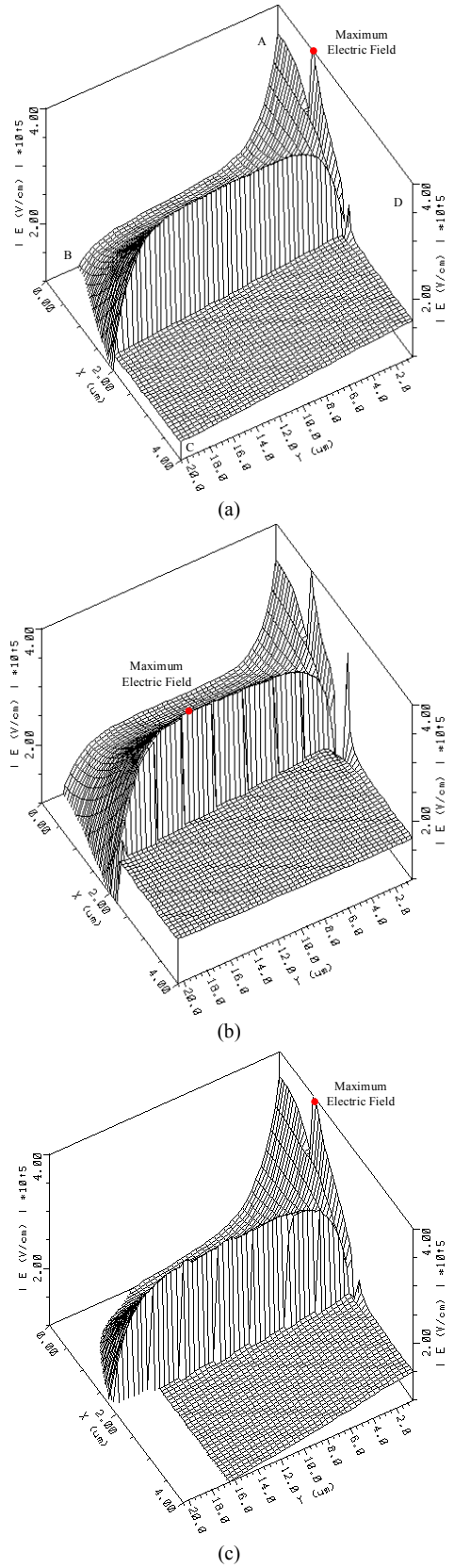


Figure 5. The 3 dimensional distribution of the electric field in High-*k* SJ-VDMOS with different gradients when the maximum impact ionization integral equals 1, (a) Δa = 0, V_b =293 V, (b) Δa = 0.5, V_b =345 V, and (c) Δa = -0.5, V_b =237 V. The red point shows the position of the maximum electric field when the breakdown happens. The A/B/C/D in (a) shows the corresponding structure position in Fig.1b.

The simulation parameters of the devices with vertical side wall are listed in Table I, in which the performances of the High-*k* SJ-VDMOS and SJ-VDMOS have been optimized and are almost same.

By adjusting the width of the trench at the top and at the bottom, the curves of the breakdown voltages and conduction currents varying with Δa are plotted, as Fig. 4 shows. The parameter of conduction current is directly obtained from the simulation results when set V_g = 10 V and V_d = 1 V. From Fig. 4, it can be observed that the curves of the conduction currents are nearly flat for both of the devices. The reason of this result is that in the on-state, the current only flows to the source through N-pillar for the devices, and the deviation value of the side wall is

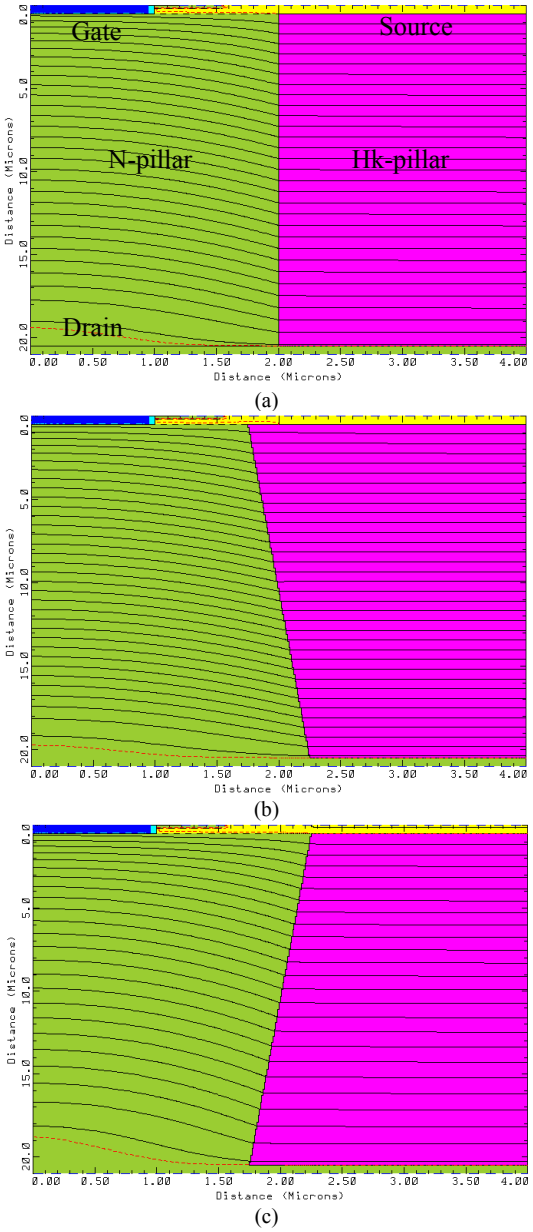


Figure 6. The potential contours of the electric field in High-*k* SJ-VDMOS with different gradients when the maximum impact ionization integral equals 1, (a) Δa = 0, V_b =293 V, (b) Δa = 0.5, V_b =345 V, and (c) Δa = -0.5, V_b =237 V. The potential difference between two consecutive lines is 10 V and to look clearer the structures have been scaled. In the figure, the green part is the N-type doped region, the aubergine region is the Hk-pillar.

such small that it is ignored compared with the depth and the width of the pillars. Therefore, a steady on-state current density is obtained in both of the devices for the gradient of the trench.

However, the impact of the side wall gradient on the breakdown voltage is different. As the Fig. 4 shows, for the High-*k* SJ-VDMOS, the V_b of it is increased when $\Delta a > 0$, and decreased when $\Delta a < 0$. As for the SJ-VDMOS, V_b of it is decreased no matter $\Delta a > 0$ or $\Delta a < 0$. By observing the movement of the breakdown point, which is the maximum electric field point in the devices as well, this phenomenon can be explained.

The 3 dimensional distributions of the electric field and the 2 dimensional potential contours of the High-*k* SJ-VDMOS are shown in Fig. 5 and Fig. 6. In the case of $\Delta a = 0$, the breakdown usually happened at the corner of the trench gate for both of the devices, as the maximum electric field point shows in Fig. 5a, due to the electric field crowding there. But when $\Delta a > 0$, the Hk-pillar is wider at the top than at the bottom for the High-*k* SJ-VDMOS. The structure is shown in Fig. 6b. Therefore, the electric displacement lines at the top emitted by the ionized donor can be more absorbed by the Hk-pillar laterally, and less absorbed by the trench gate and P-body vertically. Thus, the electric field around the gate is reduced and the one in the pillars can be bigger before the breakdown happens. So that bigger V_b is obtained. However, once Δa is too large, the electric field in the pillars will exceed that around the gate, thus, the maximum electric field moves to the middle of the device, as Fig. 5b shows. The larger electric field in the pillars can be proved by the denser potential lines in Fig. 6b as well. In this simulation, the turning point is at $\Delta a = 0.5$ μm, that is, the High-*k* SJ-VDMOS can obtain the best breakdown voltage in this case. The largest proportion of the increase of V_b for the device can reach 17.7% compared with that of $\Delta a = 0$. If $\Delta a > 0.5$ μm, the maximum electric field would be more increased to reach the critical electric field. Meanwhile, the electric field in the pillars is smaller than that of $\Delta a = 0.5$ μm. Therefore, compared with $\Delta a = 0.5$ μm, the breakdown voltage drops. However, from the simulation results, it still can be concluded that, with a positive gradient, the High-k SJ-VDMOS can really benefit the static performance of the device.

For the SJ-VDMOS of $\Delta a > 0$, the maximum electric field is around the middle of the device, where it is bigger than that around the gate, and with larger Δa, the electric field is enhanced further, so that it is easier to be broken. For the High-*k* SJ-VDMOS, if compared with the SJ-VDMOS of the same Δa, the largest increase proportion of V_b can obtain 40.6%. This amount indicates the superiority of the High-*k* SJ-VDMOS to the SJ-VDMOS when they all suffer the same fabrication deviation. Therefore, it will be advantageous to substitute the conventional SJ-VDMOS with High-*k* SJ-VDMOS.

As $\Delta a < 0$, the Hk-pillar is narrower at the top than at the bottom for the High-*k* SJ-VDMOS. Therefore the electric displacement lines at the top of the N-pillar can be less absorbed by the Hk-pillar laterally, and more absorbed by the trench gate vertically. So that the electric field around the gate is enhanced further, compared to that of the device of $\Delta a = 0$. Thus the breakdown point is still at the gate corner, as Fig. 5c shows. The increased electric field around the gate can be also observed from the denser potential lines at the top in Fig. 6c. For the SJ-VDMOS of $\Delta a < 0$, wider bottom of P-pillar increases the amount of uncompensated ionized acceptors at the bottom, which enhances the electric field at the junction of the P-pillar/N-substrate. Hence, the breakdown happens there and V_b of it is decreased.

The figure of merit FOM = $(V_b)^2/R_{on}$, is used to compare the performances of the SJ-MOSFET and conventional MOSFET [14]. Usually, bigger FOM means better performance. Because the conduction current is steady to the different deviation value, as well as R_{on}. Therefore, FOM is only relevant to the breakdown voltage when varying with the trench gradient. As is shown in Fig. 7, the curves of FOM are almost same with those of the V_b, except for the larger scale. For the High-*k* SJ-VDMOS of $\Delta a > 0$, the biggest proportion of the increase of FOM reaches 38.6% and 86.6%, when in comparison with the High-*k* SJ-VDMOS of $\Delta a = 0$ and the SJ-VDMOS of the same Δa, respectively.

B. The Effects of Different Doping Concentrantions

The simulation mentioned above is based on the doping concentration of 1E16 cm^{-3} in the devices. To

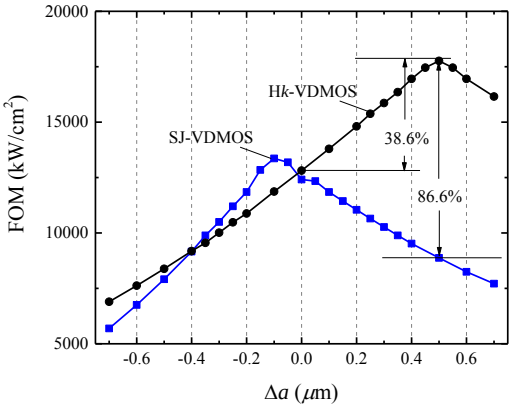


Figure 7. FOM of High-*k* SJ-VDMOS and SJ-VDMOS. $N_{pillars}$ = 1E16 cm-3.

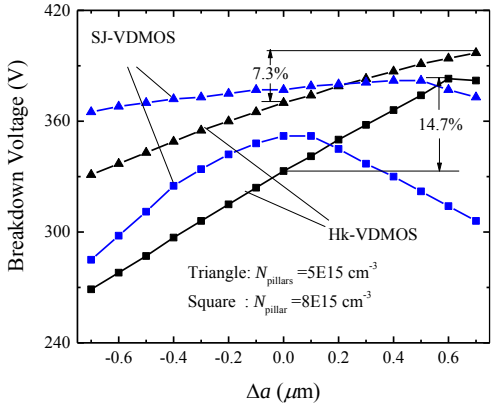


Figure 8. The Breakdown voltages of High-*k* SJ-VDMOS and SJ-VDMOS in different doping concentrations.

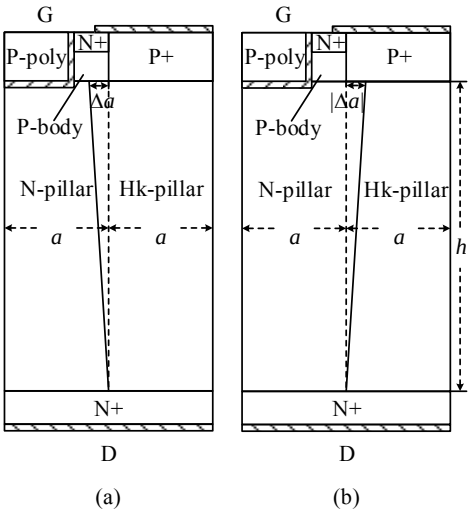


Figure 9. Schematic diagrams of High-*k* SJ-VDMOS with the bottom width of Hk-pillar is *a* and (a) $\Delta a > 0$, (b) $\Delta a < 0$.

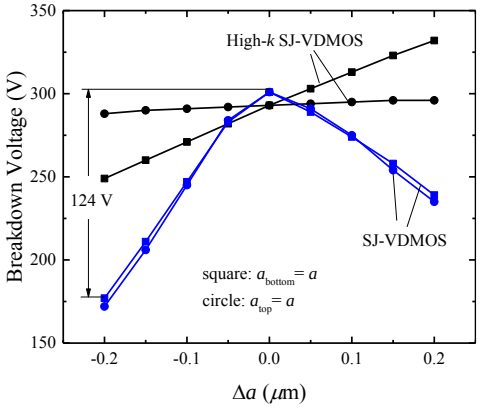


Figure 10. Breakdown voltages of High-*k* SJ-VDMOS and SJ-VDMOS when $a_{bottom} = a$ or $a_{top} = a$.

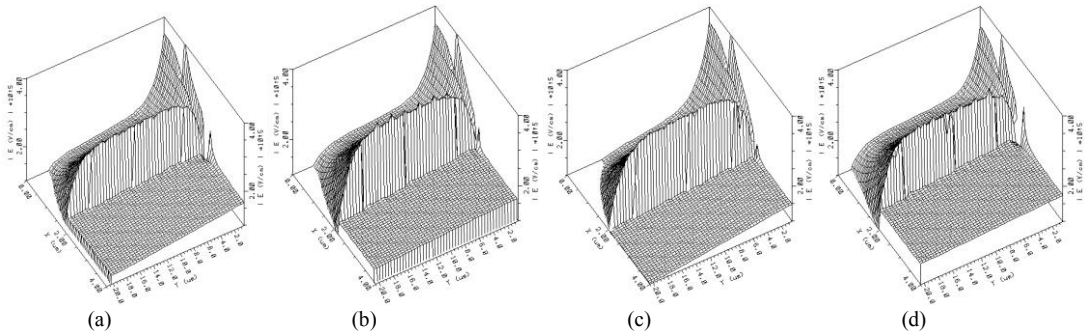


Figure 11. The 3 dimensional distribution of the electric field in High-*k* SJ-VDMOS with different gradients when the maximum impact ionization integral equals 1, when $a_{top} = a$, (a) Δa = -0.2, V_b = 288 V and (b) Δa = 0.2, V_b = 296 V, when $a_{bottom} = a$, (c) Δa = -0.2, V_b = 249 V and (d) Δa = 0.2, V_b = 332 V.

investigate the performance variation of the devices in different doping concentration, another simulation is performed, where the concentrations of the pillars are set as 5E15 cm^{-3} and 8E15 cm^{-3}, respectively. Considering the on-state performance of the devices are almost not impacted by the gradient trench, the following simulations are merely focused on the breakdown voltage of the devices.

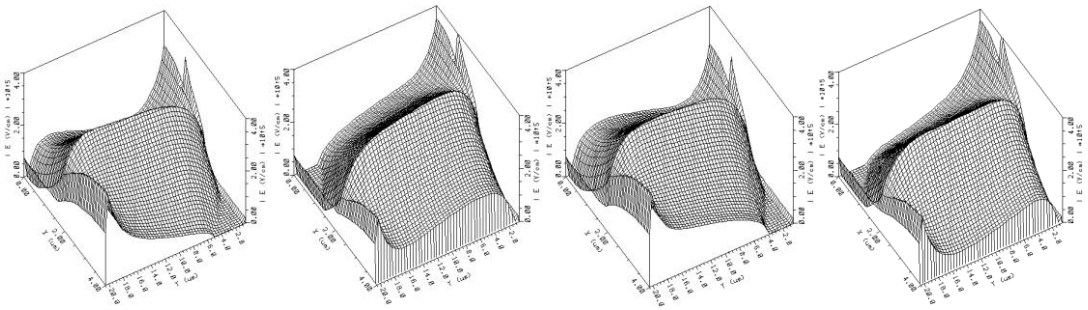
For the High-*k* SJ-VDMOS in smaller doping concentration, the amount of the ionized charges in the device and the electric displacement lines emitted by them are less. Therefore, the change of the breakdown voltage varying with the side wall deviation is smaller than that of the device in higher concentration. As Fig.8 shows, for the High-*k* SJ-VDMOS in the concentration of 5E15 cm^{-3} and 8E15 cm^{-3}, the largest increase proportions of V_b are 7.3% and 14.7%, respectively, which are smaller than the proportion of 17.7% of the device in $N_{pillars}$ = 1E16 cm^{-3}.

As for the SJ-VDMOS in smaller doping concentration, the uncompensated charges left in the pillars, and their enhancement on the electric field is lesser. Thus, the change of V_b varying with Δa is decreased. As Fig.8 shows, the curve of $N_{pillars}$ = 5E15 cm^{-3} is almost flat. Meanwhile, the curve of $N_{pillars}$ = 8E15 cm^{-3} is smoother than that of $N_{pillars}$ = 1E16 cm^{-3}.

C. The Effects When the width of the gradient P/Hk-pillar is equal to a at the top or at the bottom.

In this section, the devices having diverse trenches are simulated to study their influences on the device performances. Because in the above simulation, the doping doses of the N-pillar and P-pillar are identical for SJ-VDMOS, due to their same areas, as shown in Fig. 1b. However, in the actual fabrication process, a trench having absolutely vertical side wall is impossible to obtain. Actually, trenches (namely, Hk-pillar in Figure) like the two structures shown in Fig. 9 can be etched. In Fig. 9, the width of the trench at the bottom (a_{bottom}) is equal to *a*. In other cases, the width at the top (a_{top}) can be equal to *a* as well. Due to the unequal areas of the pillars in these conditions, the charge imbalance in the SJ-VDMOS caused by the side wall gradient is heavier. Whereupon, let $a_{bottom} = a$ or $a_{top} = a$ to simulate the effects of the side wall gradient and the range of $\Delta a = a_{top} - a_{bottom}$ is defined as -0.2 ~ 0.2 μm in this section.

In the case of $a_{top} = a$, due to the trench at the top of the High-*k* SJ-VDMOS does not change much, the gradient has little influence on the electric field there. Therefore, the V_b of it is nearly steady, as shown in Fig. 10. The electric field distribution of the devices with different Δa is similar when $a_{top} = a$, as Fig. 11a and Fig. 11b shows.



(a) (b) (c) (d)

Figure 12. The 3 dimensional distribution of the electric field in SJ-VDMOS with different gradients when the maximum impact ionization integral equals 1, when $a_{top} = a$, (a) Δa = -0.2, V_b = 172 V and (b) Δa = 0.2, V_b = 235 V, when $a_{bottom} = a$, (c) Δa = -0.2, V_b = 177 V and (d) Δa = 0.2, V_b = 239 V.

In the case of $a_{bottom} = a$, a_{top} will vary with Δa. Thus, for the High-*k* SJ-VDMOS, the electric displacement lines and the electric field at the top are greatly impacted by the side wall deviation. Due to the reduction of the electric field around the gate when $\Delta a > 0$, the electric field in the pillars is bigger, as Fig. 11d shows. The largest increase proportion of the V_b is 13.3%, which is almost twice of the proportion of the one with Δa = 0.2 μm in section II-A. When $\Delta a < 0$, the device is easier to be broken. Thus, the electric field in the pillars is smaller than that in other conditions, as is shown in Fig. 11c.

For the SJ-VDMOS, no matter $\Delta a > 0$ or $\Delta a < 0$, the changes of the V_b are especially sharp. When Δa = -0.2 μm, the V_b of the device is reduced by 124 V and 129 V for $a_{bottom} = a$ and $a_{top} = a$, respectively, which are almost ten times of the reduction of the device in section II-A. The charge imbalance plays an important role on this decrease of the V_b. The electric field distribution of the SJ-VDMOS is greatly impacted by the deviation, as shown in Fig. 12. Compared with the SJ-VDMOS, although the performance of the High-*k* SJ-VDMOS is worse in the cases of $a_{bottom} = a$, it still has better capability of resisting the gradient.

III. CONLUSION

From the simulation results for the devices with different trench gradients, this paper comes to the conclusion that, the High-*k* SJ-VDMOS with positive gradient side wall has higher breakdown voltage and FOM. Meanwhile, the on-state current of it is nearly steady under the different trench gradients. As for the SJ-VDMOS, no matter the gradient is positive or negative, its breakdown voltage is decreased. Besides, both of the devices in smaller doping are less impacted by the gradients. In the case that the areas of the N-pillar and the P/Hk-pillar are unequal, the heavier charge imbalance leads to more acute reduction of the breakdown voltage for the SJ-VDMOS. On account of all these characteristics, the High-*k* SJ-VDMOS is more resistive to the side wall gradients compared with the SJ-VDMOS, and designing a High-*k* SJ-VDMOS with positive side wall gradients in the fabrication process can obtain better static characteristics, especially at high doping concentration. Finally, the results of the study in this paper are believed to have a useful and conducive meaning for improving the High-*k* SJ-VDMOS.

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Analysis of Tunable BV_{CEO} in Horizontal Current Bipolar Transistor with Floating Field Plates

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Abstract - Open base breakdown voltage (BV_{CEO}) tuning in Double-Emitter Horizontal Current Bipolar Transistor with floating field plates (FFPs) is analyzed by the device simulations. Tuning is obtained by stepping of the FFPs potential which is controlled via capacitive coupling between neighboring FFPs. When coupled, they serve as the field plates for shaping of the electric potential distribution, introducing the additional drift regions in base-collector depletion region. Breakdown mechanisms in case of partial and complete shielding of the collector *E*-field by the FFPs are identified. In case of partial shielding, the inner electric field peaks are responsible for breakdown, whereas in the case of complete shielding, breakdown occurs at the outermost drift region. In completely shielded, device very high BV_{CEO} can be obtained by stacking a large number of FFPs. Devices with BV_{CEO} up to 70 V are obtained.

I. Introduction

In bipolar transistors, the open-base breakdown voltage (BV_{CEO}) is usually 2 to 4 times lower than the open-emitter breakdown voltage (BV_{CBO}) [1] and in general represents a tighter constraint on the safe operation limits. High voltage transistors can be used as components that can extend the application of the technology, which is especially attractive if they can be added to standard processes without significant costs. Most attractive applications would be in circuits where the higher voltage swing is desirable, such as in input-output (IO) circuits, power amplifiers and linear analog circuits.

Horizontal current bipolar transistor (HCBT) is integrated with 180 nm CMOS [2] in a simple process resulting in a low-cost BiCMOS technology suitable for the fabrication of RF communication circuits in the frequency range up to 6 GHz [3]. The technology is further improved by the addition of high-voltage devices, which are integrated at zero-cost. The improvement of the breakdown voltages is obtained by the geometry manipulation, which is accomplished by the lithography mask design and the application of existing process steps. The principle of the breakdown voltage improvement is based on reduced-surface-field (RESURF) effect [4], which is used to shape the potential and electric field distribution in the base-collector depletion region. High-voltage (HV) HCBT structures with BV_{CEO} of 10.5 V [5], 12.5 V [6] and 36 V [7] are demonstrated.

The latest reported HV HCBT structure is double-emitter (DE) HCBT with floating-field-plate (FFP) with BV_{CEO}=25 V [8]. Floating field regions are used for a junction termination in power devices [9]. In [8] they were used to improve the breakdown voltage of high-performance bipolar transistor structure suitable for RF applications. The tuning of the BV_{CEO} with multiple FFPs was demonstrated by simulations. In this paper, the breakdown mechanisms and the tuning principle are thoroughly analyzed. Practical limits of tuning and its impact on electrical performance is investigated.

II. Simulation Structure and Principle of Operation

3D model of the quarter of the DE HCBT with FFP is shown in Fig. 1 [8]. FFP is implanted in the form of the *p*+ region, together with the extrinsic base and therefore those two regions are self-aligned. The full structure is obtained by mirroring the structure along the CB and BE planes in Fig. 1. Since the breakdown physics is determined by the shaping of the potential distribution in CB-plane, a 2D simulation structure similar to the one reported in [8] is used. The breakdown of standard DE HCBT [6] is determined by the peak electric field in the drift region which is formed below the extrinsic base marked as DR 1 in Fig. 1. The FFP is floating on the potential which is set by the collector potential and the

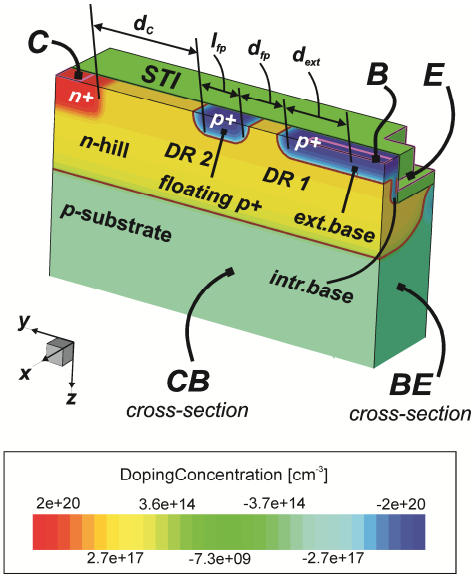

Fig. 1. 3D model of DE HCBT with FFP [8].

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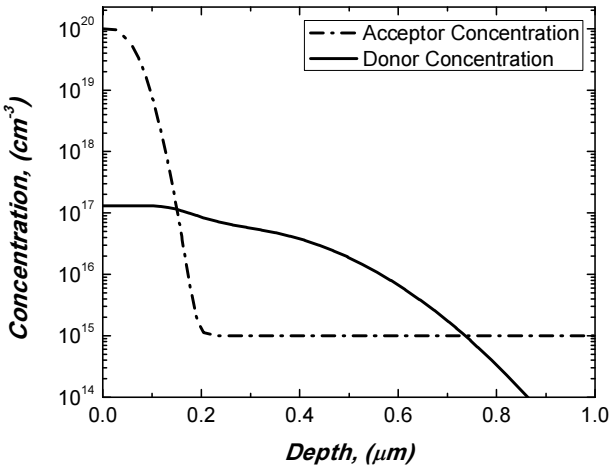

Fig. 2. Doping profile below FFP and the extrinsic base.

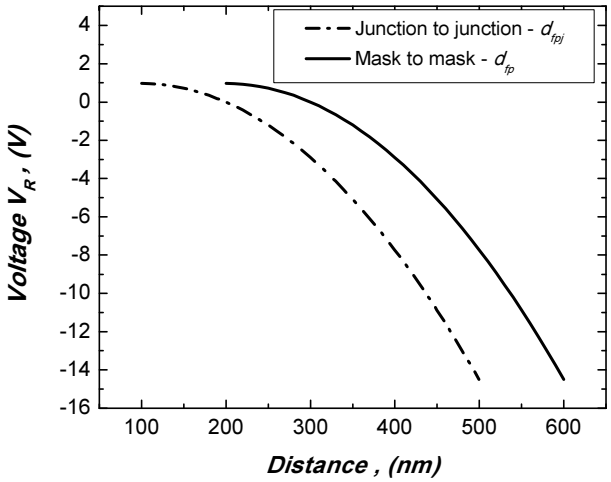

Fig. 3. Calculated punchthrough voltage dependency on the distance between extrinsic base and FFP. V_R is voltage between the anode and the chatode of the p^+n- junction.

junction built-in potential since the current across the junction is zero. As the collector voltage increases, the depletion region spreads from the extrinsic base laterally in the direction of the FFP and the extrinsic collector. At the certain voltage, the part of the collector along the distance between the extrinsic base and FFP (d_{fp}) is fully depleted (i.e., it is in punchthrough). At that point the FFP is coupled to the extrinsic base via depletion capacitance and its potential is set by the extrinsic base potential and the voltage drop across the region marked by d_{fp}. Once the FFP potential is pinned, the junction between the FFP and the *n*-collector is reverse polarized. Hence, the part of the collector below the FFP can be fully depleted from the FFP side forming the additional drift region (DR 2 in Fig. 1). The FFP then acts as a field plate shielding the lateral electric field. In this way, the maximum electric field in the DR 1 is limited and the breakdown voltage is improved. By adding multiple FFPs this principle can be extended and BV_{CEO} tuned in discrete steps as shown in [8].

III. DEVICE SIMULATIONS

Since the potential of the FFP is determined by the full depletion of the collector between the extrinsic base and the FFP, the distance between them d_{fp} is the important geometrical parameter. d_{fp} controls the total amount of donor charge in that region, which in turn sets the voltage drop across that region. Vertical doping profile below the extrinsic base (and FFP) is shown in Fig. 2 and it is similar to the one reported in [8] with slightly higher collector concentration. Acceptor concentration in the extrinsic base and the FFP is 10^{20} cm^{-3} and donor concentration in the top part of the collector is $1.3\cdot10^{17}$ cm^{-3}. Due to the lower doping, the depletion region of the extrinsic base-collector junction dominantly spreads on the collector side. The depletion region width can be approximated by step-graded junction with uniform doping concentrations:

$$d_B = \sqrt{\frac{2\varepsilon}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)\left(V_{bi}-V_R\right)}\ , \qquad (1)$$

where ε is dielectric constant of silicon, q is electron charge, N_A and N_D are doping concentrations in the extrinsic base and in the collector, respectively, V_{bi} is built-in potential and V_R is voltage applied at the junction. With $N_A >> N_D$, (1) reduces to:

$$d_B \approx \sqrt{\frac{2\varepsilon}{qN_D}\left(V_{bi}-V_R\right)} = d_{B0}\sqrt{1-\frac{V_R}{V_{bi}}}\ , \qquad (2)$$

where d_{B0} is the depletion region width at the equilibrium. Since the FFP is floating, the current across the junction is zero, it is in equilibrium condition and the depletion region width is d_{B0}. The full depletion of the top portion of the collector occurs when two depletion regions merge:

$$d_{fpj} = d_B + d_{B0}\ , \qquad (3)$$

where d_{fpj} is the distance between two junctions, d_{B0} is the width of the FFP depletion region and d_B is the width of the extrinsic base depletion region. By combining (2) and (3), we can calculate the punchthrough voltage V_R needed for the full depletion of the collector between the extrinsic base and the FFP:

$$V_R = V_{bi}\cdot\left[1-\left(1-\frac{d_{fpj}}{d_{B0}}\right)^2\right]. \qquad (4)$$

For the given doping concentrations, the built-in potential at room temperature is V_{bi}=0.967 V, and the depletion region width in equilibrium is $d_{B0}\approx$100 nm. The dependency of V_R on d_{fpj} calculated from (4) is shown in Fig. 3. It should be noted that the actual distance between two junctions (d_{fpj}) is smaller than the distance between two lithography mask segments (d_{fp}) used in fabrication due to the lateral spread of dopands. If lateral spread of dopands is taken into account the curve in Fig. 3 is shifted by twice the lateral dopand spread which is approximately 100 nm. When the d_{fp} is increased from 400 nm to 500 nm, the value of V_R increases from 2.9 V to 7.7 V, meaning that the punchthrough voltage V_R is rather sensitive to the d_{fp} value. This is the consequence of the high collector doping concentration in the top part of the transistor.

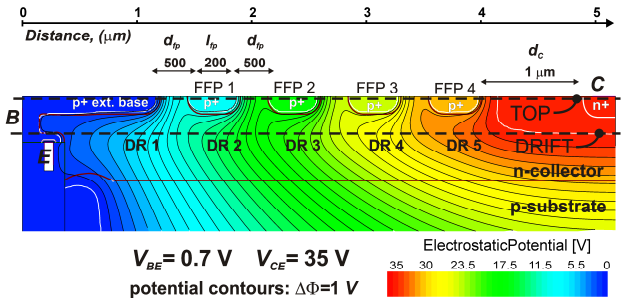

Fig. 4 Forced-V_{BE} simulation of DE HCBT with 4 FFPs showing the electric potential distribution at V_{CE} sufficient for fully depleted collector. Potential of FFPs is stepped and almost linear distribution in the drift regions is achieved. The length of FFPs is l_{fp}=200 nm and the distance between the extrinsic base and the FFPs is d_{fp}=500 nm.

This simple calculation was taken to roughly estimate the distances d_{fp} between the extrinsic base and the FFP as well as the distances between the following FFPs when multiple FFPs are used. Collector between two regions should be fully depleted for V_R smaller than the junction breakdown voltage, which is around 10 V for given collector concentration. The mask distance d_{fp}=500 nm is taken for initial simulations since it would give the punchtrough voltage V_R=7.7 V, which is the value smaller than the junction breakdown voltage. The length of the FFPs is set to l_{fp}=200 nm, the value sufficient for electric field shielding and small enough to obtain good high frequency characteristics [8].

A. Shaping of the Potential Distribution

Forced-V_{BE} simulation of the electric potential distribution of the structure with 4 FFPs at V_{BE}=0.7 V and V_{CE}=35 V, which is smaller than but near the BV_{CEO} value, is shown in Fig. 4. It can be observed that the collector below FFPs is fully depleted and that the depletion region extends all the way to the extrinsic collector. Since the electric field is perpendicular to the potential contours, it can be concluded that vertical component of the electric field exists between the collector below and the FFPs. Therefore, FFPs serve as field plates and are responsible for the formation of additional drift regions marked in Fig. 4. It can also be seen that each consecutive FFP is on the higher potential with the potential difference between two being proportional to number of potential contours between them, which equals the punchthrough voltage V_R.

The dependencies of the electric potential on the applied V_{CE} at the top of the structure and in the drift regions marked by dashed cut-lines in Fig. 4 are shown in Fig. 5. Potential distribution at the top of the structure across the FFPs is shown in Fig. 5a. For V_{CE}=10 V, it can be observed that the 3 outer FFPs are floating on the potential which is set by the collector potential and the junction built-in potential. It can also be seen that the depletion region has reached the first FFP coupling its potential to the extrinsic base. When FFP is completely enclosed by the depletion region, its potential is constant, which can be observed for the innermost FFP at higher V_{CE}. For V_{CE}=35 V (condition from Fig. 4) marked by the dash-dot line, the depletion region has spread all the way to the extrinsic collector. The height of potential stairs is equal to the punchthrough voltage V_R, which is well

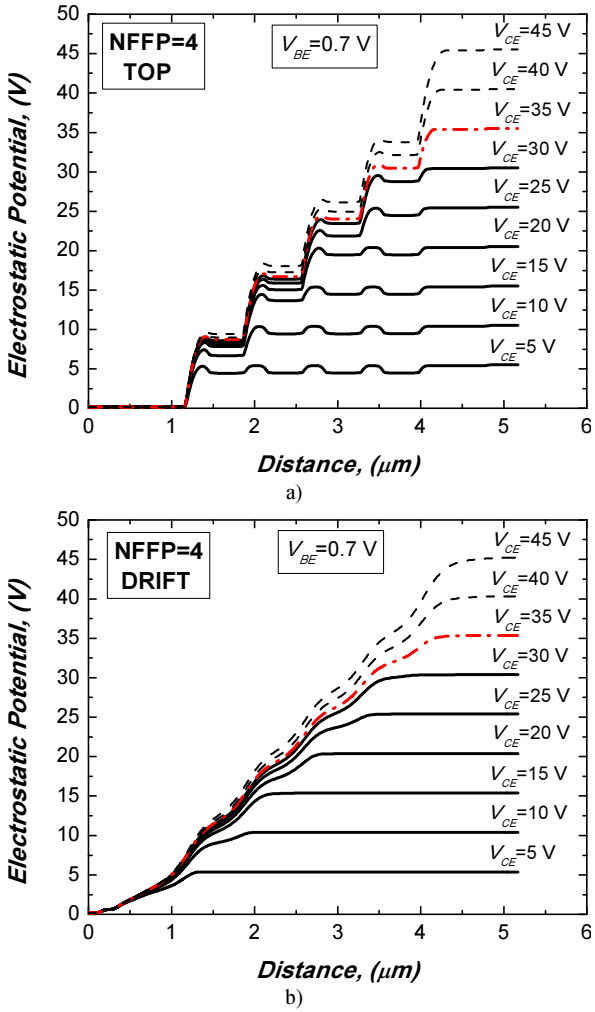

Fig. 5. Dependency of the electrostatic potential on the applied V_{CE}: a) at the top of the structure (TOP-cutline in Fig. 4), b) in the drift regions (DRIFT-cutline in Fig. 4). Red dash-dot line corresponds to the bias condition from Fig. 4. Dashed lines are for V_{CE}>BV_{CEO}.

predicted by the results from Fig. 3. In properly designed device, after the full depletion, all the FFPs are on the constant potential and *E*-field peaks associated with voltage drops between them are constant and kept below the critical value. The only potential drop that increases with V_{CE} is the one between the last FFP and the extrinsic collector (the last potential stair in Fig. 5a), and the critical *E*-field is achieved there causing the breakdown eventually. If V_{CE} is increased beyond BV_{CEO}, all the potential stairs increase (see dashed line curves in Fig. 5a) due to mobile avalanche carriers generated at *E*-field peaks placed at the *pn*-junctions corresponding to parts with steep potential gradient. Potential distribution across the drift regions is shown in Fig. 5b showing almost linear potential change and uniform electric field.

B. Tuning of the BV_{CEO}

Results of the forced-V_{BE} simulations of BV_{CEO} for structures with different number of FFPs and the distance between FFPs d_{fp}=500 nm are shown in Fig. 6. In forced-V_{BE} simulation, V_{BE} is constant, the emitter is grounded and collector voltage is swept. BV_{CEO} is determined as the V_{CE} where the base current (I_B) reverses its sign (i.e.,

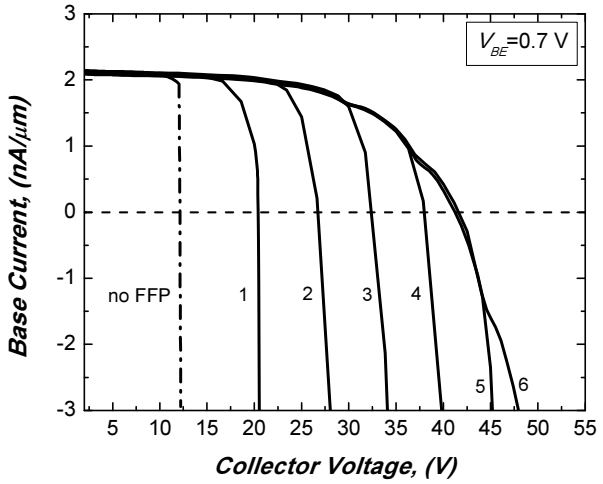

Fig. 6. Forced-V_{BE} BV_{CEO} simulations of structures with l_{fp}=200 nm and d_{fp}=500 nm with number of FFPs as a parameter.

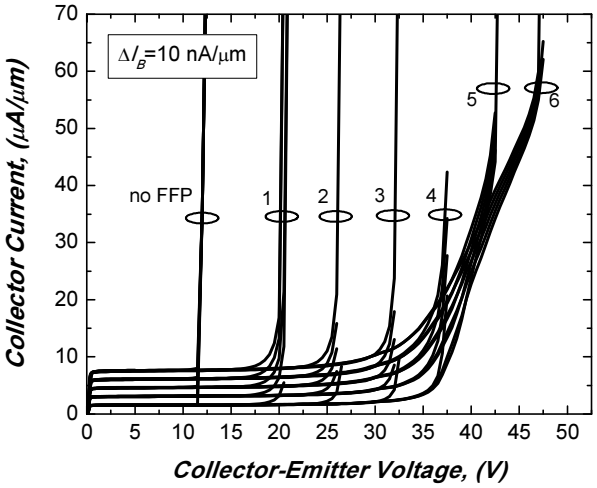

Fig. 7. Simulated forced-I_B (common-emitter) output characteristics of structures with l_{fp}=200 nm and d_{fp}=500 nm with number of FFPs as a parameter.

becomes zero). For each additional FFP, BV_{CEO} increases in almost discrete steps equal to V_R. For the given d_{fp}, tuning is accomplished up to 4 FFPs with the maximum BV_{CEO} around 38 V. The I_B in forced-V_{BE} characteristics reduces due to avalanche current generated in the base collector depletion region, which is subtracted from the current determined by the recombination and injection component set by the constant V_{BE}. In Fig. 6 the I_B reduces considerably for V_{CE} larger than 30 V and practically BV_{CEO} cannot be improved by adding more than 4 FFPs. This means that all the *E*-field peaks in the transistor are not properly shielded and that at least one of them reaches the critical value for breakdown. Forced-I_B output characteristics are shown in Fig. 7. Discrete tuning of BV_{CEO} can be observed up to 38 V and 4 FFPs. Due to the incomplete shielding, avalanche current is generated and added to the base terminal current causing the increased injection of holes to the emitter region and consequently, due to the emitter efficiency, increased collector current (I_C) for larger V_{CE}. Therefore, for the larger V_{CE} soft-breakdown behavior can be observed in the output

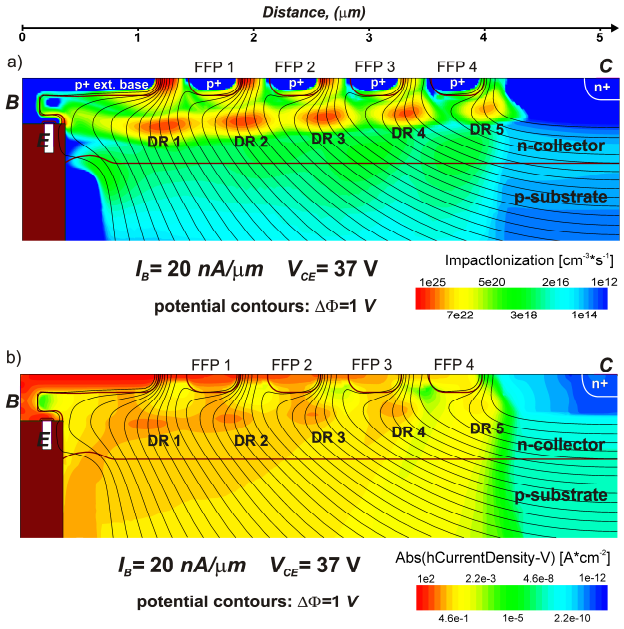

Fig. 8 Forced-I_B simulation of structure with 4 FFPs at the onset of the breakdown. a) Impact ionization rate showing the top-peaks and drift region-peaks. Due to partial shielding the higest rate is observed at the inner peaks. b) Hole current density showing the avalanche hole path from the *E*-field peaks through the FFPs to the extrinsic base. Structure with l_{fp}=200 nm and d_{fp}=500 nm.

characteristics. Also, the hard-breakdown is seen for the I_C larger than 55 μA/μm, which occurs at the voltages determined by the discrete V_R steps. The observation about incomplete shielding is confirmed by the simulation of the impact ionization rate at the onset of BV_{CEO} shown in Fig. 8a. Simulations are done with forced-I_B boundary condition in order to include the positive feedback of the BV_{CEO} mechanism. Breakdown is not taking place at the outermost FFP but is associated with inner FFPs. Peak impact ionization rate increases moving towards inner FFPs, having maximum value at the extrinsic base-collector junction (see Fig. 8a). Avalanche holes generated at *E*-field peaks flow towards the lower potential in the direction of the electric field (i.e. perpendicular to the potential contours) as shown in Fig. 8b. Therefore holes generated at drift region peaks and at top peaks flow towards the FFP and then down the potential stairs (see Fig. 5a) to the extrinsic base. When they flow through the depleted top part of the collector, they increase the total positive charge and modulate the peak *E*-field. This effect is the most pronounced at the extrinsic base-collector junction because practically all avalanche holes generated at all peaks have to flow there (see Fig.8b). Since the forced-I_B simulation is shown, the holes reaching the extrinsic base are injected to the emitter, causing the large electron back-injection and closing the positive feedback loop of classical BV_{CEO} mechanism.

Impact of the avalanche generated carriers can be compensated either by the larger length of the FFPs (l_{fp}) or by reducing the d_{fp}. Larger l_{fp} results in the better shielding property of the FFPs and the smaller d_{fp} limits the amount of donor charge placed between FFPs, which in turn reduces the voltage drop needed for its full depletion (V_R) as well as the associated *E*-field peaks. By increasing the

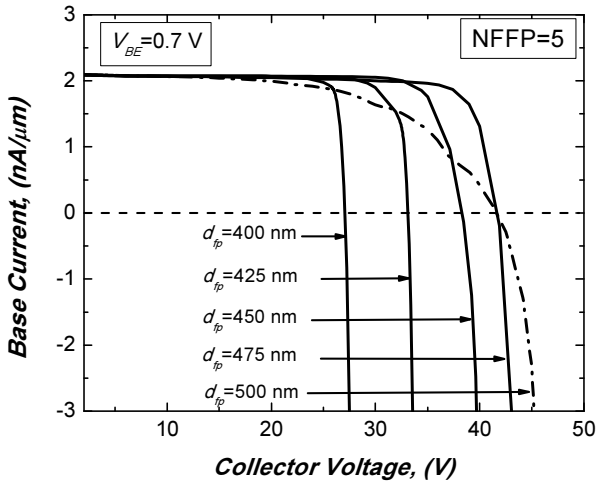

Fig. 9. Forced-V_{BE} BV_{CEO} simulations of structures with 5 FFPs, l_{fp}=200 nm and d_{fp} as a parameter. For d_{fp}≤475 nm good shielding is observed.

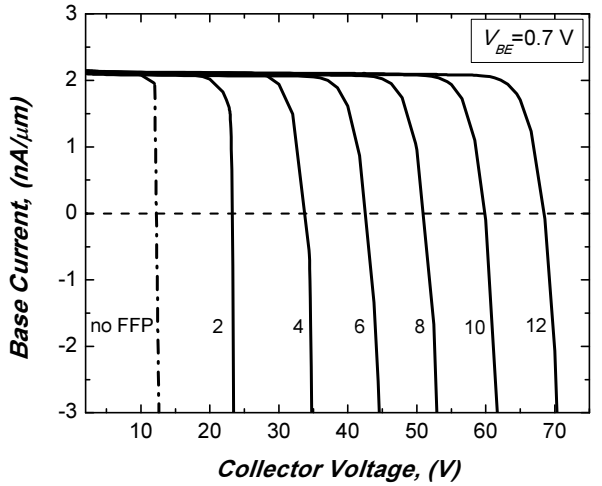

Fig. 10. Forced-V_{BE} BV_{CEO} simulations of structures with l_{fp}=200 nm and d_{fp}=450 nm with number of FFPs as a parameter.

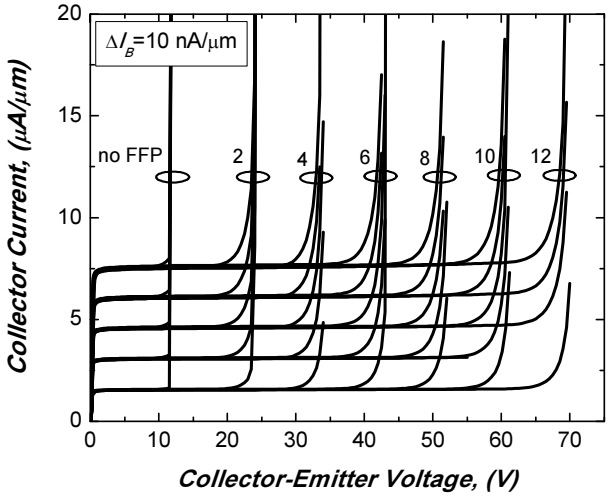

Fig. 11. Simulated forced-I_B (common-emitter) output characteristics of structures with l_{fp}=200 nm and d_{fp}=450 nm with number of FFPs as a parameter.

l_{fp}, total depletion region width is increased resulting in the longer base-collector depletion region transit time, which degrades the high frequency performance. It also results in

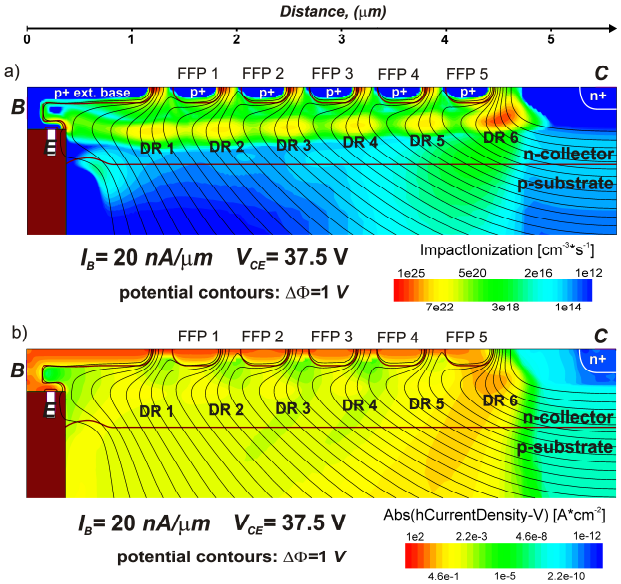

Fig. 12 Forced-I_B simulation of structure with 5 FFPs at the onset of the breakdown. a) Impact ionization rate. Due to good shielding the higest rate is observed at the outermost drift region peak. b) Hole current density showing the avalanche hole path from the outermost drift region E-field peak through the FFPs to the extrinsic base. Structure with l_{fp}=200 nm and d_{fp}=450 nm.

the less linear potential distribution and non-uniform E-field in the drift regions On the other hand, according to the results from Fig. 3, a small change in the d_{fp} can significantly reduce the punchtrough voltage V_R and reduce the electric field peaks but at the penalty that BV_{CEO} tuning by adding multiple FFPs is accomplished in smaller discrete V_R steps. This means that in order to achieve the same value of BV_{CEO}, more FFPs are needed, which also increases the depletion region transit time and degrades high-frequency characteristics. However, simulations have shown that better tradeoff is obtained if the shielding is controlled via d_{fp}. Forced-V_{BE} simulations of BV_{CEO} for structures with 5 FFPs and different d_{fp} are shown in Fig. 9. BV_{CEO} practically remains the same if d_{fp} is reduced from 500 nm to 475 nm. At the same time, avalanche is suppressed, which is seen as a constant I_B for larger V_{CE}. If the d_{fp} is further decreased, the BV_{CEO} drops due to the reduction of the value of the punchthrough voltage V_R.

As an example of the proper shielding the forced-V_{BE} simulations of the structures with d_{fp}=450 nm with different number of FFPs are shown in Fig. 10. Discrete tuning of BV_{CEO} is observed, with each additional FFP improving the BV_{CEO} by approximately 4.5 V, which is in a good agreement with the V_R results from Fig. 3. The shielding of the E-field peaks by the FFPs is efficient, which is observed as the constant I_B at larger V_{CE}. Simulated output characteristics are shown in Fig. 11. Due to the good shielding, no soft-breakdown behavior at larger V_{CE} is observed. Efficient shielding is confirmed by the forced-I_B simulation of the impact ionization rate at the onset of BV_{CEO} shown in Fig. 12a. The inner peaks in the drift regions are well shielded having smaller impact ionization rates. The BV_{CEO} is triggered by the peak E-field in the outermost drift region (DR 6 in Fig. 12). Avalanche holes generated at this peak flow to the FFP 5

and then down the potential stairs through all the FFPs toward the extrinsic base (see Fig. 12b). Due to constant I_B, holes are injected to the emitter and back-injected electrons end up at DR 6 *E*-field peak closing the positive feedback loop. Since that peak is placed along the electron current path, impact ionization is sharply increased due to the transistor current gain β. Modulation of the *E*-field by the avalanche holes at the top-peaks can also be observed with the highest peak appearing at the extrinsic base-collector junction. However, the difference between peak values at the top is less pronounced compared to the Fig. 8a because the *E*-field peaks in the inner drift regions are now contributing a smaller amount of avalanche holes (see Fig. 12b). It should also be noted that similar values of the BV_{CEO} are obtained for structures in Fig. 8 and Fig. 12 but at the expense of one extra FFP in case of the device with efficient shielding, which in turn increases the depletion region transit time and degrades the high-frequency performance. Nevertheless, with proper shielding, the device is scalable to much higher BV_{CEO}'s offering the big technological advantage.

C. Discussion on the BV_{CEO} Tuning Limits

The voltage drop in the base-collector depletion region can be easily controlled in the lateral direction by stepping of the FFPs potential via V_R and breakdown occurs at the outermost FFP where the extrinsic collector charge is not limited. We expect that even higher BV_{CEO} can be obtained by adding more than 12 FFPs, but so far we couldn't overcome the convergence problems in simulations when stacking a large number of floating regions. To the best of our knowledge, the problem is of numerical rather than physics nature. Our theoretical reasoning about BV_{CEO} limits is that the breakdown is limited by the coupling of the FFPs to the substrate potential, which depends on the amount of collector charge between the FFP and the substrate. When that part of the collector is fully depleted vertically from the substrate, the FFP potential is set by the associated punchthrough voltage. Since the FFP potential is then constant, further increase in the collector voltage above vertical punchthrough voltage, causes the reverse polarization of the FFP-collector junction. That voltage is dropped laterally in the top part of the collector. Breakdown then occurs when that lateral voltage drop reaches the value of FFP-collector junction breakdown voltage. For the given collector doping profile, simulations show that the vertical punchtrough voltage and the breakdown voltage due to the coupling of FFP to the substrate potential are approximately 129 V and 143 V, respectively.

IV. CONCLUSIONS

Tuning of the BV_{CEO} in Double-Emitter HCBT is accomplished by addition of floating field plates (FFPs). They are fabricated together with the extrinsic base allowing the best possible control of the distances between them as well as zero-cost integration. Due to unique structure of HCBT, where the additional p^+-regions can be placed within the *n*-collector, multiple FFPs can be fabricated on the top surface from where they can shape the potential distribution along the current path in the collector-base depletion region. Potential stepping of FFPs is obtained by the coupling via depletion capacitance and is controlled by the distance between them. Such technique is impossible to be implemented in the standard vertical-current bipolar transistors in a low-cost manner. In order to achieve the highest possible BV_{CEO} values, all *E*-field peaks in the base-collector depletion region should be properly shielded. In that case breakdown occurs due to the *E*-field peak in the outermost drift region. BV_{CEO} as high as 70 V is demonstrated by the device simulations. The theoretical BV_{CEO} limit for the given collector doping profile is estimated to be around 140 V.

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Large-signal characterization of Horizontal Current Bipolar Transistor (HCBT) by load-pull measurements

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***Abstract* – Load-pull and source-pull characterization of packaged Horizontal Current Bipolar Transistor (HCBT) is performed at 2.4 GHz. A fully-calibrated, automated load-pull measurement setup is used to determine the optimal matching conditions at both input and output of the transistor, considering maximum output power and efficiency. Three classes of power amplifier (PA) operation are investigated, namely Class A, Class AB and Class B. Matching impedances and bias points for all classes of operation are optimized by employing the load-pull and source-pull contours for output power and collector efficiency. With the output power of more than 22 dBm and gain of 11 dB, HCBT shows a great potential for RF power amplifier design for modern wireless communication standards, such as Wi-Fi and 4G LTE.**

Keywords - Horizontal current bipolar transistor (HCBT), load-pull, source-pull, RF power amplifier

I. INTRODUCTION

With the advent of modern wireless communication standards employing Orthogonal Frequency Division Multiplex (OFDM), such as Wi-Fi 802.11 [1] and 4G LTE [2], design of high-efficiency radio-frequency (RF) power amplifiers (PA) became the only way to cope with large Peak-To-Average-Power-Ratio (PAPR) RF signals. As the frequency of wireless communication enters the millimeter wavelength range [3], GaN Field Effect Transistor (FET) and InGaAs/InP Heterojunction Bipolar Transistor (HBT) become the dominant technologies in base stations and flagship handsets. On the other hand, RF CMOS and SiGe BiCMOS are used for PA design in the sub-6 GHz frequency range. Although costly in comparison to RF CMOS, SiGe BiCMOS provides superior performance with higher output power. As a pure silicon technology, Horizontal Current Bipolar Transistor (HCBT) provides a low-cost, high-performance bipolar transistor that is integrated with standard CMOS with minimal cost penalty. Thus, HCBT technology is a great alternative to SiGe BiCMOS for low-cost, high-efficiency PA design in the sub-6 GHz frequency range. Transistors with different periphery and power capabilities available in HCBT technology are packaged in industry-standard SOT343 4-pin package to enable discrete RFPA design. Additionally, the technology offers high voltage transistors [4][5], which can also be utilized in high-efficiency designs, such as Doherty PA [6] and Envelope Tracking PA [7].

In this paper, an HCBT is characterized by load-pull measurements at 2.4 GHz to gain insight into the large-signal behavior of the transistor and to facilitate large-signal modeling. An automated load-pull setup is implemented which uses two passive mechanical impedance tuners for varying the input and output matching impedances presented to the transistor. A fixture is designed and fabricated which provides SMA-to-microstrip transition at input and output while adding low insertion loss. Both source-pull and load-pull is performed to optimize output power, collector efficiency and gain in three classes of PA operation, namely Class A, Class AB and Class B. The DC output characteristics of the transistor are measured to determine the quiescent points for the respective classes of operation and to determine the load line resistance, output power and efficiency corresponding to the ideal load line. Load-pull and source-pull measurements give information about optimum match at the output and input, respectively, considering output power, efficiency or gain. AM/AM characteristics are measured prior to and after the load-pull and source-pull for each class of operation.

II. LOAD-PULL CHARACTERIZATION

A. Horizontal Current Bipolar Transistor (HCBT)

Horizontal Current Bipolar Transistor (HCBT) is the lowest-cost silicon bipolar transistor technology integrated with 180 nm CMOS by adding minimal process complexity [8]. Due to a very compact structure, HCBT outperforms all other silicon lateral transistors and can be used as a low-cost, high-performance alternative to SiGe BiCMOS. The optimized HCBT has a peak cut-off frequency (f_T) and maximum frequency of oscillations (f_{max}) of 51 and 61 GHz, respectively, whereas the $f_T BV_{CEO}$ product equals 173 GHz·V. Therefore, HCBT technology allows PA design with the possibility of low-cost integration with CMOS, enabling fully integrated RF front-ends for sub-6 GHz frequency range.

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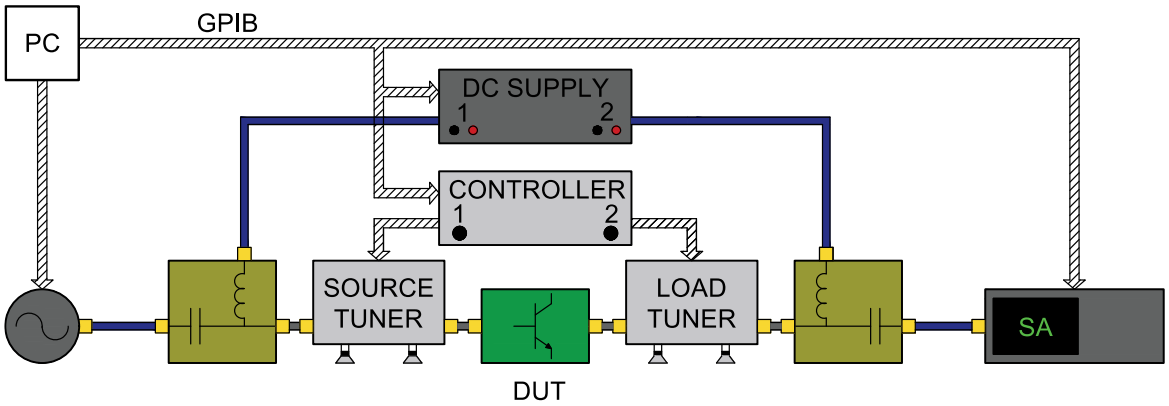

Figure 1. Automated load-pull setup used for DC and RF measurements of packaged transistors. Both source and load tuners are operated by tuner controller which communicates with PC. Input and output bias tees, used for DC biasing, are placed away from the DUT to minimize the losses between the tuners and the DUT. Signal generator, signal analyzer and DC power supply are also controlled by PC.

B. Load-pull setup

A block diagram of the load-pull setup used for large-signal characterization of packaged HCBTs is shown in Fig. 1. The setup is of a traditional scalar type [9], and it enables automated DC and RF measurements, such as input and output *I-V* characteristics, RF power sweeps, PA efficiency and linearity, source-pull and load-pull. The components enabling swept-impedance measurements are passive mechanical impedance tuners based on a slab transmission line and a shunt sliding short. Two stepper motors, operated by the tuner controller, set the impedance at tuner ports to a predefined value. Source tuner sets the impedance seen by the input of the DUT looking towards the signal generator, whereas load tuner sets the impedance seen by the output of the DUT looking towards the signal analyzer. Signal generator is used as a source of continuous wave (CW) RF signal that drives the input of the DUT. Output signal power is measured with signal analyzer at frequencies of up to 7.5 GHz. Biasing of the DUT is implemented with coaxial bias tees positioned before the source tuner and after the load tuner. Such positioning eliminates additional insertion loss that would otherwise be contributed by bias tees in between the tuners and the DUT. In that case, the additional insertion loss would lower the maximum synthesizable reflection coefficient (Γ) seen by the input and output of the DUT. Signal generator, signal analyzer, DC power supply and tuner controller are connected to PC to achieve complete automation and synchronization of signal generation, tuner movement and signal measurement.

HCBT transistors are packaged in industry-standard 4-pin SOT343 package. Since the package is SMD type, a fixture is designed and fabricated on a 1-mm-thick FR4 substrate which provides a low-loss transition from microstrip to coaxial SMA connectors (Fig. 2). Base and collector pins are connected over 50-Ohm microstrip lines to input and output SMA connectors, respectively. Both emitter pins are grounded using 4 plated vias with a diameter of 0.5 mm, thus securing a low impedance path to the bottom ground plane. In the figure, the input and output reference planes of the DUT are designated with dashed lines. The accuracy of the synthesized reflection coefficients at DUT reference planes is a critical parameter in load-pull measurement setup. Reflection coefficient at the input reference plane depends on the source chain, namely signal generator, bias tee, source tuner position, source half of the fixture and on any additional RF components in between, such as SMA adapters. Similarly, reflection coefficient at the output reference plane depends on the load half of the fixture, load tuner position, bias tee and signal analyzer. Therefore, every component in the RF path is characterized by S-parameter measurements using Vector Network Analyzer (VNA). Using measured S-parameters, reference planes are shifted from the tuner ports to the input and output of the DUT for every position of the source and load tuners. The power loss of the source and load chain is subtracted from the measurements to accurately predict the available input power and delivered output power of the DUT.

C. Output DC characteristics

In order to determine the quiescent point and load line for the Class A operation, output DC characteristics are measured and shown in Fig. 3. The characteristics are measured with base-emitter voltage V_{BE} as a parameter. A dynamic load line is also shown for the maximum collector current $I_{C\max}$ of 100 mA and maximum collector-emitter voltage $V_{CE\max}$ of 5 V. For this load line and Class A operation, quiescent point is defined with I_{CQ} = 50 mA and V_{CEQ} = 2.875 V. Thus, collector current swings from 0 mA to 100 mA whereas collector-emitter voltage swings from 0.75 V to 5 V where the minimum value of V_{CE} is restricted with the knee voltage V_{knee} of 0.75 V at I_C = 100 mA. The amplitudes of collector current and collector-emitter voltage are 50 mA and 2.125 V, respectively. Output RF power, load line resistance and collector efficiency are given with

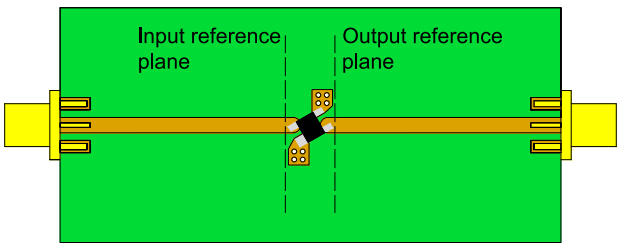

Figure 2. Measurement fixture for transistors packaged in SOT343 package. Input and output reference planes of the DUT are shown with dashed lines.

$$P_{\mathrm{OUT}} = \frac{1}{2} I_{C\max} V_{CE\max} = 53.13\ \mathrm{mW} = 17.24\ \mathrm{dBm} \quad (1)$$

$$R_L = \frac{V_{CE\max} - V_{\mathrm{knee}}}{I_{C\max}} = 42.5\ \Omega \quad (2)$$

$$\eta = \frac{P_{\mathrm{OUT}}}{P_{\mathrm{DC}}} = \frac{P_{\mathrm{OUT}}}{V_{CEQ} I_{CQ}} \cdot 100\% = 39.7\% \quad (3)$$

where P_{OUT}, R_L, and η are output RF power, load line resistance, and collector efficiency, respectively [10]. Load line resistance R_L is the optimal matching resistance that is to be presented to the collector reference plane in order to achieve output power P_{OUT}. While R_L is purely resistive, optimal matching impedance at the package reference plane has a reactive component due to transistor's output capacitance and reactance of the package that need to be compensated. This impedance is found by load-pull measurements.

D. Load-pull and source-pull analysis

Firstly, to determine the maximum linear output power of the unmatched transistor, AM/AM characteristic is measured with both input and output matched with 50 Ω (Fig. 4). In this and all subsequent measurements, the transistor is characterized at the frequency of 2.4 GHz. Quiescent bias point is set by V_{BE} and V_{CE} equaling 0.94 V and 2.87 V, respectively, resulting in collector current I_C of 55 mA. Input power available to the transistor, P_{IN}, is swept from -23 dBm to 11 dBm to cover both linear region and compression. Output power delivered to the load P_{OUT}, transducer gain G_T and collector efficiency η are monitored. Output delivered power begins to saturate at around 16.04 dBm with P_{IN} = 6 dBm. This point represents a maximum linear power of the unmatched transistor in Class A operation with I_C = 55 mA and V_{CE} = 2.87 V. In the compression point, where G_T drops by 1 dB, P_{IN} and P_{OUT} are 7.91 dBm and 17.54 dBm, respectively. Transducer gain is 10.62 dB in linear region of operation and 8 dB for P_{IN} of 11 dBm. Therefore, the unmatched transistor provides output power of 17.54 dBm with gain of 9.62 dB at the compression point in Class A operation. The transistor operates with a maximum collector efficiency in the compression region where it reaches 44% (P_{IN} = 11 dBm), whereas at the point of maximum linear power (P_{IN} = 6 dBm), it drops to around 28%. Further into the compression region, efficiency

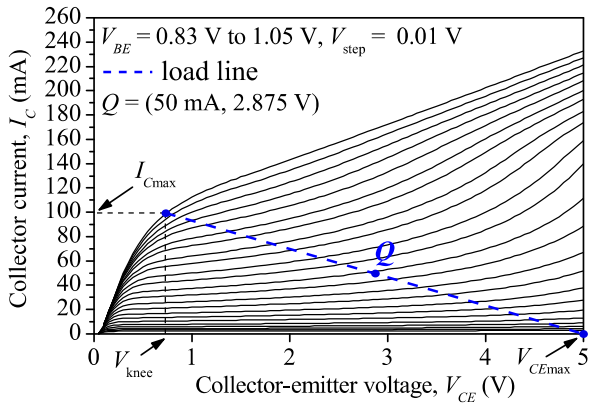

Figure 3. Output *I-V* characteristics and load line of packaged HCBT. Base-emitter voltage, V_{BE}, is swept from 0.83 V to 1.05 V with the step of 0.01 V.

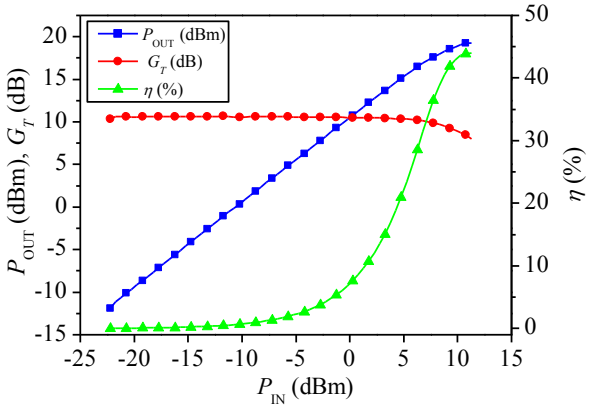

Figure 4. Delivered output power P_{OUT}, tranducer gain G_T and collector efficiency η for available input power in the range from -23 dBm to 11 dBm. Base-emitter and collector-emitter DC voltages are 0.94 V and 2.87 V, respectively. Input and output of the transistor are matched with 50 Ω.

saturates due to a rise in DC collector current that increases the dissipated DC power. After this measurement, a load-pull and source-pull analysis is employed to find the optimum matching impedance at the input and output of the transistor to maximize linear output power and collector efficiency.

To achieve maximum output power or efficiency, appropriate input and output matching impedances need to be presented to the transistor. During load-pull and source-pull measurements in this paper, the impedance presented to the input and output of the transistor is varied, respectively, while the output power and collector efficiency are measured. Since the goal is to find the output matching impedance Z_L for maximum linear output power, which is achieved for P_{IN} = 6 dBm, load-pull measurement is done for constant available input power of 6 dBm with I_C = 55 mA and V_{CE} = 2.87 V. After the optimum output matching impedance is found, source-pull is performed to determine the optimum input matching impedance Z_S while the output of the transistor is matched with Z_L. There is a negligible change of the optimum output impedance with input impedance presented to the transistor, therefore, there is no need for iteration in order to achieve simultaneous input and output match for this transistor.

Load-pull contours of constant output power at 2.4 GHz are shown in Fig. 5a. The impedance at the output reference plane of the DUT is varied while the input is matched with 50 Ω. Output power and efficiency are measured in order to determine the optimum matching impedances for both maximum output power and maximum collector efficiency for a constant input available power P_{IN} of 6 dBm. Maximum output power of 16.95 dBm is achieved for Z_L = 34.7 – j1.45 Ω, whereas maximum collector efficiency of 31.5% is achieved for Z_L = 40.9 + j1.65 Ω. The results are in good agreement with the values predicted from DC analysis (1), (2) and (3). Optimal matching impedance is not purely resistive as in (2) but has a small reactive component of 1.45 Ω that cancels the contribution of the package and output capacitance of the transistor.

Source-pull measurements are performed to find the optimum matching impedance at the input of the

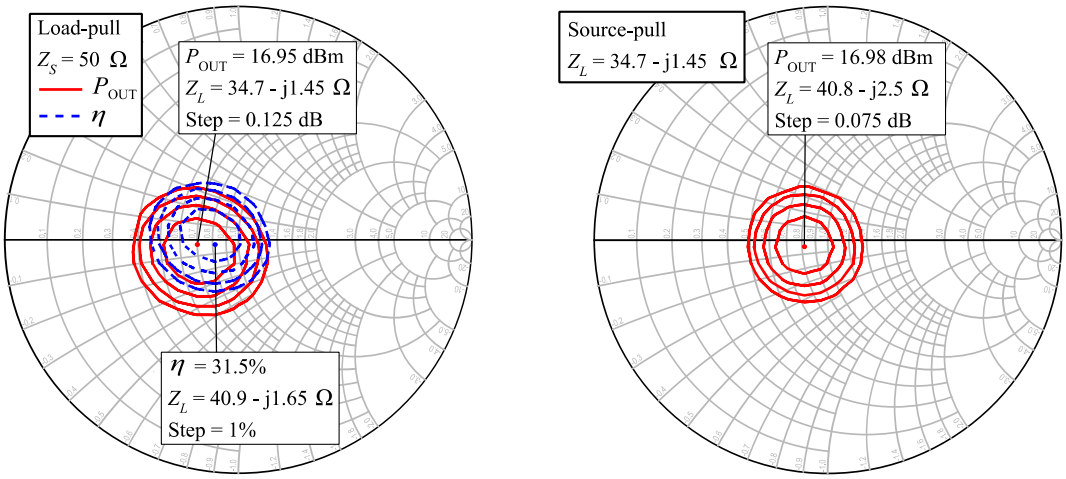

Figure 5. a) Output power and collector efficiency load-pull contours with constant available input power P_{IN} of 6 dBm with input matched with 50 Ω. b) Output power source-pull contours with output matching impedance Z_L = 34.7 – j1.45 Ω. Contours are drawn by interpolating the measured data using Advanced Designs System (ADS).

transistor. Source-pull contours of constant output power at 2.4 GHz are shown in Fig. 5b. Impedance at the input reference plane of the transistor is varied and output power is measured, while the output is matched with optimum matching impedance determined from load-pull, Z_L = 34.1 – j1.45 Ω. Maximum output power of 16.98 dBm is achieved for Z_S = 40.8 – j2.5 Ω. Therefore, with optimum input match, a modest increase in output power of 0.03 dB is gained, thus, the transistor can be unmatched at the input and still provide maximum output power in Class A operation. While the input signal of 6 dBm drives the input of the transistor in small-signal regime, output signal experiences clipping for certain output matching impedances. This is confirmed while comparing the source-pull and load-pull contours. Characteristic of small-signal regime are contours of constant output power resembling concentric circles, whereas load-pull contours are oval shaped, as predicted by load-pull theory [10]. Since both Z_L and Z_S are close to 50 Ω for Class A operation at 2.4 GHz, matching network design for discrete HCBT implies simple network topologies with a small number of passive components.

With the transistor matched with optimum input and output impedances for maximum output power, AM/AM characteristic is again measured and compared to the characteristic of the unmatched transistor (Fig. 6). Optimum match at the output increased the maximum linear output power and output power at the compression point from 16.04 dBm and 17.54 dBm to 16.9 dBm and 18.7 dBm, respectively, whereas the optimum match at the input increased the gain in linear region from 10.62 dB to 11.1 dB. Since optimum impedances for maximum output power and efficiency are similar, collector efficiency is also increased for all values of available input power and for P_{IN} = 6 dBm equals 30%. By matching the input and output of the transistor with optimum impedances for maximum output power in Class A operation, an increase in output power and efficiency of 0.86 dB and 2% is achieved, respectively.

Further efficiency increase is achieved by decreasing the DC collector current I_C, yielding Class AB and Class B mode of operation. In Class AB regime, DC collector current is set between the Class A value and 0 mA,

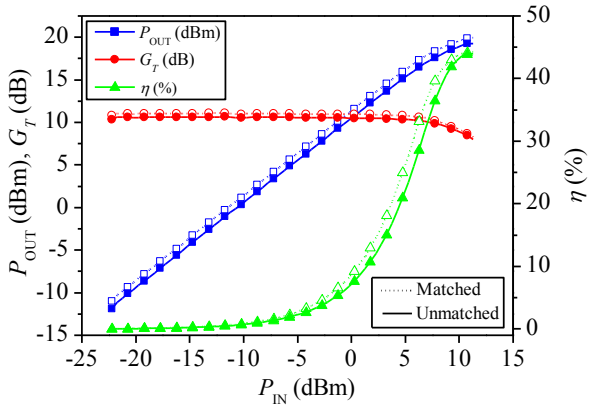

Figure 6. Delivered output power P_{OUT}, tranducer gain G_T and collector efficiency η for matched and unmatched transistor.

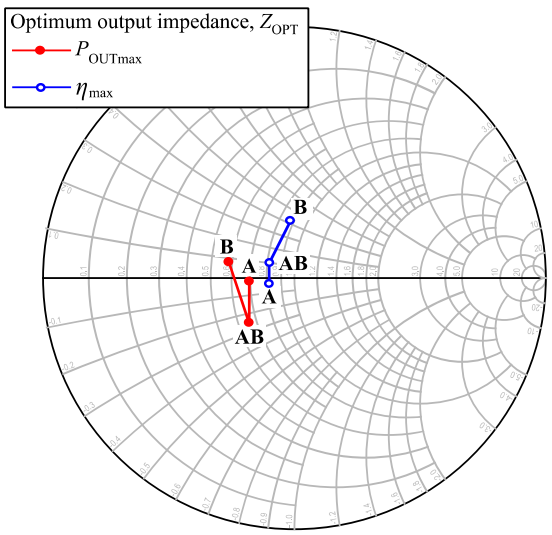

Figure 7. Optimum output matching impedances for maximum output power and maximum collector efficiency for Class A, Class AB and Class B operation.

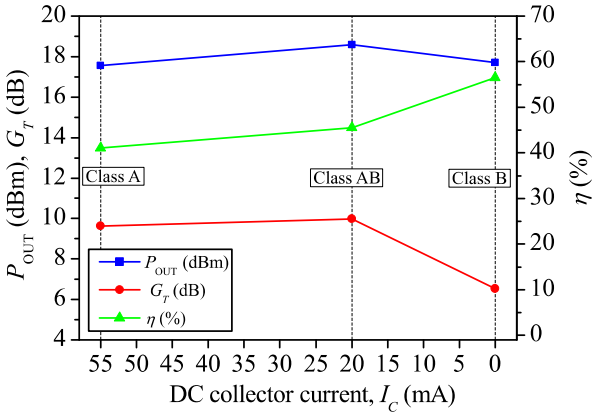

Figure 8. Delivered output power P_{OUT}, tranducer gain G_T and collector efficiency η at the compression point for Class A, Class AB and Class B mode of operation. The transistor is matched with optimum input and output impedances for maximum output power.

whereas in Class B regime the collector current is set to 0 mA. As it is done for Class A operation, a load-pull and source-pull analysis is performed for Class AB and Class B regime with I_C = 20 mA and I_C = 0 mA, respectively. Optimum input and output matching impedances for maximum output power and maximum collector efficiency are shown in Fig. 7 for the three classes of operation. Output delivered power P_{OUT}, transducer gain G_T, and collector efficiency η for Class A, Class AB and Class B regime are shown in Fig. 8. The results are shown at the compression point and for the transistor matched with optimum input and output impedance for maximum output power. Since the maximum collector current is 100 mA, available input power is increased to 9 dBm and 11 dBm for Class AB and Class B mode, respectively, due to a smaller DC collector current. Collector efficiency is increased from 41.1% in Class A to 56.5% in Class B mode. In Class B, transducer gain is equal to 6.53 dB with a similar output power as in Class A of 17.7 dBm. Large decrease in gain is the result of Class B operation that demands higher input power to reach the same output power as in Class A. On the other hand, the output power in Class AB mode of 18.6 dBm, collector efficiency of 46% and transducer gain of 9.98 dB are higher than the respective values in Class A mode. Higher output power at the fundamental frequency in Class AB mode also depends on the second harmonic termination and can be a sign of Class J operation [10].

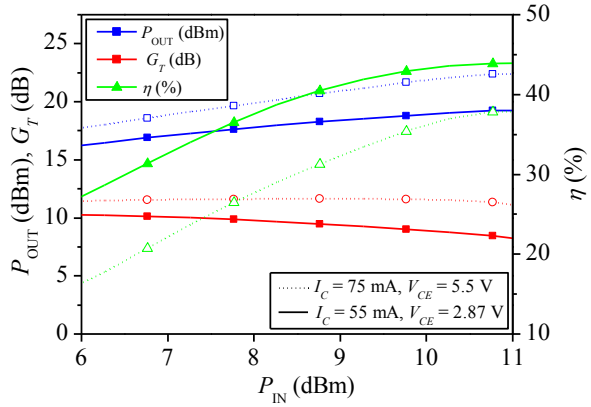

Figure 9. Delivered output power P_{OUT}, tranducer gain G_T and collector efficiency η for matched transistor for the two quiescent points, namely Q_1 = (55 mA, 2.87 V) and Q_2 = (75 mA, 5.5 V).

The results show that HCBT technology can be used for PA design with linear output power of around 17 dBm, such as Wi-Fi 802.11 standards. To investigate the possibility of HCBT PA design for 4G LTE cellular standard, which allows maximum power of 23 dBm, DC collector current I_C and voltage V_{CE} are increased to 75 mA and 5.5 V, respectively, far into the nonlinear region of output *I-V* characteristics. The results for the transistor matched at the input and output with optimum matching impedances (Z_L = 40.9 Ω, Z_S = 32.8 – j6.9 Ω) for both quiescent points are shown in Fig. 9. For I_C = 75 mA and V_{CE} = 5.5 V, HCBT outputs 22.6 dBm of power, with collector efficiency of 37.9% and gain of 10.9 dB for P_{IN} = 11 Bm. Therefore, the transistor can be used to design power amplifiers for higher linear output power than 17 dBm. Additionally, HCBT technology offers devices with even more power handling capability that can be utilized in more complex PA designs to implement highly efficient RF front-ends for both Wi-Fi and cellular wireless standards.

III. Conclusion

Large-signal characterization of HCBT is performed at 2.4 GHz using automated load-pull setup. Input and output matching impedances for maximum output power and collector efficiency are found for Class A, Class AB and Class B operation. HCBT in Class A provides output power of 17.54 dBm, efficiency of 31.5% and gain of 10.8 dB, and output power of 17.7 dBm and 56.5% efficiency in Class B. In Class AB regime, HCBT outputs 18.6 dBm of power with 46% efficiency and 9.98 dB of gain. A higher output power in Class AB mode indicates the possibility of tuning the second harmonic termination to achieve even higher power and efficiency. By increasing the DC collector current from 55 mA to 75 mA and DC collector-emitter voltage from 2.87 V to 5.5 V, HCBT can provide 22.6 dBm of output power and 11.3 dB in Class A operation. Thus, HCBT is suitable for both Wi-Fi and 4G LTE power amplifier design for handsets operating in the sub-6 GHz frequency range.

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Timing Closure of Clock Enable Signals on a 32 nm Intel Itanium Processor

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***Abstract*—With modern high speed circuit design using state of the art automated place and route (APR) flows, synthesis of clock enable (CE) signals is becoming increasingly difficult in terms of timing closure. The size of APR blocks in digital physical design in microprocessor projects is expanding with every generation of microprocessors as the implementation tools become more capable of handling large designs with high quality results and fast turnaround times. However, larger APR blocks make CE synthesis progressively difficult as timing closure complexity on these signals increases dramatically. The main problem is due to a single CE register driving the signal to a relatively larger area of the design, and to a greater number of clock gating cells. In this paper, we present automated duplication of CE logic in the APR flow to achieve timing closure on a 32 nm Intel Itanium project. We show how timing convergence is achieved without any additional effort from the physical designers, and with no changes required in the RTL. Solutions to the CE problem with smaller degree of automation and more manual effort, which were used on our previous projects, are also discussed and compared, and the reasons they are deemed inadequate are explained.**

***Index Terms*—Clock enable, clock tree synthesis, CTS, place, route, timing closure**

I. Introduction

THE recent advancements in electronic design automation (EDA) tools for logic synthesis and APR have enabled physical designers of digital microprocessor blocks to implement significant portions of their layout by using automation [1, 2]. Consequently, the overall area of the chip designed with traditional custom circuit design techniques proportionally decreases. In the Silicon on Chip (SoC) world, the automated approach to circuit design is even more prevalent than in the microprocessor field. This approach is made possible by the EDA tools producing increased quality of results with every generation of their releases, making it possible to significantly increase efficiency by merging several custom or synthesized blocks into one larger synthesized block.

Although larger synthesis blocks contribute many positive outcomes (e.g., improved turnaround time, smaller numbers of blocks and interfaces, reduced design complexity through automation), synthesis of clock enable (CE) signals of high frequency clocks suffers. The reason is simple; a single CE register has to drive the CE signal to a relatively larger area and a greater number of clock gating elements. With high speed clock frequencies staying flat or increasing from one generation of microprocessor to another, timing closure on these CE signals is a problem that is only becoming worse.

In this paper, we introduce the approach of handling timing closure of the CE signals in the synthesis blocks from the Intel Itanium project in the 32 nm Intel's technology (code name: Poulson [3]). An overview of the clock distribution at the block level is provided, followed by an analysis of the previous methods for solving the same CE problem in earlier projects at Intel. Finally, an approach to CE optimization implemented on Poulson is introduced, and results on several APR blocks are detailed.

Although it is not explicitly mentioned from this point onward, the clock referred to in this paper is the main functional clock. The discussion presented here is not relevant for test-related clocks, although it can apply generally to any clocks.

II. Overview of the Clocking Scheme

An overview of circuit design methodologies on Poulson is illustrated in [4], together with the specification and implementation guidelines for the clock distribution network. Details of the global clock distribution on Poulson fall outside the scope of this text, but it is important to reiterate that the clock is distributed to the functional (synthesis) blocks in a gridded manner. The block designer receives the location of the spines at a higher metal layer, and has to implement the clock tree network from the spines to the registers. The metal layer of the clock spines pushed by the full-chip layout designers to the synthesis blocks is the lowest metal layer used for the global clock distribution over the blocks (it can be different for different blocks).

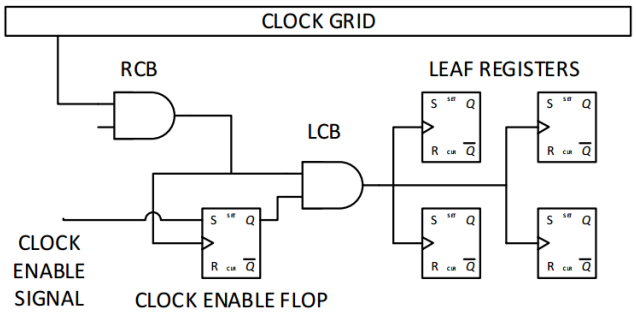

Figure 1. Basic Poulson clocking structure

The clock design manual specifies details on how the clock network must be implemented. The general approach is to have two levels of clock buffers between the clock spines and the registers. In Fig. 1, the buffers are denoted as RCB (Regional Clock Buffer) and LCB (Local Clock Buffer).

Both the RCB and LCB are AND gates, but serve different purposes in the design [5]. The details of their differences are outside of the scope of this text because we are concerned only with the CE distribution for the LCB, as illustrated by the register "Clock Enable" in Fig. 1. In this example, the CE register is driving the LCB directly, but in a general case there can be some CE logic between the two (for example, the LCB enable pin could be driven by two CE registers AND'ed together).

RCB and LCB cells are coded in the RTL, but only as single logical instances per functional clock, which means that, for example, one LCB cell drives 10,000 registers before clock tree synthesis (CTS). The purpose of CTS is to duplicate the RCB and LCB cells as much as needed to satisfy the tight clock requirements (e.g. clock arrival time, clock slopes, etc.). The CTS flow is built as a set of custom TCL procedures running in the APR flow after cell placement and before routing [6]. During CTS, the RCB and LCB cells are duplicated, placed and sized, and the clock nets are detail-routed as priority nets and frozen, after which the regular non-clock signals are routed and incrementally optimized. It is important to note that CTS preserves the topology of the clock network so that all registers receive the clock through one RCB and one LCB [6, 7]. No additional buffers are permitted to be inserted by the APR flow before the RCB, or between the RCB and the LCB, or between the LCB and the registers. This is because the clock arrival times at the register clock pins must be tightly controlled due to the clock skew requirements. Of course, several registers can share one LCB, and several LCBs can share one RCB.

Fig. 2 displays the section of the final layout for one APR block. The highlighted rectangle in the middle is an LCB cell, and the highlighted routes show the output net of the LCB fanning out to 20 registers. The LCB cell is a duplicated physical cell corresponding to a logical LCB cell in the RTL (every logical LCB cell has more than one physical instance in general, and every physical LCB cell corresponds to exactly one logical LCB). The LCB cell is typically placed in the middle of the cluster of registers it is driving.

Fig. 3 is similar to Fig. 2, but it shows the clock enable latch driving eight LCB cells. There is also a buffer at the latch output, but it is not displayed. The latch is duplicated in the CTS flow similar to the LCB cell shown in Fig. 2, and represents one of several physical instances of the logical latch coded in the RTL. The latch is typically placed in the middle of the cluster of the clock drivers it is driving. Please note that in Fig. 1 the LCB cell contains an integrated clock enable latch, so the latch is not shown specifically in the schematic between the CE flop and the LCB cell. The Poulson standard cells library contained LCBs with and without integrated CE latches, and the designers are able to choose between the two variants (both are fully supported by the APR flow, and specifically by the CE optimization approach described in this paper).

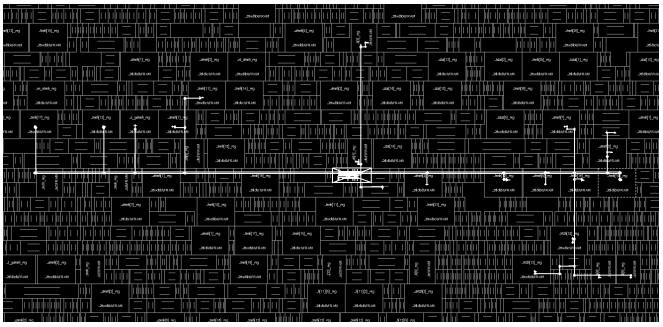

Figure 2. LCB driving 20 registers

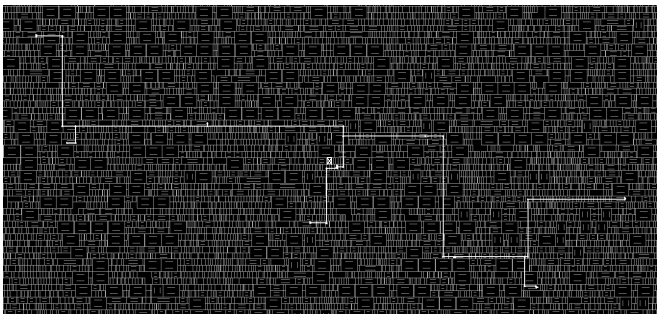

Figure 3. Clock enable latch driving 8 LCB cells

III. CLOCK ENABLE DISTRIBUTION – PROBLEM STATEMENT

The APR flow can generally be divided into three major steps (see Fig. 4):

1) The placement step takes the input data (synthesized netlist, timing constraints, and floorplan) and optimizes the placement of cells (in terms of timing and power) in the given area. In this step, the clocks are treated as ideal and the entire clock network is marked with appropriate ideal delays for timing purposes (the same ideal setup for the clocks is also applied earlier in the logic synthesis that produces the input netlist to the APR flow).

2) CTS optimizes the clock drivers to ensure that the clock is distributed to all receivers in a timely and power-efficient manner. In our case, CTS duplicates the existing RCB and LCB cells and sizes them for the given load, and aside from these duplicates, no additional buffers are added. At the end of CTS, the ideal setting is removed from the clocks, and the clocks are treated as propagated (i.e., timed by the timing engine) for the rest of the APR flow.

3) Routing and post-route optimizations produce routed design optimized for timing and power, which is then handed over to the sign-off tools. As already stated, the clock nets are routed first (priority routing) in this step, after which the entire clock tree is frozen (the size and location of each register and clock driver, as well as all clock routes, are fixed). This action is followed by routing of the signal nets and final optimization of the signal timing paths (possibly with several iterations).

The problem with CE is that the logic cells in its path are placed and optimized during the placement step (step 1), but the final number of receivers (i.e., LCB cells) and their location are

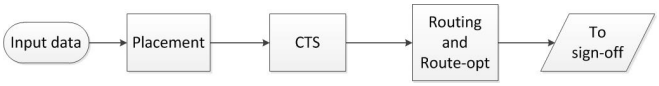

Figure 4. General APR flow

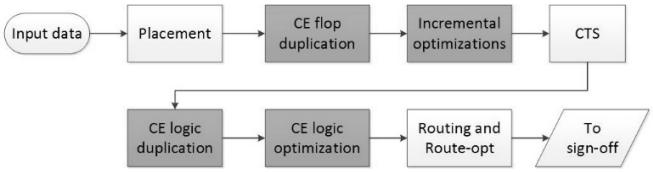

Figure 5. APR flow with CE optimization

not yet known at that point. The majority of LCB cells are added in the CTS step (step 2) and then placed across the floorplan (LCBs are placed close to the registers that they are driving and the locations of the registers are determined by the placement algorithm without special constraints). Therefore, the CE signals are heavily under-optimized at the end of the CTS step because the load on the CE drivers has changed completely since the last time they were optimized in the placement step. In addition, the CE registers cannot be moved to more optimal locations or resized after CTS because all cells in the clock tree (all clock drivers and receivers, including the CE registers) are at that point fixed in terms of size and location. In large blocks, incremental optimizations performed in the route and post-route optimization steps are simply not sufficient to close timing on the CE paths. Hence, some pre-optimization measures have to be taken prior to CTS.

IV. Earlier Methods of Clock Enable Optimization

In this section, we discuss two methods previously used for CE optimization in our group. Although these methods were used with success in earlier Intel Itanium and Xeon projects, they were not the right choice for Poulson, for the reasons discussed here.

One way of handling the high frequency clock network is by preplacing clock spines for the last level clock nets, i.e., the nets connected directly to the register pins. With respect to Fig. 1, this would mean preplacing the clock spines (pre-routes) for LCB output nets, which allows the LCB and RCB cells to also be preplaced, as the location of the spines is already known in the floorplanning stage of the flow (before placement). In this case, the CE paths could easily be optimized during placement because their receivers (i.e., RCBs and LCBs) are known and already preplaced at that point. The drawback is that the placement of all registers is forced into regions around these spines, and this type of forced clustering almost always results in suboptimal cell placement [8]. Planning the spines is an iterative process and the spines must be refined with time as the RTL matures and the timing constraints are developed. Although this methodology was successfully used on a previous project [9], it was not used for Poulson because of the complexities related to clock spines planning.

Another method of CE optimization is to simply duplicate the CE registers (and any CE logic associated with them) in the RTL. The approach is to run the APR flow once with the original RTL with no CE register duplicates, and then a second time based on timing violations to duplicate the CE registers in the RTL as deemed necessary by the designer. For every new CE register, we also need to create one LCB duplicate, and finally connect the desired bank of registers to it. With several iterations and additional optimization of the CE registers in the RTL, timing convergence can easily be automated in the APR flow and made transparent to most physical designers [6]. However, the drawback is that the clock scheme in the RTL might become suboptimal with time because the placement of the registers (and therefore the LCB cells after CTS) might significantly change as the RTL, timing constraints, and floorplan mature. This issue is particularly prevalent when the RTL is leveraged from one project to another and the context of the block changes significantly (different floorplan and timing constraints). This exact situation happened with one synthesis block on Poulson, with the RTL leveraged from a different project and CE register duplicates being already coded in the RTL. To make timing convergence possible, these duplicates had to be completely removed from the RTL so that the design started with just one CE register instance per functional clock. This approach also increased effort in logic design and validation domains, which are almost always on the critical path and driving the project schedule.

V. Clock Enable Optimization on Poulson

The two main criteria chosen for the CE optimization on Poulson were: 1) to make it completely transparent to the physical designers, and 2) to ensure no RTL changes are necessary for successful timing closure on CE paths. The two methods described in the previous section were clearly not meeting these needs, so another solution was deemed necessary.

As a starting point, we decided to pursue the idea of CE register duplication because the timing convergence is relatively simpler in that case. However, instead of requiring the registers to be duplicated in the RTL, we decided to implement the duplication in the APR flow with TCL scripting.

For this reason, additional steps were added to the flow, as illustrated in Fig. 5. Here, four steps were added to the three

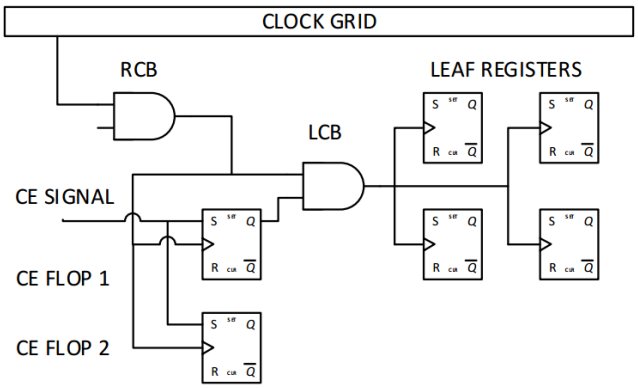

Figure 6. Clocking structure after CE register duplication

existing steps (Fig. 5). These additional steps are CE register duplication, incremental optimizations, CE logic duplication, and CE logic optimization. Two of these steps are performed immediately after placement, and two immediately after CTS. More details are provided in the following sections.

A. CE Register Duplication

In this step, the CE registers are duplicated to create more instances for each register responsible for gating off a large area of the design.

As already stated, the placement of LCB cells is not yet known after the placement step because these cells are only created in CTS. But, what *is* known is the placement of the registers, and because the LCBs will eventually be placed close to the registers they are clocking, we have an approximate idea of where the CE signals of LCBs will eventually have to go, even before CTS.

The duplication is hence performed if the CE register gates off the registers that occupy a larger region than 500 by 500 microns after the placement step is complete (this window size was obtained experimentally and can be changed by the physical designers on individual blocks). In these cases, we add as many instances as needed to ensure that each 500 by 500 microns window has exactly one CE register associated with it, and we place one of these duplicated instances in the middle of each of those windows (the actual number of leaf registers within each window is not important). At this point, all the duplicates are dangling, i.e., not driving anything, but simply waiting for CTS to complete to take over driving of the CE signals in their respective regions. Their inputs, however, are connected to the same nets as the original CE registers.

Fig. 1 illustrates the basic schematic of the clocking structure with four leaf registers. If we assume that the top two registers are placed in one 500 by 500 microns window after placement, and the bottom two registers are placed within another window, the flow at this point creates one copy of the CE flop and connects its inputs to the same signals as the original flop, while leaving the output unconnected. The schematic after this step is depicted in Fig. 6.

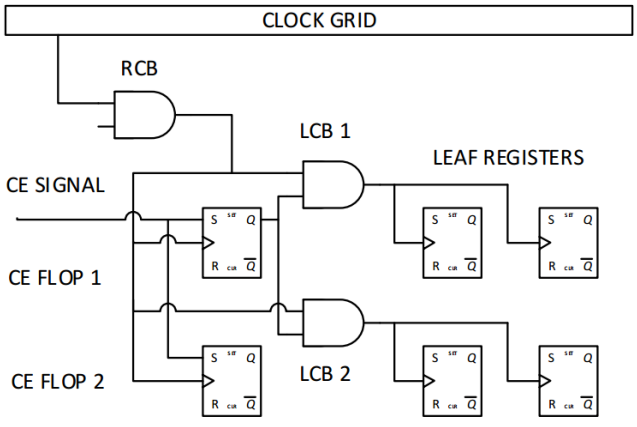

Figure 7. Clocking structure after CTS

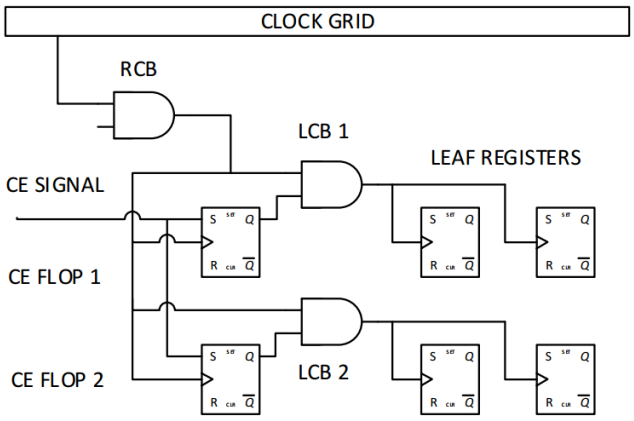

Figure 8. Clocking structure after re-connecting the LCB enable input

B. Incremental Optimizations

In this step, we perform optimization of the paths leading to the input pins of the duplicated CE registers. The logic on these paths is not optimal at this point because the new CE instances have been created and custom-placed after the completion of the placement step. To optimize these paths, we run incremental optimizations, such as placement refining, buffering, and cell sizing. We observe that relatively low effort optimizations are already sufficient to make timing closure on these paths possible. However, with even larger blocks expected to be synthesized in the future projects, it might be necessary to increase the optimization effort in this step, or even duplicate the registers in the previous pipeline stage.

C. CE Logic Duplication

This additional step is performed after CTS. The idea is that all LCB cells have been created, so we can connect them to the closest CE register duplicate. It is important to note that immediately after CTS, all LCB cells are initially still driven by the original CE register, as depicted in Fig. 7. In this step, however, they are reconnected. In the case that the CE register is driving the LCB directly, simply disconnecting the LCB from the original CE register and connecting it to the nearest duplicate is sufficient. The final clocking structure for our small example is illustrated in Fig. 8. However, in most cases there is some logic on these paths, and this logic has to be duplicated for each duplicated instance. This aspect is the trickiest part of the entire process because the cell duplication must be scripted in TCL while ensuring that the functional equivalence is preserved. Fortunately, by careful coding and planning of all the scenarios up front, we were able to avoid bugs and preserve functional equivalence in all blocks.

After the CE logic is duplicated for a given CE duplicate and connected to the rest of the design as needed, the LCB cells in the corresponding region are disconnected from the original driver and connected to the new one (i.e. the closest duplicate).

D. CE Logic Optimization

In this step, the CE logic that was duplicated in the previous step must be placed and optimized for timing. This proved to be a relatively difficult problem because each duplicated instance

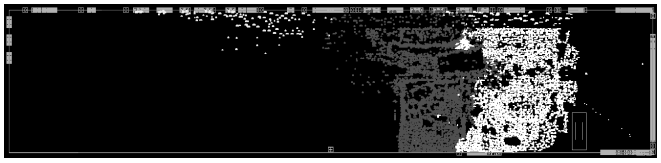

Figure 9. Three clusters of registers for a single CE signal

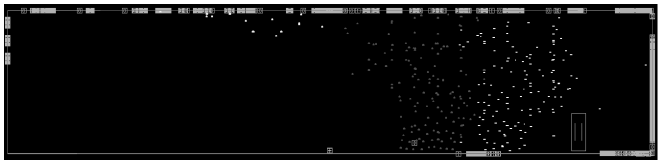

Figure 10. LCB cells highlighted by cluster

can drive many LCB cells in the 500 by 500 microns window. With careful automation, however, this issue was also resolved and the CE optimization solution was thus complete. It is important to note that any logic at the output of the CE registers is only duplicated once per CE register. For example, if the two CE registers are AND'ed and driving the clock enable signal, only one AND gate would be created per duplication window, and the buffer tree would be built, if needed, from the AND gate to drive all LCB cells in that window. Theoretically, it would be possible to duplicate the AND gate multiple times within the window to potentially facilitate timing convergence, but this was avoided to keep the load on the CE registers constant and thus avoid problems with sizing them after CTS (sizing any registers after CTS is almost always a bad idea).

VI. DESIGN EXAMPLES

In this section, two APR blocks and the CE solution on some of their CE signals are presented. One way to prove the effectiveness of our CE signal convergence would be to present the APR results with our duplication approach turned on and off. However, this comes with significant effort to make the comparison worthwhile because if we do not use our duplication approach, we still have other methods to fully converge the design (for example, the aforementioned duplication of the CE registers in the RTL), which are complex and time consuming. We believe that this was simply not worth the effort. We made the engineering judgment to use our method on Poulson and throughout the project, it was field-tested by the design community and widely accepted (and is currently being used on the follow-on projects).

The figures presented in this section show layout snapshots from the APR tool, with block boundaries, primary ports, and standard cells under observation. Note that only the cells under observation are displayed in order to concentrate just on the cells of interest.

Fig. 9 depicts three clusters of registers that are clocked by a CE signal. There are three instances of the CE register driving the CE signal, one of which is the original instance synthesized from the RTL and two are the registers duplicated by our flow. The block has 91,000 standard cells and relatively low area utilization. The large rectangle near the lower right corner is a hard macro. Given the high frequency of the clock and the relatively large floorplan with an aspect ratio of 5 to 1, timing convergence of the block was relatively difficult and would not have been achieved on this CE signal without duplication (in either the RTL or the APR flow).

Fig. 10 highlights the LCB cells corresponding to the clusters of registers in Fig. 9. As expected, it is apparent that the LCB cells are placed in the same area as the registers. We could present a similar snapshot of the corresponding CE latches, but their number is much smaller (shared per multiple LCB cells), and therefore almost invisible on this scale. It is interesting to note how the separation between the clusters, shown in both Fig. 9 and Fig. 10, is not a straight line. This effect arises because the CE latches are actually the cells connected to the CE register instances, and are always connected to the nearest of the duplicated instances. Therefore, the separation line of the different CE latch clusters would be perfectly straight. Here, the clusters of registers and LCBs are simply intermingled due to the nature of the CTS clustering algorithm. The details of this algorithm is outside the scope of this paper.

Fig. 11 and Fig. 12 present another APR block that has 114,000 standard cells and 12 hard macros. The overall area of the block is approximately 70% of the block discussed previously, and the aspect ratio is 2 to 1. The complexity of the block is driven by the relatively large number of hard macros and ports. The frequency of the main clock is again relatively high, and timing convergence relatively difficult, both on the CE signals and in general.

Figure 11. Two clusters of registers for s single CE signal

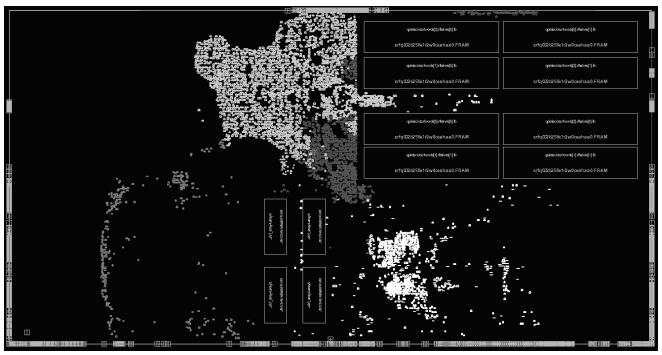

Figure 12. Four clusters of registers for a single CE signal

Fig. 11 depicts the registers gated by the same logical CE signal and divided into two clusters, one covering the left half of the block and the other covering the right half. Fig. 12 shows the registers in the same block, but gated by a different CE signal, for which the flow created four clusters. The reason for having different number of clusters for different CE signals is that the flow creates as many instances as needed for the cluster size not to exceed a predefined threshold, as discussed previously. The registers shown in Fig. 12 apparently cover a larger area than those in Fig. 11 (especially in the vertical direction), and therefore, the flow has created two additional clusters. In both scenarios, the cluster size is clearly close to the threshold. It is important to note that the threshold, i.e., the window size, is a parameter of the flow that can be changed by the block owner. Thus, it can be tuned as needed to achieve a more optimal solution. In this case however, we estimate that the solution of two versus four cluster has insignificant influence on timing, area, and power consumption of the block, so the default behavior of the flow has not been customized for the block.

VII. CONCLUSION

In this paper, we present a novel method of clock enable optimization for high frequency clocks. We detail the main challenges related to this problem and how the solution was approached based on past learnings. We believe that the method presented here satisfies certain crucial criteria for successful timing closure, such as transparency and complete automation without RTL modifications. We plan to bring this method forward to the projects of next generations and observe how well it serves its purpose as the area of synthesis blocks expands even further. Possible improvements in case of any issues could be to increase targeted optimization efforts on the clock enable paths and duplicate the previous stage of the clock enable registers. Importantly, the latter could become required if the synthesis blocks grow even larger and the input paths to the CE registers become dominant critical paths.

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Modelling of a Transmission Line Pulse Measurement Setup

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***Abstract*—A mixed lumped-distributed model of a transmission line pulse (TLP) measurement setup is presented. The model of the TLP generator, rise-time filter and probing needles is extracted based on the TLP measurements of open, short and matched loads in the voltage range up to 650 V. A behavioural model of an ESD protection device is built based on the measured quasi-static TLP characteristic and on the small-signal S-parameters of the device. The presented TLP generator and DUT models are verified by comparing the measured time-domain waveforms with the simulation results.**

***Index Terms*—Transmission Line Pulse (TLP) measurements; behavioural modelling; TLP de-embedding**

I. Introduction

Electrostatic discharge (ESD) events are an important consideration for all integrated circuits (IC). The voltages applied to an IC during an ESD event exceed the supply voltage by several orders of magnitude [1]. In order to protect the IC from ESD events, ESD protection devices such as silicon-controlled rectifiers (SCR) [2] are implemented in the IC design. The standard ESD tests include the human body model (HBM) test [3], the transmission line pulsing (TLP) test [4], and the machine model (MM) test [5].

An important parameter of the ESD protection devices is the I-V characteristic of the device-under-test (DUT) for high values of the voltage and current. In order to avoid the systematic thermal breakdown of the DUT caused by the high DC current values, the I-V characteristic is measured using the TLP measurement method, in which a series of pulses of 100 ns in duration is applied to the DUT. The I-V pairs are extracted from the quasi-DC steady-state of the pulse. The pulses are generated by discharging a coaxial cable pre-charged to a DC voltage that defines the pulse energy.

The goal of this paper is to establish a simulation environment that reproduces the TLP measurement of a gate-coupled NMOS silicon-controlled rectifier (GCNSCR), a type of SCR devices. A physical model of the SCR is presented in [2]. The methodology for semi-physical modelling of the TLP characteristic of ESD devices with more than one triggering voltage is presented in [6]. The presented models are implemented in Verilog A and they correctly reproduce the TLP I-V characteristic, but not the time-domain behaviour of the modelled device. The methodology presented in [7] enables building purely behavioural models of the I-V characteristic directly from the TLP measurements. In this paper, the TLP generator is modelled and simulated together with the behavioural model of a GCNSCR device built using the methodology presented in [7]. Both the I-V characteristic and the TLP time-domain waveforms are observed.

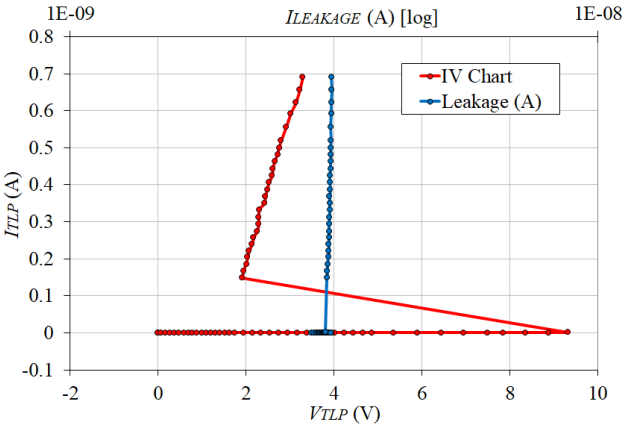


Fig. 1: Measured TLP characteristic of a gate-coupled NMOS silicon-controlled rectifier ESD protection device.

This paper is organized as follows. Section II presents the TLP measurement system and its physical model derived from measurements. Section III presents the ESD protection device, its behavioural model based on the measured TLP characteristic, and its small-signal model based on the measured reflection coefficient in the on-state. Section IV discusses the presented modelling results and Section V concludes the paper.

II. Transmission Line Pulse System Model

Fig. 1 shows the I-V characteristic of a GCNSCR device obtained by TLP measurements. The independent variable in the graph is the DC voltage V_{IN} used to charge the coaxial cable. Each point in the I-V characteristic represents the settled voltage and current values in the quasi-DC steady-state of the pulse measured using a high-speed oscilloscope. The DC leakage current of the DUT $I_{LEAKAGE}$ is measured after each applied pulse and it is plotted in the upper x-axis as a function of V_{IN}. An increase in the DC leakage current

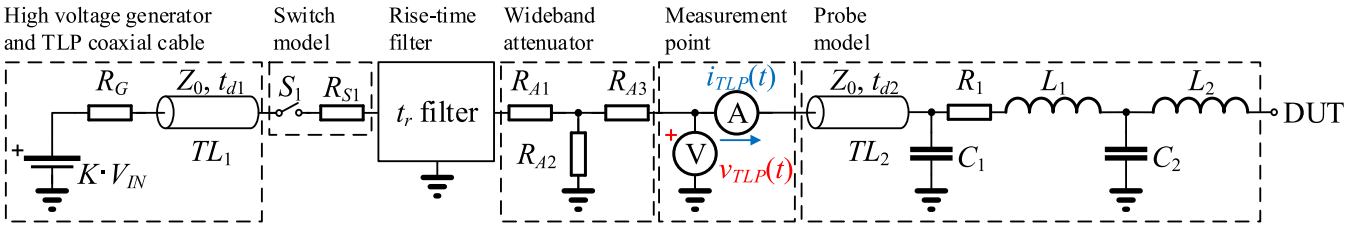
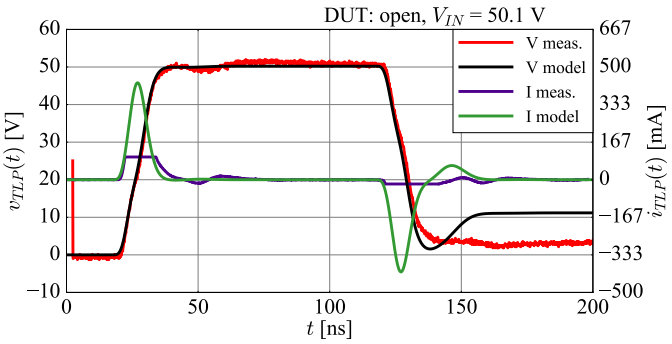


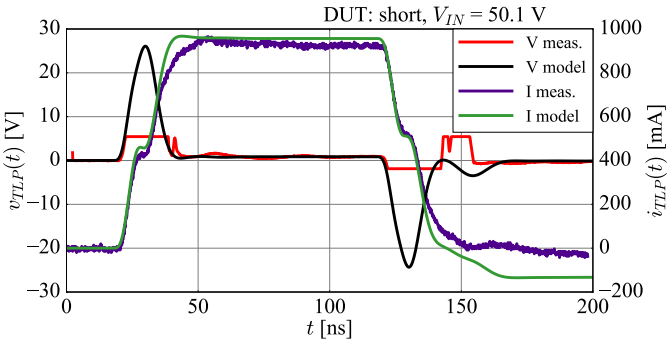
Fig. 2: Mixed lumped-distributed model of the TLP generator.

TABLE I: The lumped-distributed model parameters of the TLP generator model.

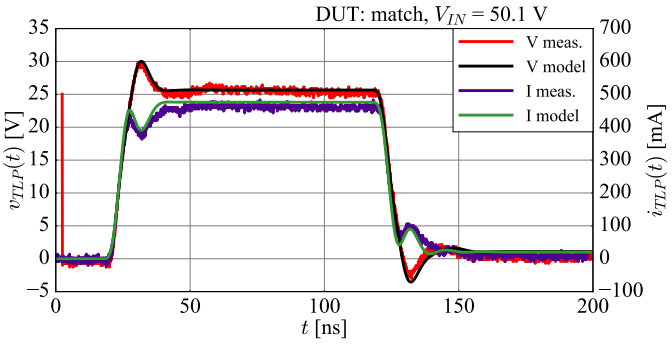
parameter	value	parameter	value
K	2.3	R_{A3} [Ω]	20
R_G [MΩ]	10	t_{d2} [ns]	2
Z_0 [Ω]	50	C_1 [pF]	18
t_{d1} [ns]	50	R_1 [Ω]	0.9
R_{S1} [Ω]	2.5	L_1 [nH]	5
t_r [ns]	6	C_2 [pF]	10
R_{A1} [Ω]	20	L_2 [nH]	180
R_{A2} [Ω]	56		



(a) Open load. The modelled voltage tends towards zero after 400 ns.



(b) Short load. The modelled current tends towards zero after 400 ns.



(c) Match load.

Fig. 3: Measured and modelled TLP response of the open, short and match loads for V_{IN} = 50.1 V.

would indicate that the DUT is permanently damaged by the TLP measurement. The measured value is constant at approximately 3 nA, i.e. the measurement is done non-destructively.

The mixed lumped-distributed model of the TLP measurement system is presented in Fig. 2. The model topology is built using the measured TLP current and voltage waveforms of the open, short and match loads shown in Fig. 3. The model parameters obtained by manual tuning are summarized in Table I. The coaxial cable is modelled as a lossless transmission line defined by the characteristic impedance $Z_0 = 50\ \Omega$ and by the propagation delay $t_{d1} = 50$ ns. The DC voltage source $K \cdot V_{IN}$ charges the transmission line TL_1 while the switch S_1 is in the open position. The energy accumulated in TL_1 is discharged through the series resistance R_{S1} of the switch S_1 when the switch is closed, generating a rectangular pulse of $2t_{d1} = 100$ ns in duration.

The rising and falling edges of the resulting rectangular pulse are shaped by the 6 ns rise-time filter, which is modelled using the 9th order lumped model presented in [8]. The resistive T-network consisting of the resistances R_{A1}, R_{A2}, R_{A3} defines a wideband attenuator with the attenuation factor $K = 2.3$. The attenuator is optimized to minimize the waves reflected from unmatched loads in order to achieve approximately the correct voltage value in the open load case, and the correct current value in the short load case after the 100 ns pulse. It should be noted that the modelled voltage in the open load case and the modelled current in the short load case both tend towards zero after 400 ns. The DC voltage of the power supply model is increased by the attenuation factor K in order to compensate for the attenuator. The TLP voltage and current waveforms $v_{TLP}(t)$ and $i_{TLP}(t)$ are measured using a high-speed oscilloscope at the output of the attenuator. The clipping observed in Figs. 3a, 3b is caused by the oscilloscope range settings. The pulse is applied to the DUT using a probe modelled by the lossless 50 Ω transmission line TL_2 defined by the propagation

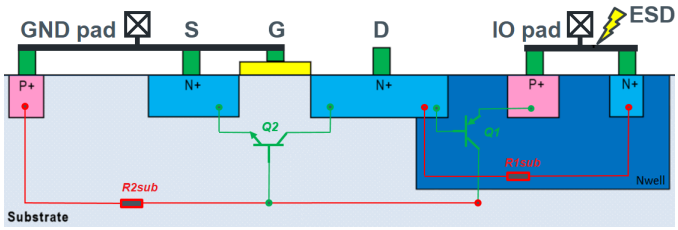


Fig. 4: Cross-section of the GCNSCR device protecting an IO-pad during an ESD event.

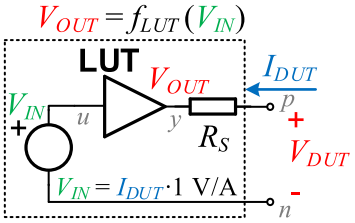


Fig. 5: Architecture of the behavioural model of the ESD protection device TLP characteristic based on [7]. The look-up table (LUT) is built from the TLP measurement data.

delay $t_{d2} = 2$ ns, analogously to [4]. The probe tip is modelled by two CL networks consisting of C_1, L_1, C_2, L_2 and the series resistance $R_1 = 0.9\ \Omega$. The second transmission line TL_2 is required to properly model the knee visible in the rising and falling edges of the current waveform in the short load case in Fig. 3b. The knee shape is caused by the constructive interference of the incident wave and the wave reflected from the DUT that travels back through the transmission line TL_2. Similar, but less pronounced knee shapes are present in the rising and falling edges of the voltage waveform in the open load case in Fig. 3a. The lumped element values are manually tuned in order to correctly capture the overshoots observed in the voltage and current waveforms in the matched load case in Fig. 3c. Similar agreement between model and measurements observed in Fig. 3 is achieved for values of V_{IN} up to 650 V.

III. Modelling Results

A. GCNSCR device description

The modelled ESD protection device is the gate-coupled NMOS silicon-controlled rectifier (GCNSCR) fabricated in a 180 nm technology node. The cross-section of the GCNSCR is given in Fig. 4. The device is used as ESD protection of IO-pads. It is composed of two bipolar transistors: the PNP transistor Q_1 and the NPN transistor Q_2, with the base of Q_2 shorted to the collector of Q_1. The resistors R_{1sub} and R_{2sub} are the substrate and N-well resistances. When there is no ESD event, the collector-base pn-junction of Q_2 is reverse biased, and the device is turned off. An ESD event applied to the IO-pad in Fig. 4 increases the potential of the collector of Q_2, and when it reaches the breakdown voltage V_{T1} of the collector-base pn-junction, the transistor Q_2 turns on. The voltage drop generated across the resistor R_{1sub} supplies the base current of Q_1 and turns it on. In this way, a low-resistance path is defined between the IO-pad and the ground pad, and the voltage across the structure decreases suddenly to the holding voltage V_h. This effect is referred to as the snapback effect, and it is observed in the measured TLP characteristic shown in Fig. 1.

The breakdown voltage V_{T1} of standard SCR devices is often too high for protecting the low-voltage ICs. In order to reduce the breakdown voltage V_{T1}, an NMOS transistor with the grounded gate is added to the structure to define the GCNSCR. The NMOS reduces the breakdown voltage of the collector-base pn-junction of Q_2 by providing more

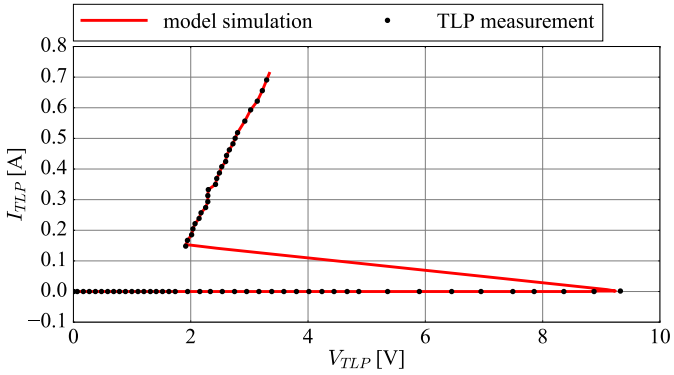
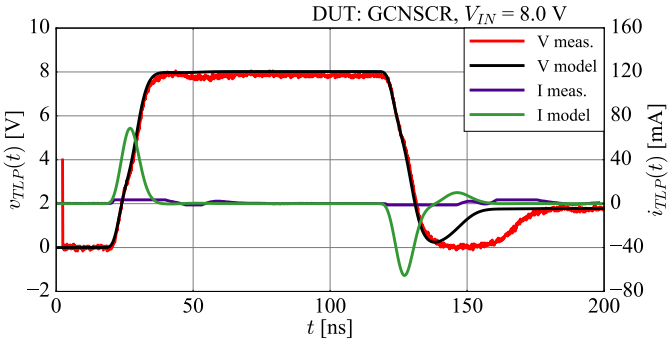


Fig. 6: Comparison between the measured and modelled TLP characteristic of the GCNSCR device. The I-V pairs are obtained by sampling the time-domain waveforms in Fig. 7 at t = 100 ns. The DC voltage V_{IN} of the power supply is swept from 0.1 V to 40 V in 100 mV steps.

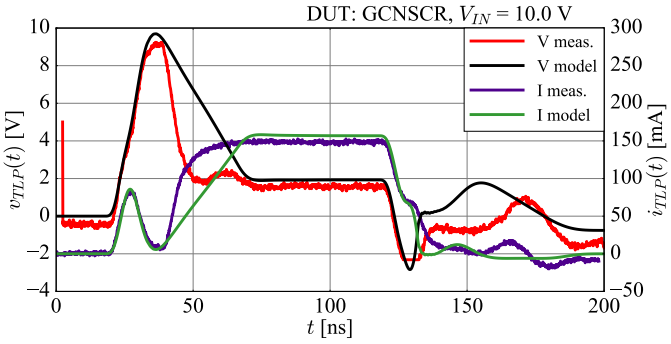
current to Q_2 and controls the triggering voltage V_{T1} of the complete structure. The low holding voltage V_h and the low resistance on-state path generated between the IO-pad and ground make the GCNSCR suitable for power applications.

B. Behavioural model of the snapback characteristic

The measured TLP characteristic of the GCNSCR device shown in Fig. 1 is a function of the implicit variable V_{IN}, i.e. the DC voltage used to pre-charge the coaxial cable TL_1 in Fig. 2. Nevertheless, according to the methodology presented in [7], the obtained I-V characteristic can be observed as if the current I_{TLP} is the independent variable and the voltage V_{TLP} is the dependent variable. The alternative setup in which the voltage V_{TLP} is the independent variable cannot be used because a single value of the voltage V_{TLP} would have more than one corresponding value of the current I_{TLP} due to the snapback effect. The behavioural model of the GCNSCR device is built using the methodology presented in [7]. The model architecture is shown in Fig. 5 and it is implemented in Verilog A. The TLP characteristic is modelled using a current-controlled voltage source (CCVS) implemented as follows. The current I_{DUT} flowing into the device is converted to an internal voltage $V(u, n)$. The internal voltage drives the look-up table (LUT) that generates the voltage V_{DUT} at the device pin p. The look-up table contains the (I_{DUT}, V_{DUT}) pairs obtained from the TLP measurement data using Eq. (1):



(a) Simulated time-domain waveforms in the off-state.



(b) Simulated time-domain waveforms in the on-state.

Fig. 7: Comparison between the measured and modelled TLP behaviour of the GCNSCR device in the time-domain.

$$\begin{aligned} I_{DUT} &= I_{TLP} \\ V_{DUT} &= V_{TLP} - I_{TLP} \cdot R_1 \end{aligned} \tag{1}$$

where R_1 is the resistive part of the probe tip model. Referring to Fig. 2, the TLP voltage V_{TLP} and current I_{TLP} are measured in the measurement point before the probe model. In the quasi-DC steady-state of the pulse, the DUT current I_{DUT} is equal to the measured TLP current I_{TLP}. The DUT voltage V_{DUT} is smaller than the measured TLP voltage V_{TLP} because of the voltage drop across the resistive part R_1 of the probe tip model. The series resistance R_S in Fig. 5 is included in the model architecture in [7] to improve convergence. In this test case, no convergence problems are observed, and the resistance R_S is omitted from the model.

The TLP generator model in Fig. 2 and the GCNSCR behavioural model in Fig. 5 are simulated in the Cadence® Spectre® circuit simulator using the transient (time-domain) simulator. The simulated TLP characteristic shown in Fig. 6 is obtained by sampling the voltage and current waveforms in the moment t = 100 ns. Examples of simulated time-domain waveforms in the off-state and on-state are shown in Figs. 7a and 7b. It should be noted that the behavioural model of the GCNSCR device contains only the information about the quasi-DC steady-state part of the TLP waveform, and the small-signal parasitics of the device are not included in the model.

C. Small-signal model

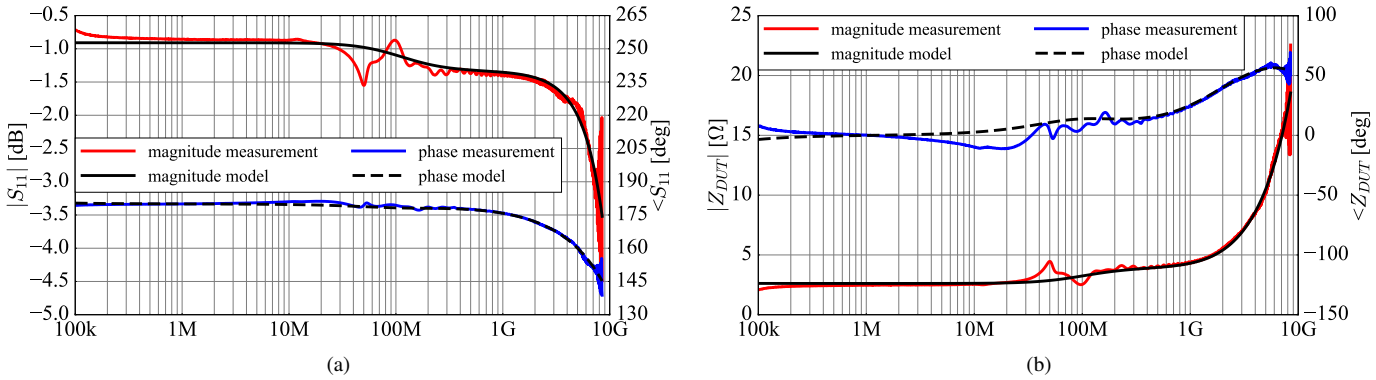
In order to extract the small-signal model of the GCNSCR device, the reflection coefficient S_{11} is measured using a vector network analyzer (VNA) in the frequency range from 100 kHz to 8.5 GHz. The DUT is probed using the Infinity Probe I40-GSG-100 from FormFactor (formerly Cascade Microtech), a GSG probe with a pitch of 100 µm. The reference plane of the 1-port S-parameter measurement is moved to the tip of the GSG probe by performing the open-short-match (OSM) calibration using the calibration substrate with short and 50 Ω calibration standards. The open calibration is done by holding the GSG probe above the calibration substrate. The resolution bandwidth of the VNA is set to 1 kHz, an averaging factor of 3 is used, and the incident power is set to -10 dBm. The DUT is biased using a DC power supply in several bias points. The maximum current limit is set to 350 mA to avoid damaging the VNA.

The measured reflection coefficient in the on-state is shown in Fig. 8a. Since the device is in the on-state, the inductive character of the DUT is expected. The model topology of a power inductor presented in [9] is used as a starting point for the modelling, and the final model topology is shown in Fig. 9. The model parameters are obtained by optimization of the reflection coefficient in Advanced Design System (ADS). The obtained model values are given in Table II. The measured and modelled small-signal impedance are compared in Fig. 8b.

IV. Discussion

The time-domain results presented in Fig. 7 show good agreement between the measurements and simulations. Since the GCNSCR model in Fig. 5 includes only the information about the settled voltage and current levels in the quasi-DC steady-state, the modelled rising and falling edges of the voltage and current waveforms are defined only by the parasitics of the TLP generator model in Fig. 2. The rising edge of the voltage overshoot waveform observed in the on-state at 20 ns to 40 ns in Fig. 7b and the corresponding current waveform are correctly predicted by the model because these transients are defined by the reactive elements in the model of the probe tip. The falling-edge of the voltage overshoot at 40 ns to 60 ns represents the turn-on time of the GCNSCR. This transient is not modelled well because it is defined by the device parasitics that are not included in the simulation model. The observed linear waveforms leading up to the settled voltage and current values are generated by the circuit simulator in order to reach the correct steady-state defined by the behavioural model.

The presented physical model of the TLP generator and the behavioural model of the GCNSCR device can be used to simulate the voltage and current waveforms generated at the reference plane of the DUT itself. This is not possible in the measurement setup because the measurement point is not located directly at the DUT. The extracted small-signal model of the GCNSCR in the on-state is a good starting point for generating a more accurate model that includes the device parasitics and their dependence on the applied voltage pulse.



(a) (b)

Fig. 8: Comparison between the measured and modelled small-signal parameters of the GCNSCR in the on-state: (a) reflection coefficient, (b) small-signal impedance. Bias point: V_{DUT} = 5.3 V, I_{DUT} = 350 mA.

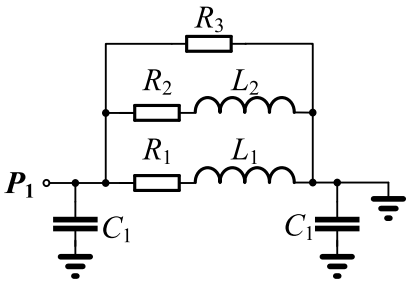


Fig. 9: Lumped model of the GCNSCR in the on-state. The model topology is based on the power inductor model in [9].

TABLE II: The extracted small-signal model parameters of the GCNSCR in the on-state.

parameter	value
C_1 [pF]	0.2320
R_1 [Ω]	7.6922
L_1 [nH]	16.0872
R_2 [Ω]	4.2683
L_2 [nH]	0.3219
R_3 [Ω]	54.9810

V. Conclusion

A mixed lumped-distributed model of the transmission line pulsing measurement system is presented. The model of the generator is based on the measurements of the open, short and match loads. The behavioural model of a gate-coupled NMOS silicon-controlled rectifier is built from the TLP measurement of the fabricated device and implemented in Verilog A. The simulated time-domain voltage and current waveforms predicted by the combination of the physical model of the generator and the behavioural model of the device are in good agreement with the measured waveforms. The small-signal model of the device-under-test is built using the measured reflection coefficient of the device.

Acknowledgment

The authors thank Andreas Wagner (ams AG) and the anonymous reviewers for constructive discussions and suggestions. This research is funded by ams AG, Austria.

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A unary coded current steering DAC with sequential stepping of the thermometer coded register in 1 and 2 LSB steps

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***Abstract*—This paper presents an 8-bit current steering DAC that uses unary current sources and a thermometer coded register. The thermometer coded register is controlled by sequentially stepping one or two steps up or down dependent on the control input. The enhanced step size mitigates the slew-rate limitation if the DAC is used in a delta-encoded tracking ADC. The sequential switching of thermometer coded DAC register does not require a binary to thermometer decoder and reduces complexity of error compensation.**

Keywords—DAC; current steering; thermometer encoded.

I. INTRODUCTION

DACs are a basic building block in ADCs, e. g. in a delta-encoded tracking ADC with current steering DAC in a feedback loop [1]. Dependent on the data rate and the topology of the ADC different types of DACs and register configuration can be used. To achieve higher resolution, the DACs can be segmented in binary encoded LSBs and thermometer encoded MSBs [2]. If the DAC is only thermometer encoded the transition time would be reduced compared to a binary encoded DAC. To improve the transition time without increasing the clock rate, the step size of thermometer coded DAC can be increased. To adjust the step size dependent on the input signal tracking, multiple comparators can be used like proposed for a tracking ADC [3].

The DAC presented here is used for a low power Tracking ADC with a sample rate up to 50 MS/s. The delta encode ADC has a step size of 1 LSB or 2 LSB up and down. Hence the register of the DAC must have the same adjustable step size. A step size of 1 or 2 LSB is well suited for a unary coded current steering DAC because only one or two current cells have to be switched at the same time. This has the advantage that there are less disturbances on the output signal compared to a binary coded DAC during switching which requires less effort for error compensation techniques [4].

The work is organized as follows: section 2 describes the structure of a unit cell and the switching modes, section 3 presents layout, section 4 discusses application and simulation, and section 5 gives a short conclusion.

II. CURRENT STEERING DAC

This 8-bit current steering DAC consist of 256 unit current sources. Each unit current source is embedded in a unit cell block. The unit cell block includes the D-FF and control logic of 1 bit of the thermometer coded register.

A. Unit Cell

The unit cell as presented in Fig. 1 has four input signals: Two for single step size mode (serin/fbin) and two for double step size mode (serin-1/fbin+1). The signals serin and serout represent the digital code of the unary and thermometer coded DAC. As the DAC can make single and double steps, the input must be connected not only to the preceding, but also to the 2nd preceding input signal serin-1. In order to allow switching of 1 or 2 DAC cells at the transition between the ones and zeros of the thermometer coded DAC, the inputs must be combined with the 1st and 2nd following logic state of the DAC cells. The input signals for single steps and double steps are combined with NAND-Gates respectively. With signal FS the multiplexer switches between the two combined inputs. The output of the multiplexer is connected to the enable of the D-FF. So the D-FF can only switch to a new value when the combined inputs are both logic 1. In this case the D-FF is set to CMP at the

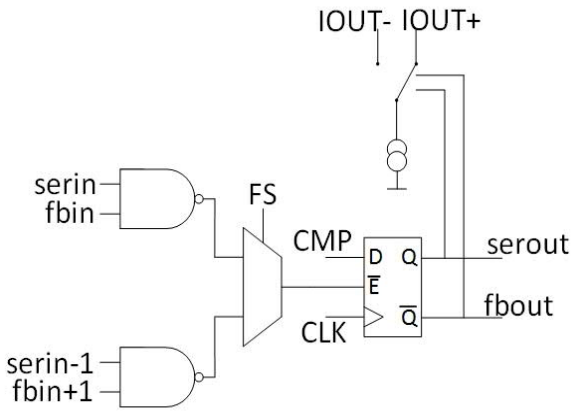

Figure 1. Unit cell block

rising clock edge. The current source can be switched either to IOUT+ or to IOUT-. Is the input CMP high, then the IOUT+ is connected to the current source otherwise IOUT- is connected. The control and interconnection of the unity cells are discussed in the next section.

B. Single/Double Step Size Modes

In Table I the possible signal combinations for each switching mode are given. The 4 modes are described below.

TABLE I. DAC SWITCHING MODES

Mode	Conditions	
	CMP	***FS***
Count +2	1	1
Count +1	1	0
Count -1	0	0
Count -2	0	1

Mode count up 1 step

In Fig. 2 the single step size mode for counting up one step of a unit cell is presented. The states of the logic control signals before and after the clock edge are given in the figure and are serin, serin-1, fbin, fbin+1, fbout and serout. Fig. 2 shows 3 unit cells and their states before and after the clock edge. The left unit cell is on state 1 before and after the clock edge, the middle cell is switched from state 0 to state 1, and the right cell is hold on state 0. In the mode count+1 the signals serin and fbin must be logic 1, which is the case for the cell in the middle. So the NAND-combination of serin and fbin enables the D-FF of the unit cell in the middle. As CMP is 1 in this cycle the output serout goes from 0 to 1. The cell on the right side has serin=0 and fbin=1, so this cell is disabled from counting up. The D-FF of the cell on the left side is enabled, but CMP is 1, so the state of this cell will not change.

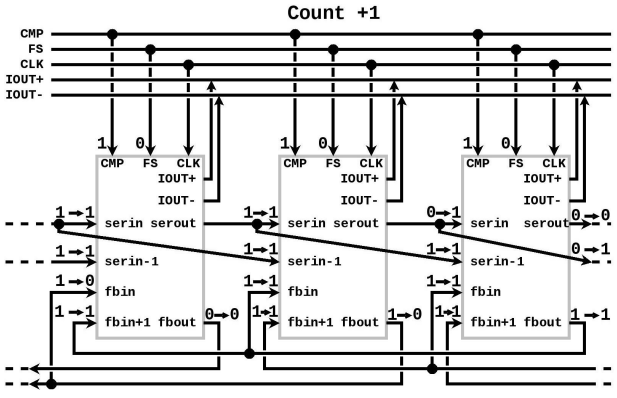

Figure 2. Single Step count up (CMP=1, FS=0)

Mode count down 1 step

In Fig. 3 the mode count-1 is explained. The left unit cell is on state 1 before and after the clock edge and the right unit cell is hold on state 0. The middle cell is switched from state 1 to state 0. The signals serin=1 and fbin=1 enable the D-FF in the unit cell in the middle. In mode count-1 input CMP is 0, so at the clock edge serout settles from 1 to 0. At the left unit cell the inputs are serin=1 and fbin=0, which disable this cell from counting down. The right unit cell is also enabled, but CMP is already 0, so the state of this cell will not change.

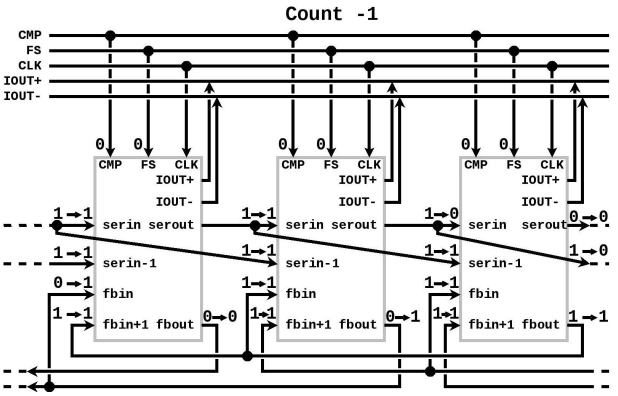

Figure 3. Single Step count up (CMP=0, FS=0)

Mode count up 2 steps

In Fig. 4 the double step size mode for counting up (count+2) is presented. All unit cells are on state 0 before the clock edge. The left and the middle unit cell are switched from state 0 to state 1 during the clock cycle. For all unit cells the state of serout is 0. The left and the middle unit cell are switched from state 0 to state 1. The double step size mode is selected by control signal FS=1. The signals serin-1 and fbin+1 must be 1 in this mode to enable a unit cell. For the left and the middle unit cells these signals are 1, and the NAND-combinations of serin-1 and fbin+1 in both of these unit cells enable the clocking of the D-FFs. The input CMP is 1, so serout of left and middle unit cells switch from 0 to 1. The right unit cell has serin-1=0 and fbin+1=1, so this cell is disabled for counting up in this clock cycle.

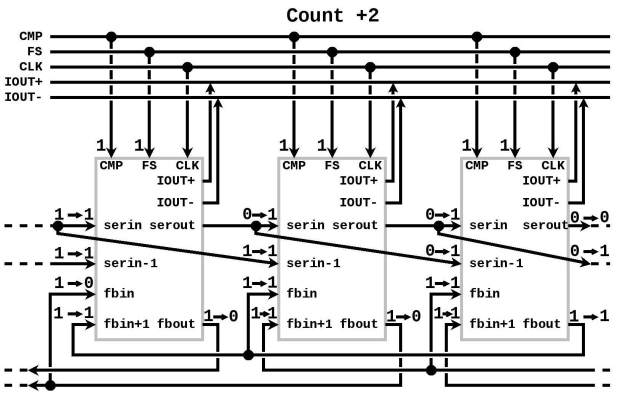

Figure 4. Double Step count up (CMP=1, FS=1)

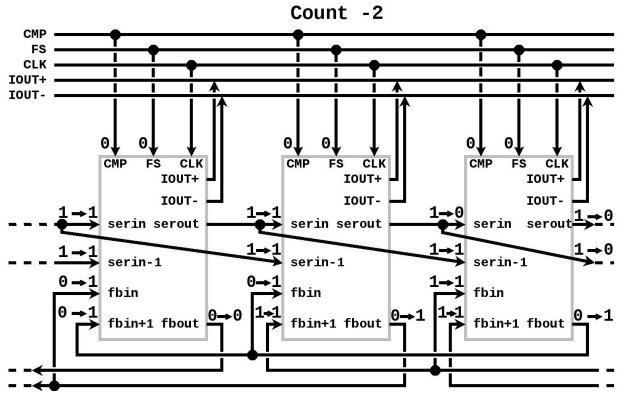

Figure 5. Double Step count down (CMP=0, FS=1)

Mode count down 2 steps

The 4th switching mode is counting down by 2 steps (count-2), which is described by Fig. 5. All unit cells are on state 1 before the rising clock edge. The middle and the right unit cell are switched from state 1 to state 0. The double step size mode is also selected with the step size select signal FS set to 1. The signals serin-1 and fbin+1 must be set to 1 to enable the D-FF of the unit cells to be switched. The logic level of CMP is 0, so the state of serout goes from 1 to 0 for the middle and the right unit cell. For the left unit cell serin-1 is 1 and fbin+1 is 0, so this cell is disabled for counting up in this clock cycle.

III. LAYOUT OF UNIT CELL

The layout of the unit cell is shown in Fig. 6. The cells can be attached in series vertically. The unit cell layout includes segments of control signal lines for step size control. The digital part of the unit cell is shown in the blue frame. The red frame contains the current source and the switch. The cell has the dimensions of 23.9 x 2.9 µm and is designed for the 65 nm low-power CMOS technology of TSMC.

IV. APPLICATION AND SIMULATION

The proposed DAC is the principal component current-steering DAC of a delta encoded tracking ADC whose block diagram is given in Fig. 7. The output of the DAC is summed to the tracking ADC input. The resulting control signal is the input to the current steering DAC.

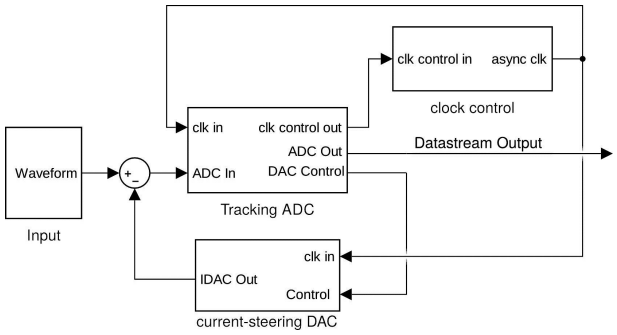

Figure 7. Delta Encoded Tracking ADC

The tracking ADC uses a 2-bit quantizer to generate the control signal for the DAC and the clock control.

Exemplary simulation results of a large signal transient are given in Fig. 8. The input signal is a ramp with a slope of 0.2 mV/1 ns followed by a constant period. This slope is twice of maximum slew rate of the DAC. So the delta signal rises. The DAC is in the double step count up mode (count+2) until the delta signal is between ±3 mV. This occurs at 1.69 µs and then the DAC is in count+1 mode. When the input signal is fully compensated the DAC toggles between count+1 and count-1 modes. In Fig. 9 the currents of the differential output are shown. During count+2 mode the output currents change by ±100 nA. Differentially this is equal to 200 nA which corresponds to 2 LSB. On the lower side of Fig. 9 the voltages for the positive and negative input of the ADC are shown.

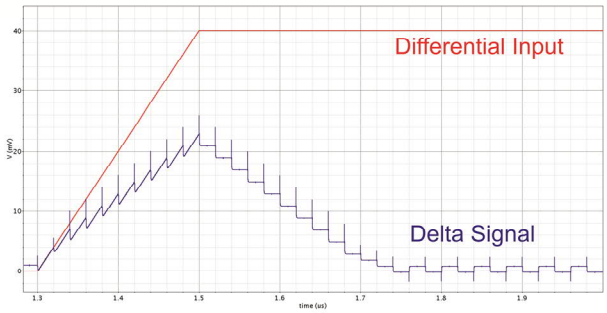

Figure 8. Input and Delta Signal of ADC

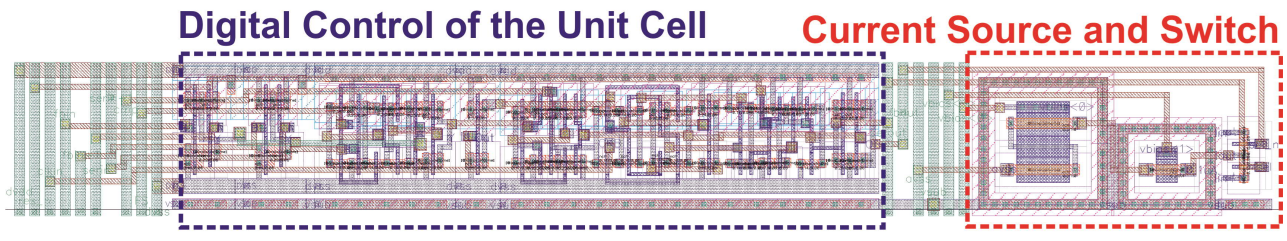

Figure 6. Layout of the unit cell

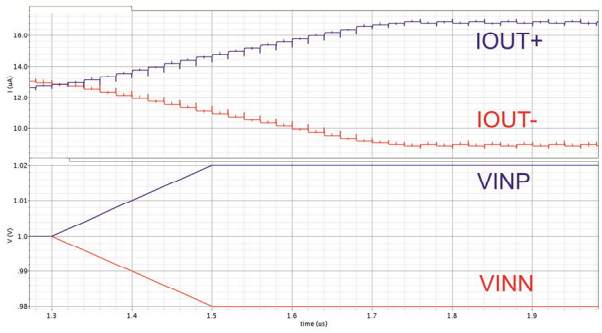

Figure 9. Output Currents of DAC and Input to ADC

A zoom of the transient signal with stepping from single to double step size is depicted in Fig. 10. Here the output current of IOUT+ is shown. In the mode count+2 every clock cycle 2 LSB are added to the output. In this case 1 LSB is 100 nA. In the mode count+1 the output rises by only 1 LSB per clock cycle. The modes for counting down are also shown in Fig. 10. For the mode count-1 the output current drops by 1 LSB per clock cycle and for count-2 the current drops by 2 LSB.

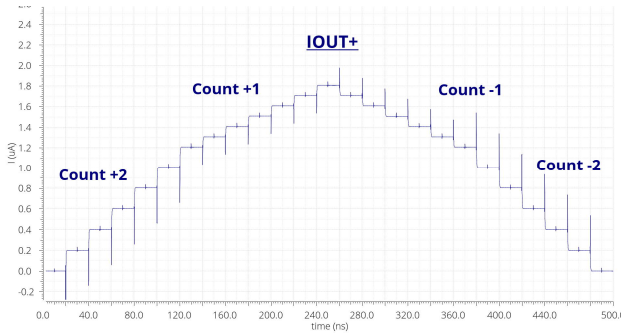

Figure 10. Single Step Size and Double Step Size Modes

V. Conclusion

The limited slew-rate which is a major disadvantage of delta-encoded ADCs with fixed clock rate is mitigated by using a DAC with variable step size. The unary coded current steering DAC can step 1 or 2 counts up or down, which increases the slew rate by a factor of 2 without the need of dynamically increasing the clock rate. The advantage of a variable DAC step size compared to a solution with variable clock used in a tracking ADC is its potential in energy savings.

The presented unit cell of the DAC has a compact layout and is implemented in an ADC with 2-bit quantizer and a control logic generating the step size control signal.

The adjustable step size of the unary coded DAC can be extended to larger step sizes and can be enhanced with asynchronous clock rate control.

Acknowledgment

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Bulk-Driven Fully Differential Difference Amplifier for Ultra-Low Voltage Applications

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***Abstract*—This paper deals with the design and analysis of a fully differential difference amplifier (FDDA) based on a pseudo differential topology that was implemented in a 130 nm CMOS technology. The proposed FDDA can reliably work with its power supply voltage as low as 0.4 V. The FDDA was designed using the bulk-driven technique, and Rail-to-Rail (RtR) input voltage range was ensured through the use of bulk-driven input transistors. Additionally, the RtR input/output CMFB, based on FDDA topology, was proposed. The output voltage range is near RtR (±0.36 V). The CMRR and PSRR of 60.2 dB and 64.4 dB was achieved, respectively. The proposed FDDA shows very good linearity in wide output range, thus the THD of -156 dB@1 mV was reached. Furthermore, the proposed FDDA was used as a building block of an ultra-low voltage-to-frequency converter.**

I. Introduction

Recent trends towards ultra-low voltage (ULV) integrated circuits (ICs) design are backed by modern nanoscale CMOS technologies, where the supply voltage is continually scaled down. In this way, demand for long-life and portable electronics can be satisfied by increasing the battery life. The ultra-low value of the supply voltage also reduces the overall power consumption of digital ICs, since it is proportional to the square of the supply voltage value. On the other hand, the power consumption of analog ICs does not decrease by scaling down the supply voltage, since the consumption depends on the required signal-to-noise ratio (SNR). Additionally, the reduction of supply voltage can decrease the dynamic range (DR) of analog ICs, since it directly depends on the supply voltage value. For these reasons, new design techniques and novel topologies of analog ICs for ultra-low supply voltage have to be developed.

In this paper, the design of a ULV bulk-driven FDDA, based on a pseudo-differential topology, is presented and its main parameters are analyzed. In Section II, backgrounds of the FDDA and common-mode feedback (CMFB) circuits are presented. The proposed FDDA, as well as other used sub-circuits (Common-Mode Feedforward (CMFF) and CMFB), are described in Section III. The achieved results are presented in Section IV. In Section V, an application of the proposed FDDA, a ULV voltage-to-frequency converter, is shown. In the last section, the obtained results are discussed.

II. Background

A. Fully Differential Difference Amplifier

To increase the DR of ULV analog ICs, fully differential (FD) signal processing has to be employed. Besides, the FD approach can improve the noise immunity as well as the power supply rejection (PSRR) of analog ICs. One of very advantageous building blocks used in the FD signal processing approach is a fully differential difference amplifier [1]–[3]. The most important advantage of the FDDA is high common-mode signal rejection [3]. Furthermore, the FDDA allows realization of both the non-inverting and inverting amplifiers without using resistors in the signal path and therefore, it can be efficiently used in low-noise applications.

In the case of ULV applications, where the supply voltage is usually less than 1 V, the possibility of using standard amplifier topologies is rather limited. Standard differential amplifier topologies are usually based on conventional structures [3] composed of four or more stacked transistors. Thus, these topologies require quite high supply voltage values. Therefore, dedicated low-voltage design techniques have to be employed. In order to achieve low-voltage operation, the bulk-driven technique was used in [4]–[7]. Nevertheless, in [4], [5], [7] the supply voltage is about 1 V. In [6], the bulk-driven quasi-floating gate technique was used, decreasing the supply voltage to 0.5 V. In all of these cases, the amplifier topology was based on the conventional differential structure. Another possibility to decrease the required supply voltage of the amplifier is to use the pseudo-differential difference (PDD) topology. This topology employs a differential pair without a tail source, which represents two independent common-source amplifiers. Additionally, the PDD topology can effectively increase the input and output voltage ranges. On the other hand, disadvantages of the PDD include high sensitivity to process, voltage and temperature variations (PVT) as well as a low value of the CMRR parameter, due to the absence of the tail source. Therefore, a CMFB or CMFF circuit is usually employed to stabilize the operational point and to increase the CMRR of the PDD amplifier [8], [9].

The general block diagram of a FDDA is shown in Fig. 1, where one can observe that the FDDA has two differential inputs that convert two differential voltages into currents. Then, these currents are subtracted from each other and

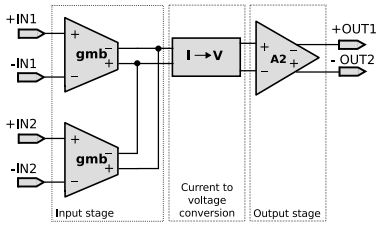

Fig. 1. General block diagram of a FDDA

converted back into a diferential voltage, which is amplified using the differential output stage. The differential output voltage of the FDDA can be expressed as:

$$V_{OUT} = A[(V_{+IN1} - V_{-IN1}) - (V_{+IN2} - V_{-IN2})], \quad (1)$$

where $V_{OUT} = V_{+OUT1} - V_{-OUT2}$ is the differential output voltage, V_{+OUT1} and V_{-OUT2} are the single ended output voltages, A is the total gain of the FDDA, while $V_{+IN1} - V_{-IN1}$ and $V_{+IN2} - V_{-IN2}$ are the first and second input differential voltages, respectively.

B. Common-Mode Feedback Circuit

In the case of a PDD amplifier, design of a high gain CMFB belongs to the crucial issues, especially from two points of view: 1. The missing tail current radically degrades CMRR and PSSR well below 100 dB [10], and according to [11], improving the gain of the CMFB can significantly suppress this effect. However, we must note that the overall impact of the CMFB mainly depends on the main amplifier performance itself (gain, mismatch, etc.) [12]. High values of these parameters tend to be more challenging to achieve using the bulk–driven approach. 2. Ensuring high common–mode (CM) loop gain under all PVT conditions can radically reduce permanent regulation deviations, that may be noticeable in ULV applications [13]. To be able to cope with these phenomena, two main approach categories exist, e.i. switched-capacitor (SC–CMFB) and continuous time (CT–CMFB) realizations. In general, a capacitor based CMFB such as SC–CMFB or its continuous-time counterpart (CTC–CMFB) from [14] do not resistively load the main amplifier output, do not cause extra power dissipation (except for the switching loss in SC–CMFB based topology) and have no headroom requirements, meaning that rail-to-rail (RtR) output swing of the main amplifier can be achieved [14], [15]. In contrast, using of SC–CMFB is usually restricted to time-discrete circuits, where the phenomena like clock feedthrough noise, charge injection problems and high switching frequency requirements ($f_{SW} > GBW$) must be taken into account [14]–[16]. Additionally, direct implementation of SC–CMFB under ULV conditions is restricted by the switching transistors not being able to turn on fully, due to the limited overdrive voltage. The CTC–CMFB behaves only as a CM detector (balanced capacitive CM–sense network) without native gain [14], [17], and therefore is not suitable for use in PDD amplifiers, where extra high gain is the priority requirement for the CMFB.

The most common implementation of a CT–CMFB for both high and low voltage applications is the resistor averaging circuit (balanced resistive CM–sense network), which performs only as a detector, and therefore requires an additional error amplifier with high gain (similar to the capacitor-based CMFB). The common characteristics of the CT–CMFB include high linearity, high immunity to the differential signal and a wide voltage swing, without a significant offset of the common-mode voltage compared to a differential difference amplifier (DDA) based CT–CMFB implementation. However, sensing resistors should be very large to guarantee that the gain of the system is not deteriorated by, leading to considerable noise and parasitic effects [13], [16], [17]. For this reason, a buffered approach has been part of many designs, to avoid the resistive loading while reducing the circuit area by using smaller resistors. The easiest way of implementing this method is a follower-based realization that is, in general, not implementable for ULV applications, due to voltage headroom requirements [18] (however, the input range can be improved by utilizing a bulk-driven topology [18]) similar to a CT–CMFB employing transistors in the deep triode region as sensing elements [16]. On the other hand, an extended solution based on an auxiliary complementary sensing method drawn from the differential pair topology, eliminating the minimum output voltage, can be a promising candidate [16].

The before mentioned approaches mostly utilize passive devices to form the CM detector, with gain of a few dB at best, followed by an error amplifier to achieve additional gain enhancement. A DDA [10], [11], [13], [18]–[22] may be able to combine both functionalities into a single block, like a pseudo-differential CM amplifier (PDCM), which represents a suitable solution for ULV designs due to only a two–above transistor topology [10], [15]. The PDCM structure can be applied to the PDDA configuration [10] or transformed from parallel MOS active resistors [15]. Generally, the incorporation of the differential pairs with nonlinear behaviour causes linearity degradation and increases sensitivity to the differential signal, which is declared as the main problem of this approach [15], [18]. Good discussion on this topic can be found in [12]. For this reason, the mostly linear behaviour of the input differential transistor pairs with small aspect ratios (W/L ratio) together with the cross–connection and current based CT-CMFB topology have been recommended in [12], and found their applications in several ULV designs [11], [13], [18], [20]–[22].

III. Proposed Pseudo Fully Differential Difference Amplifier

A. Pseudo FDDA topology

The schematic diagram of the proposed ULV pseudo FDDA (PFDDA) circuit is depicted in Fig. 2. The PFDDA was designed in a 130 nm CMOS technology and can reliably operate at the supply voltage of 0.4 V.

The first stage of the proposed topology is based on the cascode PFDDA, while the second stage is a conventional

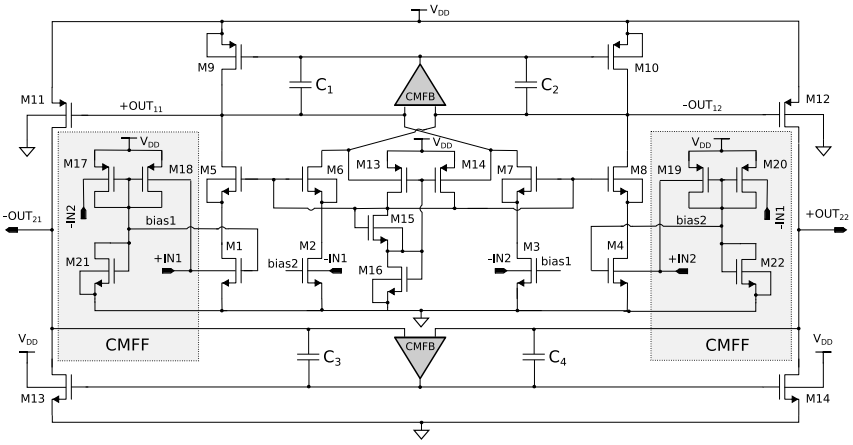

Fig. 2. Schematic diagram of the bulk-driven PFDDA-based VGA

common-source amplifier. The input bulk-driven transistors M1-M4 are used to obtain the rail-to-rail input voltage range, and together with transistors M5-M8, represent a cascode topology. However, bulk transconductance of a MOS transistor is given by $g_{mb} \approx 0.2g_m$, which means that the gain and gain-bandwidth product (GBW) of the proposed PFDDA will be decreased. Transistors M9 and M10 are used as the active load in order to achieve the current-to-voltage conversion. The simple common-source amplifier (M11-M14) was used as the second stage of the proposed PFDDA. To decrease the threshold voltage of transistors M11-M14, the bulk terminals of NMOS and PMOS devices are connected to the supply voltage (V_{DD}) and ground, respectively. This is possible to fabricate since the proposed PFDDA was designed in 130 nm twin-well CMOS technology which offers isolated bulk terminals for both NMOS and PMOS transistors.

B. Proposed CMFF circuit

The pseudo differential topology is sensitive to a difference between the common-mode voltages at the inputs. For this reason, a CMFF circuit was employed in order to regulate the gate bias voltage of the input transistors M1-M4. The developed CMFF circuit is shown in Fig. 2. Since the PFDDA has four inputs, two CMFF circuits were used. Transistors M17-M20 follow the input signal of the PFDDA, while diode-connected transistors M21-M22 convert the current generated by them to a (bias) voltage that is proportional to the common-mode voltage at the PFDDA inputs. In the case of a purely differential input signal, there is no change in the current flowing trough the diode-connected transistors M21-M22, and the voltages at the CMFF output (voltage drops on diode-connected transistor M21 and M22) is stable. However, in the case of a difference between the values of the common-mode voltage at the PFDDA inputs, the current through transistor M21-M22, and the resulting voltage drop, will be changed. This principle was used to regulate the gate voltage of the input transistors M1-M4, when the common-mode voltage at the inputs is changed, and causes less PFDDA sensitivity to the common-mode voltage as well as process and temperature variations.

C. Proposed CMFB circuit

A rail-to-rail input/output, current steering (high impedance current-mode systems), 3-stage CT–CMFB with the first stage based on the FDDA topology has been proposed (Fig. 3b). The proposed CT–CMFB modifies the robust, low differential signal sensitivity topology published in [15], where the output diode $M7A$ was replaced by transistors $M2_x$–$M3_x$, with a voltage reference connected to their bulk electrodes. The complementary topology has not been implemented into our design because the auxiliary current source $M1_x$ is sufficient to keep DM–CM conversion of the first stage reasonably low as demonstrated in [13], [22]. The RtR input and output ranges are ensured by the bulk–driven technique and push–pull differential-to-single ended stage, respectively.

$$A_{cmfb,st_1} = \frac{V_{DM,cmfb}}{V_{CM,cmfb}} = \begin{cases} \frac{g_{mb3}}{2}(r_{ds3} \| r_{ds5}) & \text{(Fig.3a)} \\ \\ g_{mb3}(r_{ds3} \| r_{ds6}) & \text{(Fig.3b)} \end{cases} \quad (2)$$

According to [12], [18], the CM loop gain of the CMFB should be at least equal to the external DM close loop gain of the amplifier. The same assertion is also valid for loop gain-bandwidth products [12]. In other words, the performance of both loops should be comparable. In ULV applications, this requirement increases demand for high currents leading to larger power consumption and circuit area. For these reasons, the 3-stage CT–CMFB has been employed to keep the idea of moderate inversion design while achieving the necessary gain. To profit from the differential structure, the first stage has been designed in this manner (similar to designs shown in Fig. 3a [11]), which is based on independent positive and negative P–type CT–CMFB circuits (Fig. 3b). In the proposed CT–CMFB, high gain is achieved by the CMFB–FDDA configuration with high output impedance. The resultind gain can be described by Eq. 2b) (under the following presumption $M2_x = M3_x$ and $M5_x = M6_x$). This is the main difference when compared to popular diode-connected loading configuration [15], [18], which are intentionally expanded by a partially cross–coupled positive feedback [11], [20] or a local feedback, in order to improved the dynamic current [21]. When

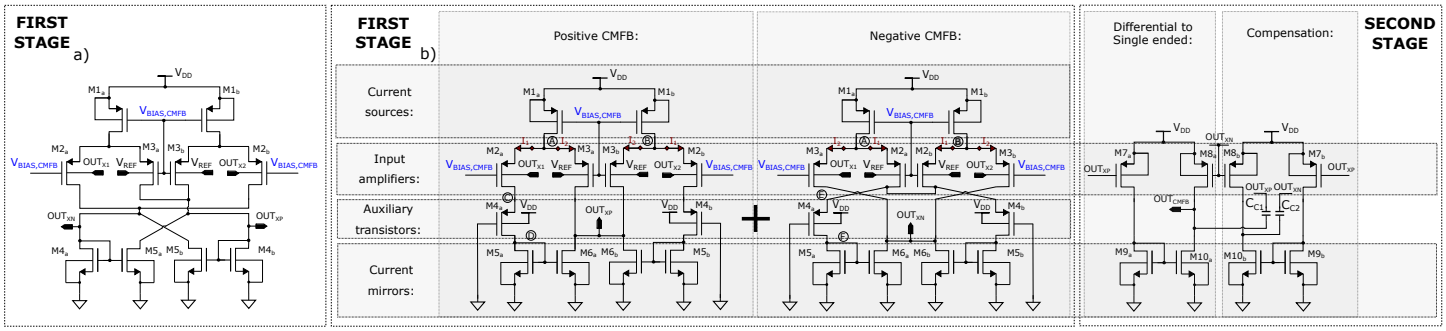

Fig. 3. a) First stage of RtR DM–CMFB taken from [11], b) Proposed first and second stages of RtR DM–CMFB (auxiliary transistors can be added to improved gain at the cost of increasing sensitivity to differential input voltage $OUT_{X1} - OUT_{X2}$).

we look closer at the only similar solution presented in [11], Eq. 2 shows that comparable gains can be achieved (because a half current flows in the proposed CT–CMFB). However, there exists a significant difference in the individual CM–DM transfer characteristics of the $1st$ stages (Fig. 4). The solution proposed in this paper, exhibits more symmetrical behaviour with the extensive linear range of single ended outputs OUT_{XP} and OUT_{XN} compared to its competitor, which is directly reflected into the differential outputs as the tradeoff between gain and the operation range (Fig. 4). Additionally, by the avoiding the partial feedback implementation, designs rather robust to PVT variations can be achieved. Finally, we must note that the stabilization issue is very challenging in the multi–stage design, and it has been solved by Miller compensation capacitors and additional $Gm - C$ stage in both CMFBs.

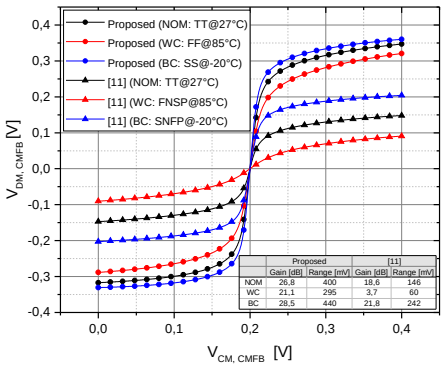

Fig. 4. Comparison of the voltage gain and the output range of the first stage (the competitor solution was redesigned to preserve inversion coefficients of individual transistors).

IV. Achieved Results

In this section, achieved results of the proposed PFDDA (including the CMFB and CMFF circuits) using a supply voltage of 0.4 V are presented. The results were obtained from Corner and Monte Carlo (MC) analyses, where the process variations as well as mismatch of devices were taken into account. The temperature range from -20°C to 85°C was considered in all simulations.

The DC transfer characteristics of the designed PFDDA in are shown Fig. 5. It can be observed that the proposed PFDDA can operate in near to rail-to-rail output voltage range. The worst case (from the output range point of view) can be observed in The fast-fast (FF) corner at temperature of 85°C, where the output range of $\pm$0.36 V was achieved. The deviation of the maximum output voltage is 24 mV when all the process corners and the whole temperature range were considered.

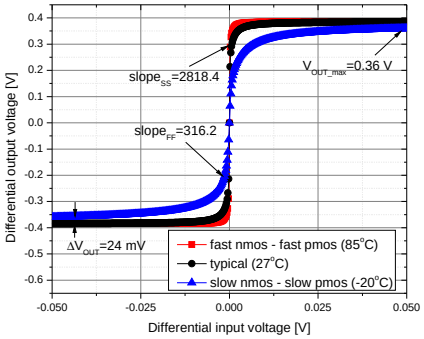

Fig. 5. Transfer characteristics of the proposed PFDDA

In order to investigate the linearity of the proposed PFDDA, the closed-loop DC transfer characteristic was obtained (Fig. 6). The PFDDA was simulated in the voltage buffer ($A_V = 1$) configuration. If we consider all process corners and the whole temperature range, the output voltage range of the PFDDA will be about $\pm$0.3 V in the worst case (FF, 85°C). However, the PFDDA can operate in the rail-to-rail input and output voltage ranges, but with reduced linearity.

In order to obtain the dependence of the linearity on the input voltage amplitude, the total harmonic distortion (THD) in the open-loop (OL) and closed-loop (CL) configurations of the PFDDA has been investigated. The dependence of the THD parameter on the differential input voltage amplitude is shown in Fig. 7. In the worst case, for the input amplitude of 1 mV, the THD parameter reaches the value of -13.9 dB and -150.8 dB in OL and CL configurations, respectively. Nevertheless, THD is less than -20 dB for all values of the input voltage amplitude below 300 mV in the CL configuration.

Fig. 8 shows the frequency response of the PFDDA, where all process corners were taken into account. In the typical case, the low-frequency gain of the PFDDA is 64.24 dB and the

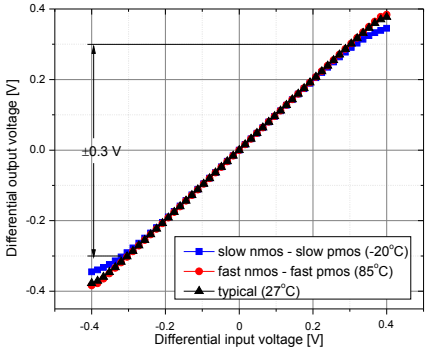

Fig. 6. Transfer characteristics of the proposed PFDDA (closed-loop configuration)

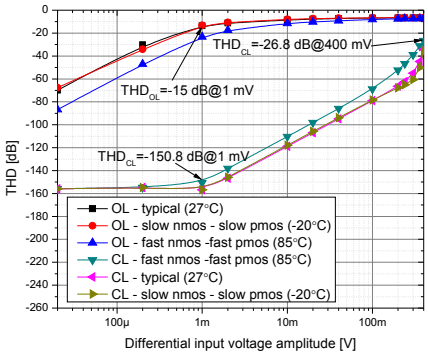

Fig. 7. Total harmonic distortion in OL and CL configurations

gain-bandwidth of 2.4 MHz was achieved. It can be observed that in the worst case, which corresponds to FF corner and temperature of 85°C, the low-frequency gain is about 50 dB and GBW parameter reaches value of 6.17 MHz. On the other hand, in the case of slow-slow (SS) corner and temperature of −20°C, gain of the proposed PFDDA is about 70 dB but the GBW will be decreased to the value of 483 kHz. These parameters were obtained for the load capacitance of 10 pF.

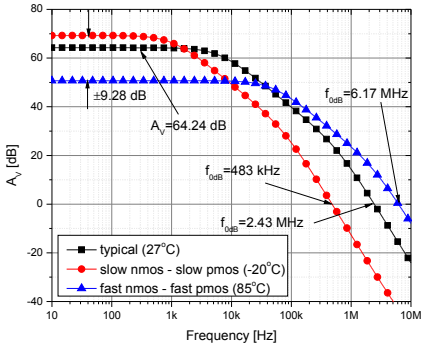

Fig. 8. Frequency response of the PFDDA

A very important parameter of the PFDDA is its CMRR. Fig. 9 shows variations of the CMRR parameter obtained from a MC analysis where deviation of $\pm 3\sigma$ was considered. The CMRR parameter varies in the range from 40 dB to 100 dB, while the mean value is about 60 dB. This is a very good result in general, which was achieved thanks to both of the CMFF and CMFB circuits being employed.

Thanks to the self-biased technique, the PSRR parameter of the PFDDA is also improved. Fig. 10 shows the variation of

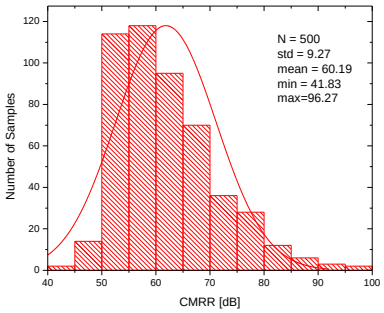

Fig. 9. Variations of CMRR evaluated by MC analysis

the PSRR. One can observe that the PSRR parameter varies in the range from 20 dB to 120 dB, while the mean value of PSRR is 64 dB. It is important to note that only a few samples will lie in the range from 20 dB to 30 dB, and therefore, the probability of obtaining PSRR lower than 30 dB is very low. Nevertheless, this will be the worst case since in the MC analysis 500 samples were considered.

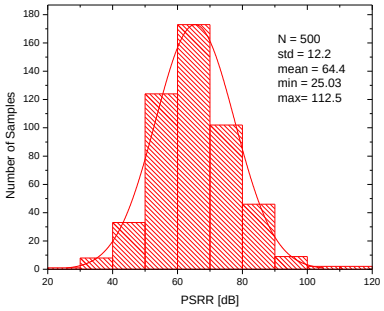

Fig. 10. Variation of PSRR obtained from MC analysis

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

TABLE I
MAIN PARAMETERS OF THE PROPOSED PFDDA

Parameter	Condition	Min	Typ	Max
A_v [dB]	$C_L = 10\ pF$	50.3	64.24	69.8
GBW [Hz]	$C_L = 10\ pF$	$483k$	$2.43M$	$6.17M$
BW [Hz]	$C_L = 10\ pF$	$1k$	$6.45k$	$46.7k$
CMRR [dB]	$V_{DD} = 0.4\ V$	40	60.2	100
PSRR [dB]	$V_{DD} = 0.4\ V$	20	64.4	120
THD [dB]	$V_{in,sin} = 1\ mV$	-	-156	-150
SR [V/μs]	$V_{in,pulse} = 200\ mV$ $C_L = 10\ pF$	0.55	2.95	6.1
Output voltage range [V]	-	-0.36	-	0.36
Total power [μW]	$V_{DD} = 0.4\ V$	8.7	78.4	385.3

V. APPLICATION OF THE PROPOSED PFDDA

The performed analysis has shown that the proposed PFDDA has very good linearity in a wide output voltage range. Additionally, the use of bulk-driven input transistors ensures the rail-to-rail input voltage range. The presented PFDDA represents an universal building block that can be used

in low-voltage differential systems. The developed PFDDA was used as a building block of a voltage-to-frequency converter (VFC). The block diagram of the converter is shown in Fig. 11. It can be observed that the PFDDA was employed in the closed-loop configuration as an amplifier and voltage-to-current converter. This implementation will be used for on-chip measurement of current consumption.

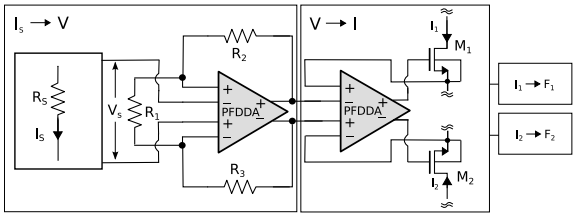

Fig. 11. Application of the PFDDA in a voltage-to-frequency converter

The voltage-to-frequency dependence is shown in Fig. 12. The sensitivity of the first and the second output is 161 Hz/mV and -244 Hz/mV, respectively.

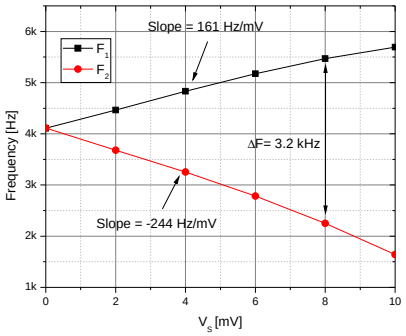

Fig. 12. VFC transfer characteristics

VI. Conclusion

The novel low-voltage FDDA circuit, based on the PDDA topology and designed in 130 nm CMOS technology, was presented. As demonstrated, the designed PFDDA represents a building block for low-voltage applications, where the supply voltage of less than 0.4 V, differential signal processing as well as high dynamic range and low distortion are required. The proposed PFDDA was used as a building block of a low-voltage voltage-to-frequency converter in order to increase its dynamic range.

Acknowledgment

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Minimizing Switching Time of Energy Harvesting Management Circuit

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***Abstract* – Energy management circuit is a mediator circuit between energy harvesting device and a load circuit. It operates without stable DC supply voltage which varies from 0 V to voltage level required by load circuit. Energy management circuit monitors the amount of energy collected from energy harvester and turns on and off the load circuit. With very low instantaneous power available from energy harvester, the energy management circuit must have as-low-as-possible power consumption. The problem is that with decrease of power consumption, the switching time increases proportionally. This paper proposes an energy management circuit with minimized switching time independent of power consumption. The proposed circuit is evaluated through simulations and laboratory measurements on a developed prototype. Evaluation has confirmed that the switching time of the proposed design is independent of power consumption and it depends only on the propagation delay time and transition time of MOS transistors used.**

Keywords – Energy harvesting; Energy management; MOSFET circuits; Switching circuits;

I. INTRODUCTION

The basic concept of an energy harvesting system is given by Fig. 1. Energy harvester is a device that extract small amount of energy from the environment. There are different energy harvesting methods (stress-strains, mechanical vibration, thermal gradient, thermal variation, solar, infrared, RF, biochemistry) which can provide from 1 µW to 10 mW of instantaneous power [1].

Load circuit is most commonly an ultra-low power wireless sensor node (WSN). During transmission, a power consumption of WSN is usually around 100 mW or higher [2].

Energy management circuit is a mediator circuit between a storage capacitor which stores energy collected from energy harvester and load circuit (e.g. WSN). It acts as a switch and connects the load circuit to storage capacitor when enough energy is harvested. Is also disconnects the load circuit when the voltage across the storage capacitor drops below certain level.

There are two basic structures of an energy harvesting system. One has step-up converter (voltage multiplier, charge pump, boost converter, etc.) circuit before the storage capacitor [3] and the second has the step-up converter after the storage capacitor [4].

In fully autonomous energy harvesting system, no batteries are used and the only supply voltage for the energy management circuit is the voltage across storage capacitor (marked "DC supply voltage" in Fig. 1). With such variable supply voltage, most energy management circuits use a startup circuit [4]-[6]. Startup circuit is used to turn on the step-up converter when the voltage from energy harvester is sufficient. Majority of the reported energy management circuit are complex and use both analog and digital circuitry [7]-[9].

The proposed design is fully analog without startup circuit and is has latch based operation principle [10]-[12], as opposed to comparator based solutions [4],[5],[7]. Single latching circuit [12] provides fast switch-ON mechanism, but slow switch-OFF mechanism. This paper proposes energy management circuit with fast switch-ON and fast switch-OFF. Fast switching is needed to avoid the occurrence of the stalemate state in energy management system [12]. The proposed design is described and measurement results are given in Section II. Section III gives the simulation results. At the end of the paper, the conclusion and references are given.

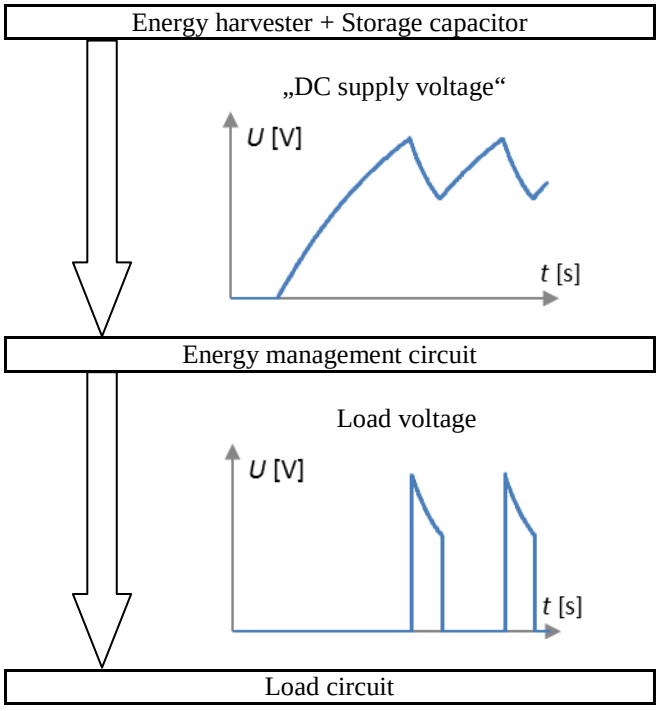

Figure 1. The basic concept of energy harvesting system

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II. ENERGY MANAGEMENT CIRCUIT WITH MINIMIZED SWITCHING TIME

Fig. 2 shows the schematics of the proposed energy management circuit. It consists of two latching circuits and two trigger circuits. Previous design [12] was realized using a single latching circuit which has a trade-in built into it. The power consumption of the energy management circuit, which has to be ultra-low, can be "adjusted" by changing the resistance of pull-up and pull-down resistors (R_PU and R_PD in Fig. 2) and the resistance of resistive dividers in trigger circuits (R1/R2 and R3/R4 in Fig. 2). Latching circuit has a short switch-ON time. When N1 starts conducting (this is an ON trigger event if P1 is conducting), P2 and N2 are forcing one another into conduction as well. Gates of both P2 and N2 have a low resistance path to ground and high rail, respectively. Such low resistance path ensures short switch-ON time. With a single latching circuit the built-in trade-off is a long switch-OFF time. When the P1 stops conducting, the gates of P2 and N2 discharge through high resistance path (pull-up and pull-down resistors) which causes long switch-OFF time.

In this paper, a second latching circuit is added which ensures a short switch-OFF time. Fig. 3 shows the waveforms of the energy management circuit measured on the built prototype, Fig. 4. The prototype is built around HEF4007 integrated circuit which consists of three CMOS transistor pairs. On Fig. 3, four waveforms are given, a voltage across storage capacitor C, voltage across load resistor R_LOAD, N2 gate voltage (ON-Latch) and N4 gate voltage (OFF-Latch).

During first charging of the storage capacitor, both latching circuits are off. With voltage increase across storage capacitor, the N1 gate voltage increases with respect to resistive divider R1/R2. Once the N1 gate voltage reaches threshold voltage value, it triggers the ON-Latch (Turn-ON trigger). N1 pulls the P2 gate to the ground, hence turning the P2 on. This can be done only if

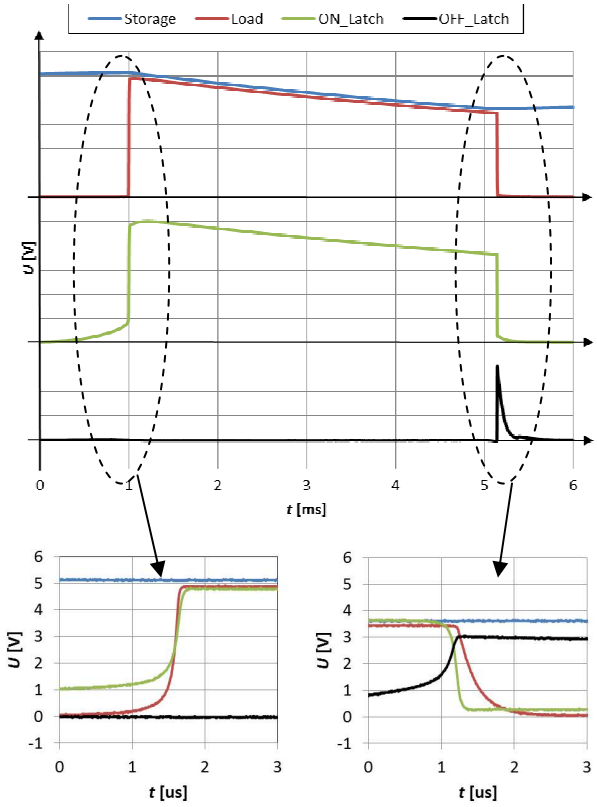

Figure 3. Energy management circuit waveforms

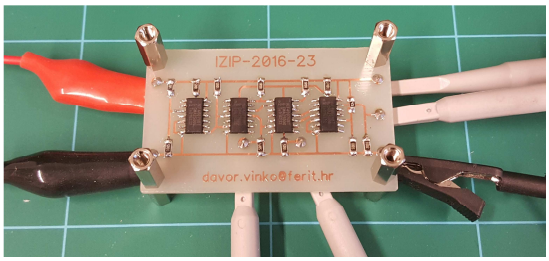

Figure 4. Energy management circuit prototype

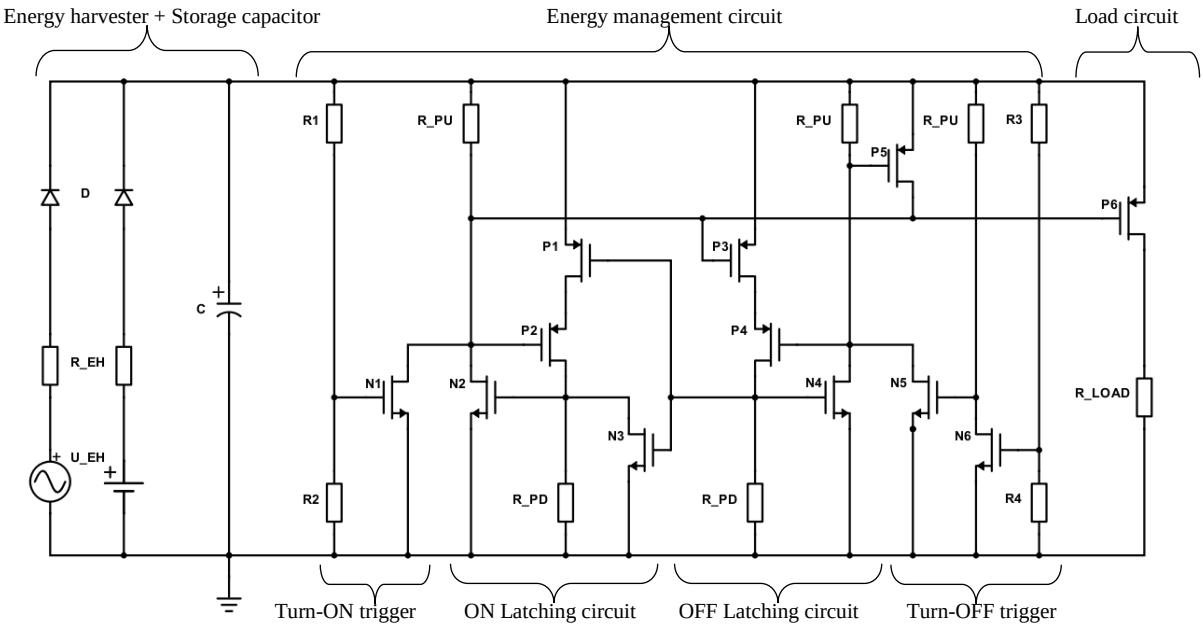

Figure 2. Energy management circuit with minimized switching time

P1 is on, what is ensured by the pull-down resistor at P1 gate. Then, P2 turns on N2, and they support each other in conduction. At the same time, P6 turns on the load circuit. With connected load, the voltage across storage capacitor starts to decrease, and the turn-ON trigger signal stops.

Fast switch-OFF of the load is achieved by OFF-Latch circuit (P4, N4). It activates only when the ON-Latch is active (P3 is on) and turn-OFF trigger activates. Turn-OFF trigger is adjusted by R3/R4 resistive divider which sets the N6 gate voltage. It is important to note that the N6 must turn-on at lower voltage than N1. When the voltage across storage capacitor drops, and the N6 turns off, N5 turns on (Turn-OFF trigger event) and pulls the P4 gate to the ground, hence turning the P4 on. P4 then turns N4 on, and they support each other in conduction.

OFF-Latch circuit turns on P5 and N3, which provide low resistance path for P2 and N2 gate discharge; hence it turns off both the load and the ON-Latch circuit in the shortest time possible. At the same time, the OFF-Latch gets disabled (P3 turns off), but P4 and N4 have high resistance path for their gate discharge, which prolongs their conduction enabling reliable and fast turn-OFF mechanism for load resistor R_LOAD.

Fig. 3 also gives zoomed-in view of the turn-ON and turn-OFF time interval. The measurements were done with 10 MΩ pull-up and pull-down resistors. For an energy management circuit with a single latching circuit, with 10 MΩ resistors, turn-OFF time was approximately 100 µs. With proposed design both turn-ON and turn-OFF time are under 500 ns. Prototype was tested with different values of pull-up and pull-down resistors and no significant difference in switching times was observed. The resistance of pull-up and pull-down resistors affects only the power consumption and the voltage threshold levels at which the energy management circuit turns on and off, which can be easily adjusted by resistive dividers R1/R2 and R3/R4.

The switching times are even faster when only ON-Latch is observed, with values under 100 ns, what correlates with transition time and propagation delay time for HEF4007 integrated circuit.

III. IC IMPLEMENTATION

The future work is the IC implementation. Proposed circuit is simulated in Cadence environment using IHP 0.25 µm SGB25v technology. Simulation results are given in Fig. 5. Simulated and measured waveforms are qualitatively the same. The main difference is duration of turn-ON and turn-OFF times, which are three orders of magnitude shorter compared to discrete realization. This is due to difference in technology used in simulations and measurement. Shorter switching time of IC solution is an additional benefit.

Simulation is done for different pull-up and pull-down resistors (ranging from 1 MΩ to 100 MΩ) and there is no significant difference in switching times. Using large resistors is not an issue for discrete realization, but it is not the best solution for the IC implementation. Therefore, a suitable current mirror structure will have to be developed.

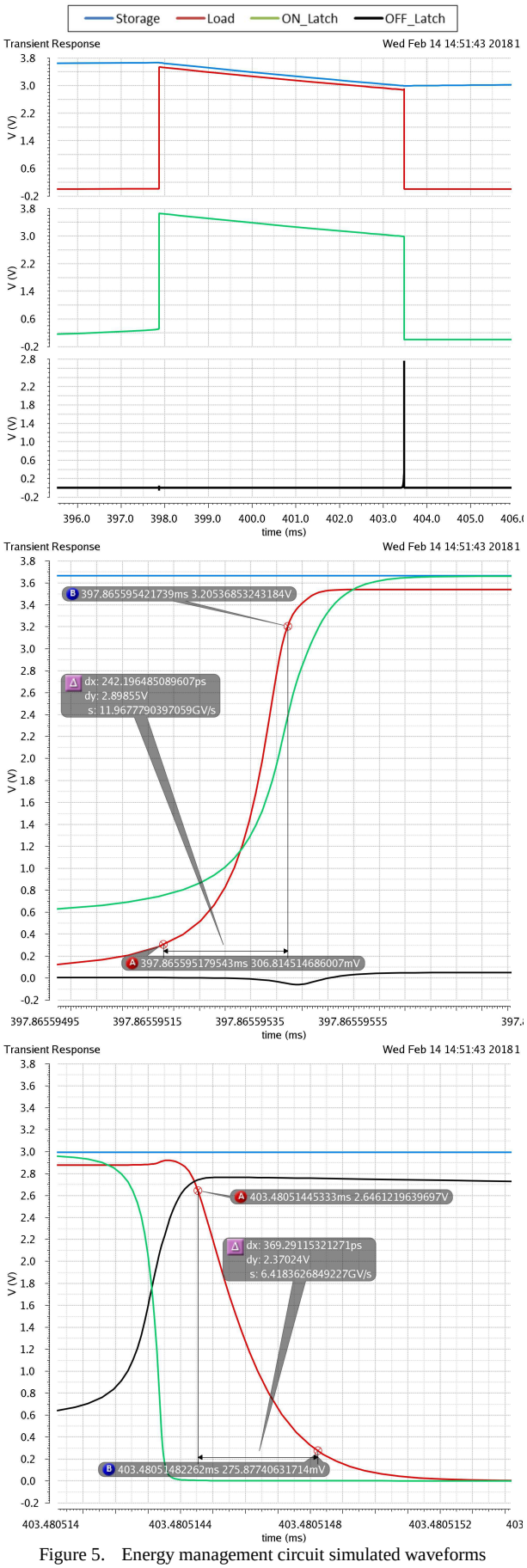

Figure 5. Energy management circuit simulated waveforms

IV. CONLUSION

Energy harvesting management circuit with minimized switching time is presented. Proposed design uses two latching circuits. This solved the trade-off between power consumption and switching time which was present in previous designs of energy management circuit. Switching time of the proposed design is dictated by transition time and propagation delay time of transistors. For discrete realization based on HEF4007 integrated circuit, measured switching times are under 500 ns, and simulations for IHP 0.25 µm SGB25v technology result in switching times under 500 ps.

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Driver for 3D-integrated nonlinear microring resonator-based optical modulators

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***Abstract* – This paper presents a driver circuit intended for optical modulators based on 3D-integrated ring resonators. The circuit was designed in a 0.35µm BiCMOS technology and the measurements are performed on the electrical test chip. The driver delivers 3-V voltage swing while consuming 160 mW at a data-rate of 10 Gb/s. The driver is suitable for NRZ binary as well as PAM-4 modulation formats.**

***Keywords* – driver; modulation; microring modulator; resonator; optical communications**

I. INTRODUCTION

Optical communication transmitters must use some form of modulation in order to encode a transmitting message. Various forms of modulation mechanisms are present, such as, for example, directly modulated vertical cavity surface emitting lasers (VCSEL) [1], or usage of Mach-Zehnder Modulator (MZM) [2] or microring modulator with continuous wave (CW) light source [3]. Microring modulators are good candidates to be included in integrated optical transmitters, since they are compact, consume little electrical power and are suitable for multi-channel communication links due to their small footprint (compared to MZMs). In this paper, we will present one topology of an electronic circuit which can be used to control the ring modulator.

The paper is organized as follows. Section II introduces the ring modulator and compares different schemes of connecting it to the electronic driving circuitry. Section III discusses the design and Section IV presents the electrical characterization of the ring modulator driver. State-of-the-art comparison is presented in Section V, whereas Section VI concludes the paper.

II. MICRORING MODULATOR

The structure of the ring modulator is sketched in Fig. 1a). An external CW laser source is injecting the light into the *in* terminal of the straight waveguide. The light component at one particular wavelength (being in resonance to the ring resonator) is then coupled into the ring-shaped waveguide structure, called (micro)ring modulator or (micro)ring resonator. After passing through the ring, this light is then coupled back into the straight waveguide and carried to the *through* port. The wavelength which can be coupled into the ring modulator

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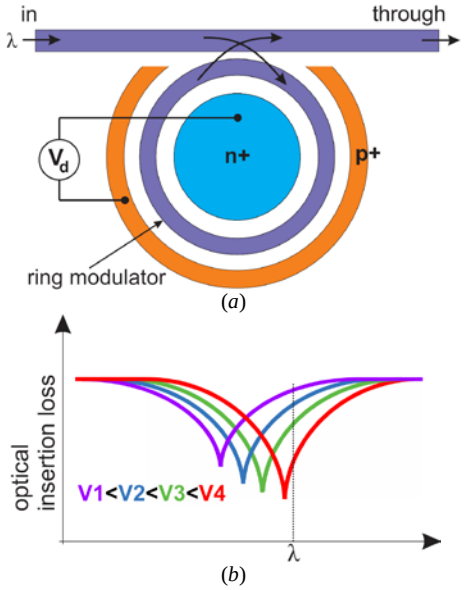

Figure 1. (a) Top view of the ring modulator with applied driving voltage V_d and (b) typical transfer characteristic

depends on its geometry. This wavelength is called the resonant wavelength. The equivalent electrical structure of the ring modulator is a PIN diode (N+ region inside of the ring and P+ outside of the ring with low doping (I-layer) in the ring waveguide).

By applying the driving voltage V_d, as shown in Fig. 1a), it is possible to control the level of attenuation of the light that will be coupled back to the straight waveguide. This is possible since the refractive index inside the ring is changed when V_d is applied. Change of the refractive index, in turn, results in the shift of the resonant wavelength [4]. If driving voltage V_d is keeping the ring modulator in the reverse bias, then the carrier depletion mechanism is occurring. Ring resonators modulated in forward bias are operating in the carrier injection regime, which is slower than the carrier depletion mode due to the limited minority carrier lifetime.

Fig. 1b) shows the typical transfer characteristic of the ring modulator in the carrier depletion mode, with the applied driving voltage as a parameter. If one particular wavelength is chosen for the communication, then the driving voltage V_d controls the intensity of the light coupled out of the ring, thus enabling the transmission of information. For example, if V_d switches between V_1 and V_4, optical output at wavelength λ switches between

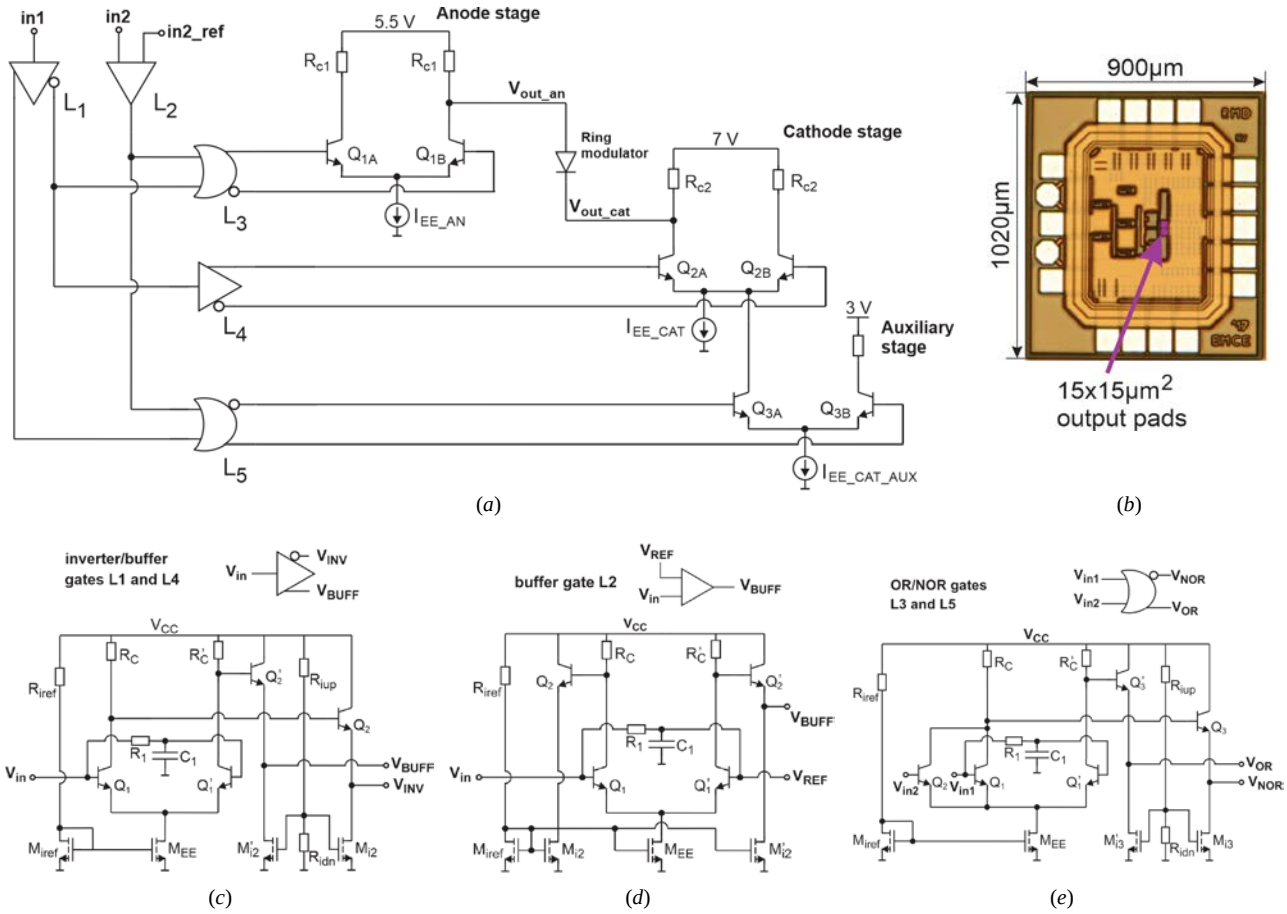

Figure 2. Schematic of the a) ring modulator driver; b) microphotograph of the fabricated chip; c), d), e) ECL logic gates

almost no attenuation and almost highest attenuation, as illustrated in Fig. 1b). This type of modulation is known as on-off keying, or binary non-return-to-zero (NRZ).

Apart from the NRZ binary modulation format, it is possible to employ a pulse amplitude modulation with four levels (PAM-4, in the literature also referred to as 4-PAM). With PAM-4, the circuit can have two times lower bandwidth for the same data rate. Both binary NRZ and modulation and PAM-4 will be used in this work.

Since the light from CW laser can consist of several wavelengths, it is possible to employ several modulators, each tuned to a different wavelength. This is the principle of the wavelength-division multiplex (WDM) where independent transmission via parallel communication channels is achieved [3].

III. Ring Modulator Driver

Ring modulator driver (RMD) is the electrical circuit whose output is the voltage V_d from Fig. 1a). There are more ways of connecting the driver with the ring modulator. They can be connected together via a bonding wire, which requires bonding pads on both chips. These pads increase the capacitive loading of the chip, typically for 50-70 fF per pad. Ring modulator can be monolithically integrated with its driving circuit. However, silicon with its bandgap energy of 1.1 eV is not suitable for optical components (as light emitter and detector) operating at standard communication wavelengths of 1.3 µm and 1.55 µm, whereas the other substrates, e.g. Ge, are not as cost effective as silicon. An alternative is a 3D integration, where the optical and electronic components are bonded together on a chip- or wafer-level, and connected using interconnection structures such as through-silicon vias [5] or inter-wafer connections [6], with low capacitive loading in the range of 7 fF to 15 fF. The ring modulator driver presented in this paper is designed to be 3D-integrated with a ring modulator.

Our previous works [6, 7] present two designs of NRZ/PAM-4 ring modulator driver. Paper [6] discusses a RMD whose output is designed to be connected to the cathode of the ring modulator, while the anode is connected to the constant supply voltage, keeping it in the reverse bias. DAC-like topology creates a voltage swing across the output resistance. The width of the output resistor needs to be relatively large in order to handle the large current flow. This large width is the reason for the large parasitic capacitance whose value was in the order of 130 fF for a 250-Ω resistor which delivers 3-V output swing. Therefore, the output RC constant produces a pole at approximately 5 GHz, which is the lower limit for the operation of the 10-Gb/s circuit.

In [7] we showed the circuit which can overcome this limitation by having two outputs, each of them handling one fraction of the total voltage swing. Output resistors, therefore, can be thinner and their parasitic capacitance smaller, increasing the speed of the ring modulator driver.

TABLE I. TRUTH TABLE OF THE RING MODULATOR DRIVER

in_1	in_2	V_{OUT_CAT}, V	V_{OUT_AN}, V	$V_{OUT} = V_{OUT_CAT} - V_{OUT_AN}$, V
„0“	„0“	$7 - R_{C2}\, I_{EE_CAT} - R_{C2}\, I_{EE_CAT_AUX} = 5.5$	5.5	5.5 – 5.5 = 0
„0“	„1“	$7 - R_{C2}\, I_{EE_CAT} = 6.2$	5.5	6.2 – 5.5 = 0.7
„1“	„1“	7	5.5	7 – 5.5 = 1.5
„1“	„0“	7	$5.5 - R_{C1}\, I_{EE_AN} = 4$	7 – 4 = 3

For PAM-4, *in2_ref* should remain unconnected, whereas it needs to be on the high value for NRZ binary modulation

One output should be connected to the modulator's cathode and another to the anode. The voltage across the ring modulator will then be the difference of the two output voltages (sum of magnitudes). When operating in PAM-4 regime, the largest output differential voltage is equal to the sum of the two smaller voltage levels. For optical output levels to be equidistant, ring modulator itself needs to meet the similar condition, i.e. its electrical-to-optical transfer characteristic needs to be linear. Specifically, if, at a certain wavelength, V_1, V_2 and V_3 are driving voltages which produce the optical output powers P_1, P_2 and P_3, respectively, then the following condition needs to be met:

$$\alpha V_1 + \beta V_2 = \gamma V_3 \;\Rightarrow\; \alpha P_1 + \beta P_2 = \gamma P_3, \qquad (1)$$

for real constants α, β and γ. It is evident, therefore, that the circuit from [7] cannot be used to drive nonlinear ring modulators with PAM-4 signals.

Fig. 2a) shows the circuit of the ring modulator driver which provides the faster rise- and fall-times by splitting the voltage swing among the two outputs as in [7], while at the same time overcomes the linearity restriction. The auxiliary stage from Fig. 2a) provides the additional voltage level at the cathode output, so that the circuit is not constrained to drive only the ring modulators whose transfer characteristic needs to satisfy condition (1).

This driver can perform PAM-4 as well as NRZ binary modulation of the ring modulator. The circuit's data-rate is 10 Gb/s in both modes of operation. Outputs V_{OUT_CAT} and V_{OUT_AN} are intended to connect to the ring modulator's cathode and anode terminal, respectively. The voltage difference $V_{OUT_CAT} - V_{OUT_AN}$ is equivalent to the driving voltage V_d from Fig. 1a). The total voltage swing is 3 V, whereas the outputs V_{OUT_AN} and V_{OUT_CAT} deliver 1.5 V each. The lowest pole stemming from the parasitic capacitance of the output resistor is located at 8.4 GHz. The circuit is designed and fabricated in a 0.35μm BiCMOS technology.

Input signals are first processed by the emitter-coupled logic (ECL) type logic gates L_1–L_5. Each of these gates has a structure of the differential amplifier with emitter followers at the outputs. Schematic of inverter/buffer gates L_1 and L_4 is shown in Fig. 2c). They have one high-speed input at the base of Q_1 and one RC circuit used to extract the DC value used as a reference at the base of Q_1'. Input voltage amplitude is 400 mV, and the difference between the input and the reference voltage is, therefore, 200 mV. This value is sufficient to steer the complete tail current from current sink M_{EE} to one branch of the differential structure with bipolar transistors. Buffer gate L_2 with the reference input is depicted in Fig. 2c). It has the V_{REF} pin and it gives only buffered output. Otherwise, its structure is the same as for the buffer/inverter gates. OR/NOR logic gates L_3 and L_5, shown in Fig. 2e), have two independent high speed inputs and the rest of the structure is similar to the buffer/inverter circuits.

Logic gates L_3-L_5 drive the output stages of the circuit, i.e. anode stage, cathode stage and auxiliary stage in Fig. 2a), respectively. Similarly to logic gates, output stages operate as switches as well. In other words, tail current of the anode stage, I_{EE_AN}, always flows completely either through Q_{1A} or Q_{1B}. Voltage V_{OUT_AN} then can take the value of anode stage's supply voltage, 5.5 V, or $5.5 - R_{C1}\, I_{EE_AN}$. Analog observations are valid for cathode- as well as the auxiliary stage.

Table I is the truth table which shows the appropriate conversion of the binary inputs to the PAM-4 output by the ECL-type logic gates. Signals are encoded using Gray code, where the change of one input signal can change the output PAM-4 signal only to an adjacent value.

When employing PAM-4, two binary inputs are necessary, denoted in_1 and in_2 in Table I and Fig. 2a). Pin in_{2_ref}, i.e. the V_{REF} input of the buffer gate L_2, should remain unconnected in the case of PAM-4 modulation. Both inputs should operate at 5 Gb/s, so that the output PAM-4 symbol rate is 5 Gbaud which is equivalent to the bit rate of 10 Gb/s.

According to Table I, when the circuit operates with NRZ binary modulation, highest output voltage swing is achieved when the in_1 terminal changes between low and high value, while the input in_2 remains at the low value. However, due to the R_1C_1 low-pass filter of the buffer L_2 shown in Fig. 2d), if in_2 is constant then the tail current generated by transistor M_{EE} would be split evenly between Q_1 and Q_1' of Fig. 2d). As a consequence, output V_{BUFF} would not be neither at is high nor at its low value. In order to force V_{BUFF} at the correct value, input pin in_{2_REF} should be accessed and be held at the appropriate value. When in_2 is low and in_{2_REF} high, tail current of M_{EE} will flow completely through Q_1, thereby V_{BUFF} at high value. If one 10-Gb/s data rate signal is then connected to the pin in_1, output signal delivered to the ring modulator will swing between 0 and 3 V at 10 Gb/s.

The microphotograph of the produced chip is depicted in Fig. 2b). Chip area is 0.92 mm^2. The input pads for high speed signals have the parasitic capacitance of approximately 70 fF per pad. Two small output pads (to the 3-D integrated ring modulator) are placed in the middle area of the chip. Their dimensions are 15x15 μm^2 and they are suitable for usual interconnection structures of 3D-integrated chips, such as through-silicon vias or inter-wafer connections.

IV. MEASUREMENT RESULTS

The circuit was experimentally characterized using GGB Industries Model 35 high-speed pico-probe to read the output voltage. Pico-probe has a 26-GHz bandwidth and a tenfold active attenuation. Its input resistance is 1.25 MΩ and shunt capacitance 50 fF. Maximum allowed voltage of the pico-probe is 6 V, so the power supply of the cathode stage (7V) from Fig. 2a) had to be lowered to 6V for rise/fall time and eye diagram measurements, to fulfill the pico-probe's operating requirements. Since the ring modulator was not present in the measurements, it was possible to reduce the power supply of the cathode stage, without changing the operating point of the anode stage. 40G SYMPULS bit pattern generator and Keysight 80-GSa/s real time oscilloscope were used for signal generation and acquisition. Pattern of the input signals was pseudo-random binary sequence whose length is 2^{31}-1 bits (PRBS31).

Fig. 3 shows the eye diagrams measured at the output pads. Since only one single-ended pico-probe was available, only single-ended eye diagrams were measured, separately for both outputs. Each measured eye diagram is attenuated ten times by the active pico-probe. Fig. 4 shows the post-layout simulation of the differential output eye diagrams for both modulation formats, binary and PAM-4, with both outputs loaded with 20 fF, which is a reasonable value for the 3D-integrated ring modulator.

Simulated and measured rise and fall times for both outputs are compared in Table II. Measured and simulated results of the anode output correspond well to each other. Rise and fall times of the cathode output are slightly worse in the measurements, due to the lower power supply than the nominal because of the pico-probe maximum voltage constraint. This led the transistors to enter sub-optimal operating points.

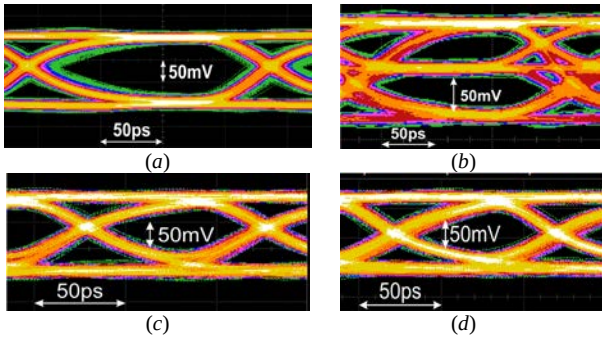

Figure 3. Measured eye diagrams: a) anode and b) cathode output for PAM-4, c) anode and d) cathode output for binary modulation. Each eye diagram is attenuated 10 times by the active pico-probe

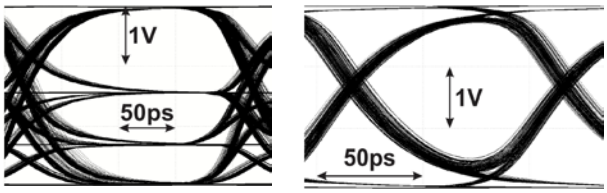

Figure 4. Simulated differential eye diagrams for a) PAM-4 and b) binary modulation, for the load capacitances of 20 fF

TABLE II. COMPARISON OF MEASURED AND SIMULATED RISE- AND FALL-TIMES

	C_L	V_{OUT_CAT}		V_{OUT_AN}		V_{OUT_DIFF}	
		t_R, ps	t_F, ps	t_R, ps	t_F, ps	t_R, ps	t_F, ps
Measured	50 fF	120	99	97	81	N.A.[a]	N.A.[a]
Post-layout simulation	50 fF	90	78	94	77	86	90
	20 fF	78	59	86	65	75	80

a. Only single-ended pico-probe was available for the measurements

V. STATE-OF-THE-ART COMPARISON

Table III shows the performance summary of some recently reported ring modulator drivers. Various connections of the driver with the ring modulator have been employed – wire-bonding, monolithic integration, as well as 3D integration. A wire-bonded RMD was reported in [8]. It employs only PAM-4 format and operates at 40 Gb/s with a 4.4-V differential voltage swing. Such a high voltage swing was achieved from 1.2 V supply voltage, by AC-coupling the electronic circuitry with appropriately biased ring modulator. In a 3D-integrated circuit, however, AC-coupling capacitors would need to be placed on chip, which would not be feasible due to the area constraints. Similar performance is reported in another wire-bonded topology that employs AC-coupling for high voltage swing [9], but with a lower power consumption of 113.5 mW at a lower data rate of 25 Gb/s. Paper [10] presented a wire-bonded NRZ/PAM-4 ring modulator driver produced in 40 nm CMOS capable of achieving 20 Gb/s. The authors of [11] report a RMD produced in 65 nm CMOS and monolithically integrated with the modulator, capable of both NRZ modulation and PAM-4 at 20 Gb/s and 40 Gb/s, respectively. Both ring modulator drivers [11, 12], therefore, have better performance than the circuit presented here. However, both are produced in technologies whose mask costs are much larger than for 0.35µm technology of our circuit. Paper [12] described another monolithically integrated ring-modulator-based transmitter in a 130 nm SOI technology. It operated only with NRZ modulation at 25 Gb/s, consuming 208 mW, which is more than our circuit consumes. A 3D-integrated ring modulator driver is reported in [13] and it has lower power consumption and faster data rate than our circuit, but it is produced in 28 nm CMOS technology and also employs only binary modulation. A 3D-integrated circuit from [14] is produced in 65 nm CMOS technology and its power consumption is only 0.6 mW. However, it achieves only 6 Gb/s data rate, and uses only NRZ modulation format. Our previous work [7] showed the ring modulator driver with the same voltage swing, modulation formats and data rate. However, as explained in Section III, it was not suitable for nonlinear ring modulators. The circuit did not have the need for the pre-driver logic conversion which drastically reduced its power consumption. The RMD from [6] had only one output, which led to increased width of the output resistor and thus increased parasitic capacitance.

TABLE III. COMPARISON WITH THE STATE-OF-THE-ART

Reference	Technology	Connection w/ modulator	Output voltage swing	Modulation type	Data rate	Power consumption (efficiency)
[8] MWSCAS '17	65 nm CMOS	Wire-bonding	4.4 V_{diff}	PAM-4	40 Gb/s	175.2 mW (4.38 pJ/bit)
[9] JSSC'15	65 nm CMOS	Wire-bonding	4.4 V_{diff}	NRZ binary	25 Gb/s	113.5 mW (4.5 pJ/bit)
[10] ISSCC'13	40 nm CMOS	Wire-bonding	551 µW [a]	NRZ binary	20 Gb/s	90 mW (4.5 pJ/bit)
			893 µW [a]	PAM-4		5.8 mW (290 fJ/bit)
[11] ISSCC '17	65 nm CMOS	Monolithic	1.55 V	NRZ binary	20 Gb/s	3.1 mW (155 fJ/bit)
				PAM-4	40 Gb/s	1.68 mW (42 fJ/bit)
[12] JSSC'12	130 nm SOI	Monolithic	2 V_{diff}	NRZ binary	25 Gb/s	207 mW (8.28 pJ/bit)
[13] ISSCC'15	28 nm CMOS	3D	240 mV_{diff}	NRZ binary	25 Gb/s	72.5 mW (2.9 pJ/bit)
[14] ESSCIRC'15	65 nm CMOS	3D	1.2 V	NRZ binary	6 Gb/s	0.6 mW (100 fJ/bit)
[7] Austrochip '15	0.35 µm BiCMOS	3D	3 V	NRZ binary / PAM-4	10 Gb/s	59 mW (5.9 pJ/bit)
[6] JSTQE '16	0.35 µm BiCMOS	3D	3 V	NRZ binary / PAM-4	10 Gb/s	160 mW (16 pJ/bit)
This work	0.35 µm BiCMOS	3D	3 V	NRZ binary / PAM-4	10 Gb/s	160 mW (16 pJ/bit)

a. Reported optical output

VI. CONCLUSION

This paper presents a ring modulator driver designed to be 3D integrated with the optical ring modulator. An electrical test chip was fabricated and experimentally verified. It can operate with NRZ binary as well as PAM-4 modulation, both at 10 Gb/s. Circuits in nanometer-scale technologies have reported larger data rates, up to 40 Gb/s for PAM-4. However, our circuit is produced in a standard 0.35 µm BiCMOS technology with much lower mask cost, which allows fabrication of ASICs in low production volumes. Wire-bonded nanometer-CMOS drivers achieved a larger voltage swing at the modulator, however, only by using ac-coupling with large capacitors, which cannot be 3D integrated. In addition, the presented driver delivers a higher voltage swing than reported monolithic and other 3D integrated drivers, which enables a larger extinction ratio. Furthermore, the suggested driver can compensate the nonlinearity of the ring modulator transfer characteristic, while consuming 160 mW.

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10-MSymbols/s QAM-16 Externally-Modulated Optical Link for Radio-Over-Fiber Applications

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***Abstract*—In baseband optical communications, information is encoded in the modulated intensity of light propagating over singlemode optical fiber. In radio communications, information is encoded in the phase and amplitude modulation of a signal oscillating at the carrier frequency. This type of modulation can also be employed in optics by creating an intensity modulated beam oscillating a carrier frequency and then modulating the amplitude and phase of this carrier. This paper discusses a preliminary investigation this technology with aim to ultimately apply it to incoherent-light communications by investigating the linearity of a Mach-Zendher optical modulator and an optical link involving QAM-16 modulation over 20-km of singlemode fiber. The conclusion of this work is that without linearization and higher optical power, the system is limited to less than 35 dBc in $ACLR$ and bit-error rate at $< 10^{-3}$.**

***Index Terms*—optical modulation, microwave photonics, radio-over-fiber, linearity.**

I. Introduction

RF over fiber is a new technology in which light is modulated by a radio frequency signal and transmitted over an optical fiber link [1], [2], [3], [4]. The advantages of this approach are low transmission losses and reduced sensitivity to noise and electromagnetic interference compared to all-electrical signal transmission. This technology is explored for use in mobile networks, cable television signals (CATV), and ground stations for satellite communications.

Presently, RF over fiber is being explored at microwave frequencies using external modulators and directly modulated lasers. This is a preliminary study aimed at applying this technology to communications employing incoherent, spectrally-sliced light. In particular, based on previous work [5], there is an opportunity to realize inexpensive medium distance (20 km) links between base-stations or microwave backhaul using incoherent light. Incoherent-light communications however, are limited by thermal noise [6] and this is a first attempt to explore the baseline properties of this system at 1 GHz using coherent light. To this end, the linearity of a MZ modulation was investigated and 20-km transmission of QAM-16 was demonstrated with better than $10^{-}3$ bit-error ratio.

II. Mach-Zehnder modulator characteristics

In order to efficiently embed amplitude and phase modulation into the carrier intensity modulated light, one requires electrical to optical conversion with high degree of linearity. Bandpass modulation schemes, such as, quadrature-amplitude modulation (QAM) of with symbols that carry multiple bits of information per symbol are very sensitive to linearity as any deviations directly impact the error-vector magnitude (EVM) at the receiver. The requirement for linearity is further enforced by adjacent and alternate channel leakage which is enhanced when odd-order nonlinearity appears in the transmission path. A Mach-Zehnder modulator (MZ) has a sinusoidal transfer characteristic and its ability to operate with minimal even and odd-order harmonics is determined by the operating point and the amplitude of the RF signal around that operating point. In this work, the harmonic content and achievable modulation depth in the optical domain of a commercial MZ modulator was characterized in order to define the useful operating range for QAM modulation.

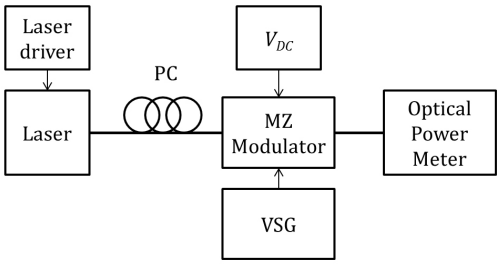

Fig. 1. Characterization setup for measuring the transmission through the Mach-Zehnder optical modulator as a function of DC voltage V_{DC} and by modulation from a vector-signal generator (VSG) using a single-mode 1550-nm DFB and the optical power was detected using an optical power meter. The entire system was computer controlled.

A commercial Mach-Zehnder modulator was selected [7] and characterized its electrical-to-optical conversion by varying the operating point using a separate DC voltage source with voltage V_{DC} and using a sinusoidal RF drive of frequency 1 GHz. Continuous-wave (CW) light emission was provided by a 1550-nm distributed-feedback laser (DFB) [8] that was controlled using a commercial laser driver [9]. The characterization setup is shown in Figure 1. The MZ modulator was coupled to the laser through a manual three-paddle polarization controller (PC) which was adjusted to provide maximum transmission at the start of the experiment. The output from the MZ modulator was coupled to an optical power meter from which the reading of average optical power was made by a remote computer.

During continuous-wave (CW) measurement, the bias on the MZ modulator V_{DC} was varied in 0.2 V steps from -8 to +8 V in order to determine the entire control curve.

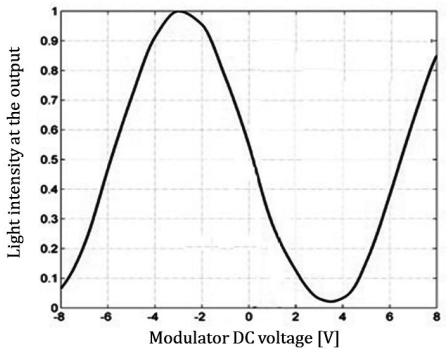

Fig. 2. Transmission through MZ modulator as a function of modulator bias voltage V_{DC}

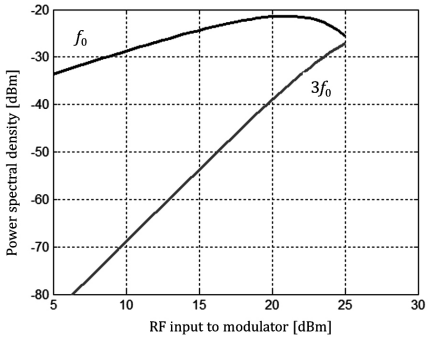

Fig. 3. Computed output power spectral density based on Figure 1 assuming the transfer function is sinusoidal and the V_{DC} = 0, which eliminates the second harmonic.

The value of $V_\pi \approx 6$ V was estimated from the results shown in Figure 2.

The linearity of the MY modulator was investigated by modulating the RF input to the modulator using a single 1 GHz tone from the vector signal generator (VSG) whose amplitude was varied between -7 dBm to +25 dBm (as shown in Figure 1). As the RF power input to the MZ modulation was varied, the fundamental (f_1) and two higher harmonics (f_2 and f_3) in the detected signal were monitored. The control voltage V_{DC} was adjusted to reach highest ratio between first and third harmonic. The primary concern was the magnitude of the third harmonic as odd harmonics are most responsible for spectral regrowth around the useful signal. The second harmonic is expected to play a minor role. The optical signal coming out of the modulator can be described as

$$P(t) = \bar{P} \cdot f(t) \tag{1}$$

where $\bar{P}$ is the average optical power and

$$f(t) = 1 + m_1 \sin(\omega t) + m_2 \sin(2\omega t) + m_3 \sin(3\omega t) \tag{2}$$

It is possible to compute the general shape of the power spectral density by inserting sinusoidal RF drive signal into the sinusoidal transfer function of the MZ modulator deduced from Figure 1. This is shown in Figure 3. The general shape matches well the measured curves shown in Figure 4, but without the small contribution from the second harmonic which is absent from the computation. It is not clear why the measured third harmonic is 6 dB lower than the theoretical value. The graphs labeled f_0, $2f_0$ and $3f_0$ in Figure 4 show harmonic powers P_i ($i = 1, 2, 3$) which are related to the modulation coefficients m_i as $P_i/\bar{P}$ = $20 \log_{10} m_i$. Here m_1 is the modulation depth, which is approximately given by the extinction ratio $ER \equiv P_{max}/P_{min}$ as $m_1 = (ER-1)/(ER+1)$. Nevertheless, the measurements shown in Figure 4 illustrate that the present configuration provides third harmonic suppression limited to about 35 dBc, which would result in a similar ACLR value.

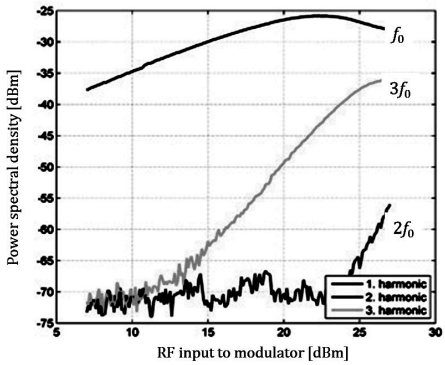

Fig. 4. Spectral content of the modulator output: three lowest harmonics are shown

III. QAM-16 MODULATED STREAM

The quality of QAM-16 transmission was investigated using the test setup shown in Figure 5, where the same DFB laser and MZ modulator were employed as in the first experiment. The optical signal is detected using a high-speed DC-coupled and amplified optical detector and digitally demodulated using a vector signal analyzer (VSA). The symbol rate was set to 10 MS/s, and sequences of 500 symbols with 15 symbol synchronization pattern were used. The VSA was used to determine the error-vector magnitude (EVM). Figure 6 illustrates the position of QAM-16 symbols and an example of received symbols.

DC bias voltage on the modulator was varied between -1 V and 3 V and the best performance was determined. Root-mean-square EVM values were noted as a function of the modulator RF drive. Back-to-back results are shown in Figure 7 and data after 20-km propagation in Figure 8. The back-to-back EVM measurement shows a wide range of modulator RF input power for which the EVM is below 10 % and equivalent to $BER < 10^{-3}$. The fast increase at higher modulator RF input powers comes from signal distortion. The 20-km measurement, on the other hand, shows significantly larger impact of receiver noise at lower modulator RF input powers and only a small region of modulator RF input power giving less than 10 % EVM. Temporal snapshot of the real and imaginary parts error-vector are illustrated in Figure 9. We also experimented with QPSK and QAM-64 modulations and obtained similar results.

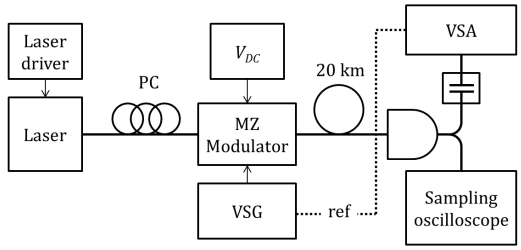

Fig. 5. Characterization setup for evaluating the transmission of QAM-16 modulated optical signal.

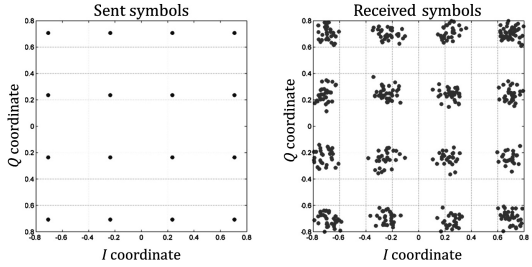

Fig. 6. Sent and received symbols for back-to-back measurement of QAM61 transmission

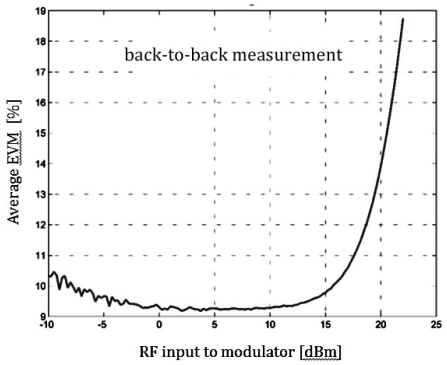

Fig. 7. Root-mean-square error-vector magnitude (EVM) for back-to-back measurement.

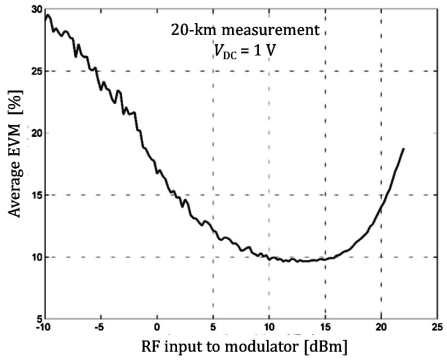

Fig. 8. Root-mean-square error-vector magnitude (EVM) measured using 20-km of singlemode fiber.

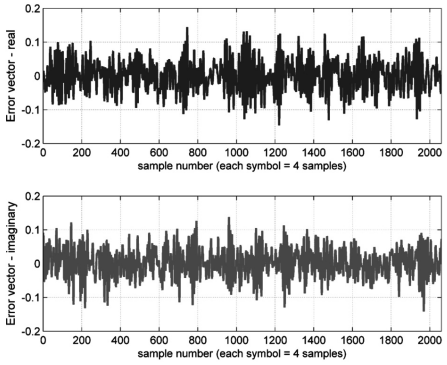

Fig. 9. Illustration of the temporal error-vector fluctuation, the average is below 10%.

IV. Conclusion

This preliminary study indicates a number of areas that require further investigation. The modulator drive exhibits conflicting requirements: high linearity is achieved with low modulator RF drive (< 10 dBm) which is required for low adjacent channel leakage, while noise requires higher modulator RF drive. The conditions obtained for lowest EVM and BER actually result in high channel leakage. The 6-dB difference between theoretical and measured third-harmonic intensity shown in Figures 3 and 4 is not entirely clear, while the large receiver noise is caused by insufficient link budget. It is clear that linearization of the modulator drive will be needed and that substantially high laser output power should be used to reduce the effects of noise. Nevertheless, transmission of QAM-16 modulated with 10 MS/s symbol rate over 20 km has been successfully demonstrated and this system will be further optimized for use with spectrally-sliced incoherent light.

V. Acknowledgement

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BEST PAPER AWARD

Sharpened Raised-Cosine FIR Filters

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***Abstract*—Shaping of transition bands in the ideal frequency response allows the analytic design of least-squares FIR filters with a direct control of the transition-band edges. The basic least-squares approximation is obtained by the Fourier series method. In this paper, we use it to develop a straightforward method for the design of steep roll-off FIR filters. The method is based on the frequency response obtained by the polynomial sharpening of raised-cosine transition band. The corresponding impulse response is well localized in time, what enables the design of low-order filters without additional window. Apparently, such an approach is suitable for the design of filters with wide transitions. However, for the design of filters with narrow transitions, composite systems are more appropriate. A computationally efficient composite system is frequency-response-masking (FRM) filter. Therefore, to obtain narrow transition filters the sharpened raised-cosine filters are incorporated into the FRM structure. The features of the presented single and composite filters are illustrated by examples which include the design of spatial filters and Hilbert transformers.**

I. Introduction

Polynomial sharpening is an efficient technique for improving the amplitude response of symmetric finite-impulse-response (FIR) filters. Depending on the application at hand, the sharpening can be applied to the entire amplitude response or to a specific part of the response. The sharpening was introduced by Kaiser and Hamming [1]. Later, a generalization of the Kaiser-Hamming sharpening was proposed by Samadi [2]. Nowadays, the original and generalized sharpening are mostly used in the design of FIR filters for decimation [3]−[5]. However, for this purpose the optimum sharpening can also be found [6], [7].

The sharpening is suitable for the design of sharp filters. However, for the design of very sharp FIR filters composite systems are preferable. A computationally efficient technique for their design is the frequency-response masking (FRM) proposed by Lim [8]. The FRM filters proved very efficient in the synthesis of many signal processing systems including half-band filters [9], Hilbert transformers [10], [11], decimators and interpolators [12], [13], filter banks [14], and spatial filters [15].

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Despite many efficient techniques for the design of FIR filters, we found the Fourier series method suitable for the design of sharp filters. In this paper, we use it to develop a method for the design of steep roll-off FIR filters. The method is based on the polynomial sharpening of raised-cosine amplitude response. Such shaped amplitude ensures well-localized impulse response, what enables the design of low order filters without additional window. Furthermore, it enables an explicit control of the transition-band edges. On the other hand, the impulse response is given in a closed-form expression, thus ensuring fast and robust design. However, such an approach is suitable for the design of filters with wide transition bands. To obtain filters with narrow transitions, we incorporate the sharpened raised-cosine filters into the frequency-response masking structure.

Recently, the FIR filters with raised-cosine transitions have been proposed [16]. However, the raised-cosine response is only a special case of the sharpened raised-cosine response. Therefore, the proposed approach can be considered as a generalization of the raised-cosine shaping.

II. Sharpened Raised-Cosine Amplitude Response

A. Raised-Cosine Lowpass Response

The frequency response of the ideal raised-cosine lowpass filter with transition at $\omega_p < |\omega| < \omega_s$ is given by [16]

$$H_{RC}(\omega) = \begin{cases} A_{RC}(\omega) e^{j(\varphi - D\omega)} & , \; -\pi \le \omega < 0 \\ A_{RC}(\omega) e^{-j(\varphi + D\omega)} & , \; 0 \le \omega < \pi \end{cases} \tag{1}$$

where φ is a phase shift, D is a delay, and $A_{RC}(\omega)$ is the raised-cosine amplitude response having the form

$$A_{RC}(\omega) = \begin{cases} 1 & , \; 0 \le |\omega| \le \omega_p \\ \frac{1}{2} + \frac{1}{2}\cos\left(\pi \frac{|\omega| - \omega_p}{\omega_s - \omega_p} \right) & , \; \omega_p < |\omega| < \omega_s \\ 0 & , \; \text{otherwise} \end{cases} \tag{2}$$

The value of phase shift determines the type of FIR filters. Linear-phase filters are obtained by setting $\varphi = 0$ or $\varphi = \pi/2$. Apparently, symmetric filters have $\varphi = 0$, and conventional Hilbert transformers $\varphi = \pi/2$. On the other hand, fractional Hilbert transformers have the shift which takes a value from the interval $0 < \varphi < \pi/2$.

B. Sharpened Lowpass Response

The sharpening polynomial of order M is given by

$$f(x) = \sum_{m=1}^{M} a_m x^m \tag{3}$$

By substituting $x = A_{RC}(\omega)$ into (3), we obtain the sharpened raised-cosine amplitude response. It is given by

$$A_{LP}(\omega, \mathbf{a}) = \sum_{m=1}^{M} a_m A_{RC}^m(\omega) \tag{4}$$

where $\mathbf{a}$ is the vector of polynomial coefficients given by $\mathbf{a} = [a_1, a_2, ..., a_M]$. Using (2) and assuming $f(1) = 1$ and $f(0) = 0$, the sharpened response takes the form

$$A_{LP}(\omega, \mathbf{a}) = \begin{cases} 1 & , \ 0 \le |\omega| \le \omega_p \\ \sum_{m=1}^{M} a_m A_{RC}^m(\omega) & , \ \omega_p < |\omega| < \omega_s \\ 0 & , \ \text{otherwise} \end{cases} \tag{5}$$

The raised-cosine response in (2) can be written in a more compact form in the transition band, as in

$$A_{RC}(\omega) = \begin{cases} 1 & , \ 0 \le |\omega| \le \omega_p \\ \cos^2\left(\frac{\pi}{2}\frac{|\omega| - \omega_p}{\omega_s - \omega_p}\right) & , \ \omega_p < |\omega| < \omega_s \\ 0 & , \ \text{otherwise} \end{cases} \tag{6}$$

By substituting (6) into (5), we arrive at

$$A_{LP}(\omega, \mathbf{a}) = \begin{cases} 1 & , \ 0 \le |\omega| \le \omega_p \\ \sum_{m=1}^{M} a_m \cos^{2m}\left(\frac{\pi}{2}\frac{|\omega| - \omega_p}{\omega_s - \omega_p}\right) & , \ \omega_p < |\omega| < \omega_s \\ 0 & , \ \text{otherwise} \end{cases} \tag{7}$$

The even power of cosine is given by

$$\cos^{2m}(x) = \frac{1}{2^{2m}}\binom{2m}{m} + \frac{2}{2^{2m}}\sum_{k=0}^{m-1}\binom{2m}{k}\cos[2(m-k)x] \tag{8}$$

By substituting (8) into (7), $A_{LP}(\omega, \mathbf{a})$ takes the form given in (9).

Based on (1), the frequency response of the ideal sharpened lowpass filter is given by

$$H_{LP}(\omega, \mathbf{a}) = \begin{cases} A_{LP}(\omega, \mathbf{a}) e^{j(\varphi - D\omega)} & , \ -\pi \le \omega < 0 \\ A_{LP}(\omega, \mathbf{a}) e^{-j(\varphi + D\omega)} & , \ 0 \le \omega < \pi \end{cases} \tag{10}$$

The impulse response is obtained by applying the inverse discrete-time Fourier transform, as in

$$h_{LP}(n) = \frac{1}{2\pi}\int_{-\pi}^{\pi} H_{LP}(\omega, \mathbf{a}) e^{j\omega n} d\omega \tag{11}$$

Solving the integral, the impulse response is obtained as

$$h_{LP}(n) = \begin{cases} \frac{\cos\varphi}{\pi}\left[\omega_p + (\omega_s - \omega_p)\sum_{m=1}^{M}\frac{a_m}{2^{2m}}\binom{2m}{m}\right] & , \ n = D \\ \text{in (13)} & , \ n \ne D \end{cases} \tag{12}$$

C. Sharpened Bandpass Response

Let us now consider the bandpass filter with passband $\omega_2 \le |\omega| \le \omega_3$, which is sharpened with $f(x)$ within transition bands $\omega_1 < |\omega| < \omega_2$ and $\omega_3 < |\omega| < \omega_4$, where $0 \le \omega_1 < \omega_2 \le \omega_3 < \omega_4 \le \pi$. Its frequency response can be expressed as

$$H_{BP}(\omega, \mathbf{a}_2) = H_{LP2}(\omega, \mathbf{a}_2) - H_{LP1}(\omega, \mathbf{a}_1) \tag{14}$$

where $H_{LP1}(\omega, \mathbf{a}_1)$ and $H_{LP2}(\omega, \mathbf{a}_2)$ are the lowpass frequency responses with transition bands $\omega_1 < |\omega| < \omega_2$ and $\omega_3 < |\omega| < \omega_4$, and $\mathbf{a}_1$ and $\mathbf{a}_2$ are the vectors of coefficients of polynomials $1 - f(1 - x)$ and $f(x)$. The impulse response of the bandpass filter is then obtained as the linear combination of two lowpass responses

$$h_{BP}(n) = h_{LP2}(n) - h_{LP1}(n) \tag{15}$$

where $h_{LP1}(n)$ and $h_{LP2}(n)$ correspond to $H_{LP1}(\omega, \mathbf{a}_1)$ and $H_{LP2}(\omega, \mathbf{a}_2)$.

It is clear from (13) and (15) that bandpass response does not contain component $\sin\varphi / \pi / (n - D)$. Since this

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$$A_{LP}(\omega, \mathbf{a}) = \begin{cases} 1 & , \ 0 \le |\omega| \le \omega_p \\ \sum_{m=1}^{M}\frac{a_m}{2^{2m}}\binom{2m}{m} + 2\sum_{m=1}^{M}\frac{a_m}{2^{2m}}\sum_{k=0}^{m-1}\binom{2m}{k}\cos\left[(m-k)\pi\frac{|\omega| - \omega_p}{\omega_s - \omega_p}\right] & , \ \omega_p < |\omega| < \omega_s \\ 0 & , \ \text{otherwise} \end{cases} \tag{9}$$

$$h_{LP}(n) = \frac{\sin\varphi}{\pi(n-D)} + \frac{\sin[\omega_p(n-D) - \varphi]}{\pi(n-D)} + \frac{\sin[\omega_s(n-D) - \varphi] - \sin[\omega_p(n-D) - \varphi]}{\pi(n-D)}\sum_{m=1}^{M}\frac{a_m}{2^{2m}}\binom{2m}{m} +$$

$$\frac{2}{\pi(n-D)}\sum_{m=1}^{M}\frac{a_m}{2^{2m}}\sum_{k=0}^{m-1}\binom{2m}{k}\cdot\begin{cases} \dfrac{(-1)^{m-k}\sin[\omega_s(n-D) - \varphi] - \sin[\omega_p(n-D) - \varphi]}{1 - \left[\dfrac{(m-k)\pi}{(\omega_s - \omega_p)(n-D)}\right]^2} & ; \ n \ne D \pm \dfrac{(m-k)\pi}{\omega_s - \omega_p} \\ (-1)^{\frac{m-k-1}{2}}\dfrac{(m-k)\pi}{2}\sin\left[\dfrac{\omega_p + \omega_s}{2}(n-D) - \varphi\right] & , \ m-k \text{ odd} \\ \pm(-1)^{\frac{m-k}{2}}\dfrac{(m-k)\pi}{2}\cos\left[\dfrac{\omega_p + \omega_s}{2}(n-D) - \varphi\right] & , \ m-k \text{ even} \end{cases} \quad ; \ n = D \pm \frac{(m-k)\pi}{\omega_s - \omega_p} \tag{13}$$

component has slowly decreasing tails, the bandpass response is better localized in time than the corresponding lowpass responses.

D. Sharpened Highpass Response

The frequency response of the highpass filter can be easily derived from the bandpass response in (14). Namely, the highpass response sharpened with $f(x)$ within transition band $\omega_1 < |\omega| < \omega_2$ is obtained by setting $\omega_3 = \omega_4 = \pi$ and $\mathbf{a}_2 = \mathbf{0}$ in $H_{LP2}(\omega, \mathbf{a}_2)$. The highpass response thus takes the form

$$H_{HP}(\omega, \mathbf{a}_2) = H_{LP2}(\omega, \mathbf{0}) - H_{LP1}(\omega, \mathbf{a}_1) \tag{16}$$

The corresponding impulse response is given by

$$h_{HP}(n) = h_{LP2}(n) - h_{LP1}(n) \tag{17}$$

where $h_{LP2}(n)$ corresponds to the fractional Hilbert transform of the delta function. It is given by [17]

$$h_{LP2}(n) = \begin{cases} \cos\varphi & , \quad n = D \\ \dfrac{2\sin^2\left[\dfrac{\pi(n-D)}{2}\right]}{\pi(n-D)}\sin\varphi & , \quad n \neq D \end{cases} \tag{18}$$

III. Sharpening Polynomials

In [1], Kaiser and Hamming constructed the polynomial which has a pth-order tangency at $x = 1$, qth-order tangency at $x = 0$, and passes through the points (1, 1) and (0, 0). Their polynomial is given by

$$f_{p,q}(x) = x^{q+1}\sum_{r=0}^{p}\frac{(q+r)!}{q!r!}(1-x)^r \tag{19}$$

where $p + q = M - 1$.

A generalization of the Kaiser-Hamming polynomial was proposed by Samadi in [2]. In the paper referred to, Samadi constructed the polynomial having a pth-order tangency to the line $y = 1 - \sigma(1 - x)$ at $x = 1$ and qth-order tangency to the line $y = \delta x$ at $x = 0$. The Samadi polynomial is given by

$$f_{p,q,\sigma,\delta}(x) = \delta x + \sum_{m=q+1}^{M}(b_{m,0} - \sigma b_{m,1} - \delta b_{m,2})x^m \tag{20}$$

where

$$b_{m,0} = b_{m,1} + b_{m,2} \tag{21}$$

$$b_{m,1} = \sum_{n=q+1}^{m}(-1)^{m-n}\binom{M}{m}\binom{m}{n}\left(1 - \frac{n}{M}\right) \tag{22}$$

$$b_{m,2} = \sum_{n=q+1}^{m}(-1)^{m-n}\binom{M}{m}\binom{m}{n}\frac{n}{M} \tag{23}$$

In this generalization the Kaiser-Hamming polynomial is obtained by setting $\sigma = 0$ and $\delta = 0$.

Finally, we give a property of the Samadi, and, consequently, the Kaiser-Hamming polynomial, which is useful in the design of sharpened filters. Namely, it can be shown that the Samadi polynomials satisfy the equality

$$f_{p,q,\sigma,\delta}(1-x) + f_{q,p,\delta,\sigma}(x) = 1 \tag{24}$$

From (24) it follows that if $f(x) = f_{p,q,\sigma,\delta}(x)$ then $1 - f(1 - x) = f_{q,p,\delta,\sigma}(x)$. Therefore, $\mathbf{a}_1$ and $\mathbf{a}_2$ used in (14) and (16) contain the coefficients of $f_{q,p,\delta,\sigma}(x)$ and $f_{p,q,\sigma,\delta}(x)$.

IV. Design of Sharpened FIR Filters

The transfer function of a sharpened raised-cosine FIR filter of the Nth order is given by

$$H_{SRC}(z) = \sum_{n=0}^{N} h_{SRC}(n)z^{-n} \tag{25}$$

where $h_{SRC}(n)$ is filter's impulse response. By applying the Fourier series method, $h_{SRC}(n)$ is obtained by the truncation of $h_{LP}(n)$, $h_{BP}(n)$, or $h_{HP}(n)$. To ensure $h_{SRC}(n)$ is the best approximation, these responses must be calculated for $D = N / 2$. The impulse response of the lowpass filter is then obtained as

$$h_{SRC}(n) = h_{LP}(n) \quad ; \quad n=0, 1, ..., N \tag{26}$$

The same truncation, but applied to $h_{BP}(n)$ or $h_{HP}(n)$, is used for the design of bandpass or highpass filters.

The transfer function in (25) is suitable for the design of filters with wide transition bands. However, to obtain filters with narrow transition bands, we incorporate the sharpened raised-cosine filters into the frequency-response-masking structure.

For convenience, we summarize the FRM technique for the design of linear-phase FIR filters. The transfer function of the symmetric FRM filter is expressed as [8]

$$H(z) = H_a(z^R)H_{ma}(z) + H_c(z^R)H_{mc}(z) \tag{27}$$

where R is a nonnegative integer representing the frequency scaling factor, $H_a(z)$ is a prototype filter, $H_c(z)$ is the complementary filter of $H_a(z)$, and $H_{ma}(z)$ and $H_{mc}(z)$ are masking filters which process passbands of the periodic filters $H_a(z^R)$ and $H_c(z^R)$. For the given $H_a(z)$, the complementary filter is obtained as

$$H_c(z) = z^{-D} - H_a(z) \tag{28}$$

where D is the delay of $H_a(z)$.

The realization of the FRM filter is shown in Figure 1. In this structure, $H_a(z^R)$ is derived from $H_a(z)$ by substituting each delay element by R delay elements. In addition, to avoid a half-sample delay in implementing z^{-DR} the order of $H_a(z)$, N_a, and factor R should be selected such that $N_a R$ is even. Furthermore, the delays of branches with $H_{ma}(z)$ and $H_{mc}(z)$ must be the same. If the orders of $H_{ma}(z)$ and $H_{mc}(z)$ are N_{ma} and N_{mc}, a half of the absolute difference between N_{ma} and N_{mc} must be added as the delay in the branch with lower delay. In addition, to avoid a half-sample delay, the parity of N_{ma} and N_{mc} must be the same.

The transfer function in (27) is suitable for the design of filters with wide passbands. However, in the design of narrowband filters, a special case of this function is used. The narrowband FRM filter with transition at $\omega_p < |\omega| < \omega_s$ is given by

$$H(z) = H_a(z^R)H_{ma}(z) \tag{29}$$

where $H_a(z)$ and $H_{ma}(z)$ have the transitions at $R\omega_p < |\omega| < R\omega_s$ and $\omega_p < |\omega| < 2\pi / R - \omega_p$, respectively.

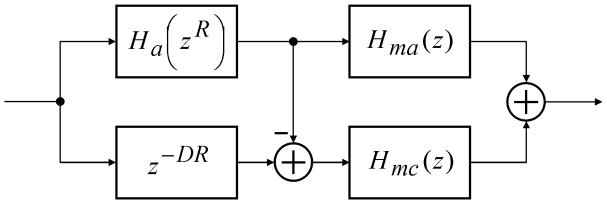

Figure 1. Realization of symmetric FIR filter using frequency-response masking technique [8].

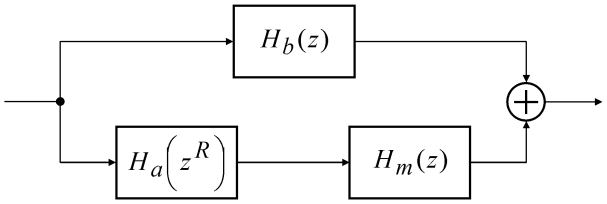

Figure 2. Realization of FIR conventional Hilbert transformer using frequency-response masking technique [11].

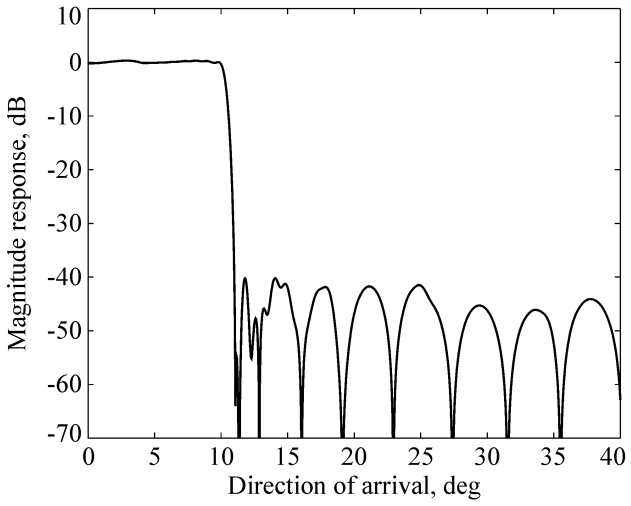

Figure 3. Wideband beampattern with $\theta_p = 10°$ and $\theta_s = 11°$, obtained by frequency-response-masking structure containing sharpened raised-cosine filters.

The FRM technique for the design of conventional Hilbert transformers has another form. The transfer function of the FRM transformer is given by [11]

$$H(z) = H_b(z) + H_a(z^R) H_m(z) \tag{30}$$

where $H_b(z)$ is a low-order basic Hilbert transformer, $H_a(z)$ is a prototype filter, and $H_m(z)$ is a low-order masking filter. In this masking, the cascade $H_a(z^R)\, H_m(z)$ must have antisymmetric impulse response.

The realization of the FRM transformer is shown in Figure 2. In this structure, the delays of parallel branches must be the same. If the orders of $H_b(z)$, $H_a(z)$, and $H_m(z)$ are N_b, N_a, and N_m, respectively, a half of the absolute difference between N_b and $R\,(N_a + 1) + N_m - R$ must be added as the delay in the branch with lower delay. In addition, to avoid a half-sample delay, N_b and $R\,(N_a + 1) + N_m - R$ must have the same parity.

V. Design Examples

The features of the proposed filters are illustrated with the design of spatial filters, also called beamformers, as well as fractional and conventional Hilbert transformers.

A. Beamformers

Uniform-linear-array beamformer is a linear-phase FIR filter if the beamformer operates at a single temporal frequency [18]. Assuming the spacing between sensors in array is half a wavelength of the signal, the beampattern is given by $H(\omega) = H(\pi \sin\theta)$, where θ denotes the direction of arrival. The direction takes a value from the interval $-\pi/2 \le \theta < \pi/2$.

The reduction of the number of sensors in arrays can be achieved by the frequency-response masking. Such a reduction is accomplished by constructing a linear sensor array consisting of several subarrays, each associated with one FRM subfilter [15]. Such obtained arrays are called interleaved linear array beamformers.

Here, let us describe the design of a wideband FRM beamformer with a sharp transition between $\theta_p = 10°$ and $\theta_s = 11°$ in azimuth domain and minimum stopband attenuation of 40 dB [15]. Such a synthesis corresponds to the design of a symmetric lowpass filter with $\omega_p = 0.174\pi$ and $\omega_s = 0.191\pi$. To obtain the beamformer in (27), we use the specifications of the subfilters as follows: $R = 8$; $N_a = 32$, $\omega_p = 0.472\pi$, and $\omega_s = 0.608\pi$ for $H_a(z)$; $N_{ma} = 30$, $\omega_p = 0.076\pi$, and $\omega_s = 0.191\pi$ for $H_{ma}(z)$; and $N_{mc} = 30$, $\omega_p = 0.174\pi$, and $\omega_s = 0.309\pi$ for $H_{mc}(z)$. In addition, for the design of $H_a(z)$ we choose the Samadi polynomial $f_{1,1,1,2}(x)$ with $\mathbf{a} = [2, -2, 1]$, whereas for the design of $H_{ma}(z)$ and $H_{mc}(z)$ we take polynomial $f_{2,2,2,1}(x)$ having $\mathbf{a} = [1, 0, -4, 7, -3]$. Figure 3 shows the beampattern obtained. It is clear that the proposed beamformer exhibits similar beampattern as one shown in Figure 9 in [15]. However, our beamformer requires 64 sensors, whereas the beamformer in [15] needs 74 sensors.

Narrowband beampatterns are obtained by reducing the passband at a single frequency point. As an example, we design two FRM beamformers with the same transition between $\theta_p = 0°$ and $\theta_s = 3.5°$, and the minimum stopband attenuation of 50 dB. Each beamformer corresponds to the FRM filter in (29) with $\omega_p = 0$ and $\omega_s = 0.061\pi$. For both beamformers, we use the specifications of the subfilters as suggested in [15]. They are $R = 10$; $N_a = 9$, $\omega_p = 0$, and $\omega_s = 0.610\pi$ for $H_a(z)$; and $N_{ma} = 29$, $\omega_p = 0$, and $\omega_s = \pi/5$ for $H_{ma}(z)$. Furthermore, for the sharpening of $H_{ma}(z)$ we choose $f_{0,1,0,0}(x)$. However, in the design of $H_a(z)$ we employ polynomials, $f_{0,1,0,0}(x)$ and $f_{1,1,0,1}(x)$, with $\mathbf{a} = [0, 1]$ and $\mathbf{a} = [1, 1, -1]$. Figure 4 shows the beampatterns obtained. It is clear that our beampatterns have stopband attenuation similar to one shown in Figure 10 in [15]. However, the proposed beampattern with $f_{0,1,0,0}(x)$ exhibits a narrower aperture region, whereas the beampattern with $f_{1,1,0,1}(x)$ brings a flatter aperture.

B. Fractional Hilbert Transformers

Fractional Hilbert transformer with $\varphi = \pi/4$ usually exhibits the largest phase error [16]. Therefore, we consider here only this transformer. As an example, let us design a transformer of the 90th order, operating within the

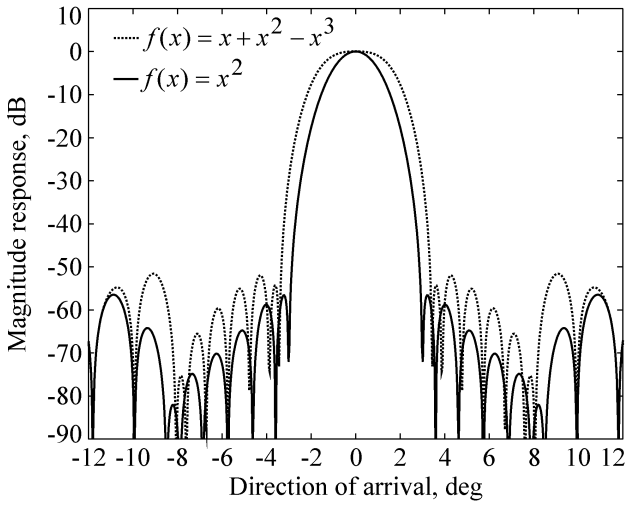

Figure 4. Narrowband beampatterns with $\theta_p = 0°$ and $\theta_s = 3.5°$, obtained by frequency-response-masking structure containing sharpened raised-cosine filters. Each beampattern is synthesized with prototype filter incorporating sharpening polynomial $f(x)$.

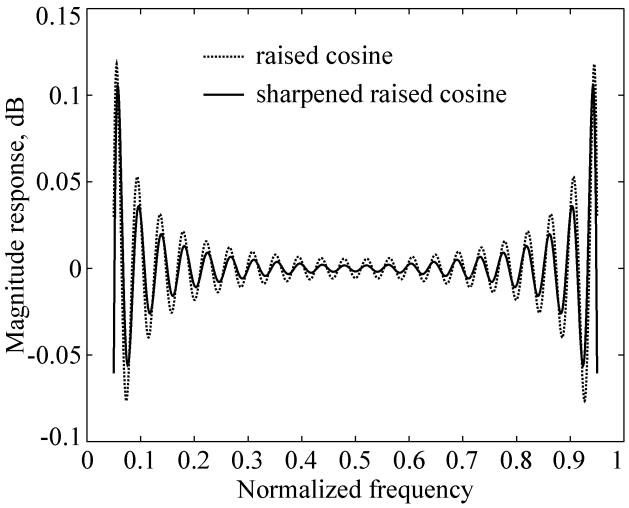

Figure 5. Passband magnitude responses of raised-cosine [16] and sharpened raised-cosine fractional Hilbert transformers of 90th order with phase shift of 45° and $\omega_1 = 0$, $\omega_2 = 0.05\pi$, $\omega_3 = 0.95\pi$, and $\omega_4 = \pi$.

band of interest $0.05\pi \le |\omega| \le 0.95\pi$. To ensure the best localization of its impulse response, the whole bands below and above the passband are specified as transition bands. Therefore, the design parameters are chosen as $N = 90$, $\omega_1 = 0$, $\omega_2 = 0.05\pi$, $\omega_3 = 0.95\pi$, and $\omega_4 = \pi$. In the sharpening, we use $f_{1,1,4/3,5/4}(x)$ with $\mathbf{a}_2 = [5/4, -5/6, 7/12]$. Consequently, $\mathbf{a}_1 = [4/3, -11/12, 7/12]$. Figure 5 shows the passband magnitude response of the sharpened transformer together with the response of the raised-cosine counterpart [16]. It is clear that the sharpened response has smaller maximum deviation than the unsharpened response, and it equals 0.17 dB. Figure 6 shows the corresponding passband phase errors, each obtained as $\Theta(\omega) + D\omega + \varphi\,\mathrm{sgn}(\omega)$ where $\Theta(\omega)$ is transformer's phase response. The sharpened transformer introduces the maximum error of 0.2°, which is less than the error of the raised-cosine counterpart.

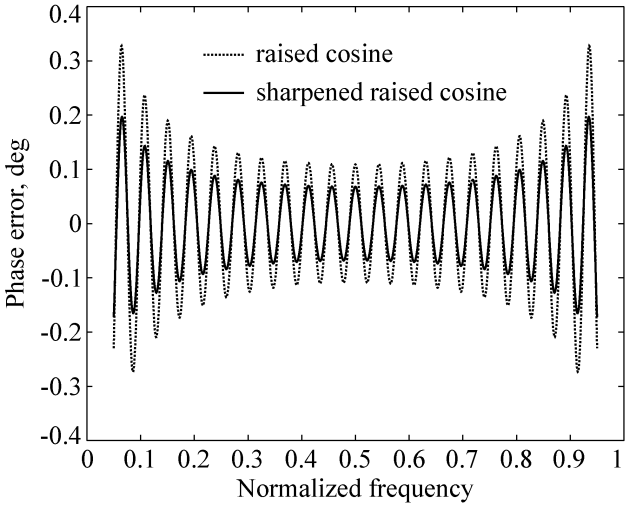

Figure 6. Phase errors of raised-cosine [16] and sharpened raised-cosine fractional Hilbert transformers of 90th order with phase shift of 45° and $\omega_1 = 0$, $\omega_2 = 0.05\pi$, $\omega_3 = 0.95\pi$, and $\omega_4 = \pi$.

C. Conventional Hilbert Transformers

In the previous example, we described the design of a bandpass fractional transformer. However, conventional transformer can also be designed as a highpass filter provided its order is odd. It results in wider passband and smaller approximation error. As an example, let us design the transformer of the 91st order with the transition band $0 < |\omega| < 0.02\pi$. For the sharpening we choose the combination of Samadi's polynomials given by $f(x) = f_{1,1,4,1}(x) + x\,f_{1,1,1,4}(1-x)$. This polynomial has the coefficients $\mathbf{a}_2 = [2, -4, 6, -3]$. Based on (16), in the design we deal with $1 - f(1-x) = x\,f_{1,1,1,4}(x)$, which has $\mathbf{a}_1 = [0, 4, -6, 3]$. Figure 7 shows the passband magnitude response of the sharpened transformer together with the response of the equiripple counterpart. The equiripple transformer introduces the ripple of 0.42 dB. However, our transformer brings smaller deviations within a major part of the passband, except near the cutoff where it has the maximum deviation of 0.69 dB. Such behavior is expected since the Fourier series method results in the least-squares approximation.

Finally, let us design the FRM transformer having the same transition band and the same number of nontrivial coefficients as the previously described transformer. In the FRM design, we use $R = 7$; $N_a = 45$, $\varphi = \pi/2$, $\omega_1 = 0$, and $\omega_2 = 0.140\pi$ for highpass prototype $H_a(z)$; $N_m = 22$, $\varphi = 0$, $\omega_p = 0$, and $\omega_s = 0.266\pi$ for lowpass masking filter $H_m(z)$; and $N_b = 21$, $\varphi = \pi/2$, $\omega_1 = 0$, and $\omega_2 = 0.266\pi$ for highpass basic transformer $H_b(z)$. Since $H_m(z)$ and $H_b(z)$ have low orders, in their design we use $f(x) = x$, bringing the raised-cosine filters. However, in the sharpening of $H_a(z)$ we use $f_{1,1,1,2/5}(x)$, resulting in $\mathbf{a}_1 = [2/5, 6/5, -3/5]$. From the subfilters' orders and scaling factor it follows that the additional delay of 158 samples must be added to $H_b(z)$. Figure 8 shows the obtained passband response. It has the maximum deviation of 0.15 dB, which is less than the deviations of the responses shown in Figure 7. However, this improvement is paid by additional delay elements.

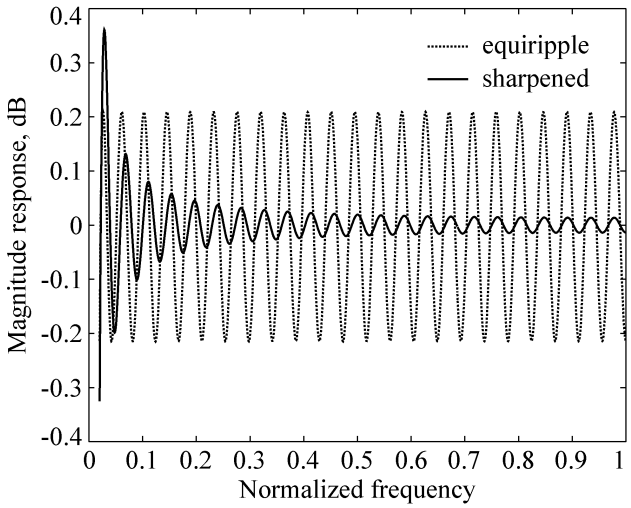

Figure 7. Passband magnitude responses of equiripple and sharpened raised-cosine conventional Hilbert transformers of 91st order with $\omega_1 = 0$ and $\omega_2 = 0.02\pi$.

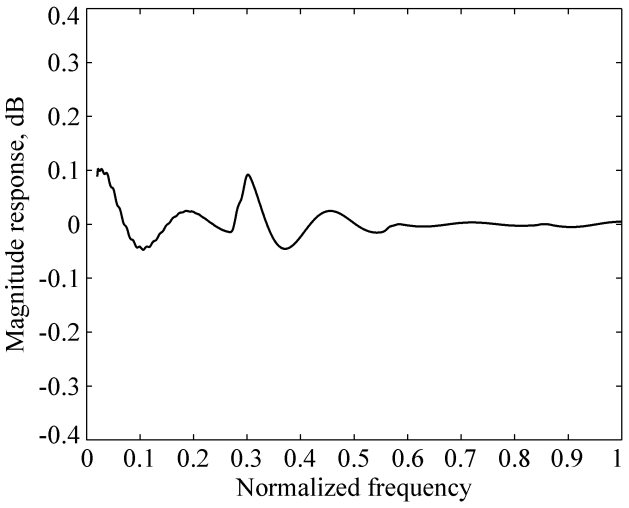

Figure 8. Passband magnitude response of conventional Hilbert transformer with $\omega_1 = 0$ and $\omega_2 = 0.02\pi$, obtained by frequency-response-masking structure containing sharpened raised-cosine filters.

VI. Conclusion

A straightforward method for the design of least-squares FIR filters with steep roll-off amplitudes and arbitrary phase shifts was presented. The method is based on the polynomial sharpening of raised-cosine amplitude response. The sharpening using generalized Kaiser-Hamming polynomials proved efficient in the design of linear-phase filters and fractional Hilbert transformers with wide transition bands. Furthermore, in the design of linear-phase filters with narrow transition bands the sharpening was successfully combined with the frequency-response masking technique.

VII. References

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Closed-Form Approximation of Hilbert Transforms of Gaussian Derivatives Based on Weighted Polynomial Fitting

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***Abstract*—Hilbert transforms of Gaussian derivatives are related to Dawson's integral. Since this integral cannot be expressed in a closed form, various methods for the approximation of the derivatives have been developed. A closed-form approximation can be obtained by using the weighted polynomial fitting in which Gaussian function is used as the weighting function. Such an approach results in explicit approximation formulas. In literature, they are available only for the derivatives of the second, third, and fourth order. Furthermore, they utilize only low-order polynomials. In this paper, we propose an approximation of the Hilbert transforms of the Gaussian derivatives of arbitrary orders, which utilize high-order polynomials. The coefficients of these polynomials are obtained by using the least-squares error criterion. Closed-form expressions are provided for their calculation.**

I. Introduction

Hilbert transforms of Gaussian function and its derivatives find application in many signal processing areas, such as in image processing [1], [2], ultra-wideband communications [3], and wavelet analysis [4]. The Hilbert transform of Gaussian function is given by Dawson's integral [5]. This integral also appears in the Hilbert transforms of Gaussian derivatives [6]. However, Dawson's integral cannot be expressed in a closed form. Therefore, significant effort has been made to develop approximate expressions for derivatives' transforms. Popular methods are based on numerical integration as well as on series expansions via sets of polynomials [6]. The numerical integration should be performed for each point of the derivative's transform, what makes the former approach computationally demanding. On the other hand, the later approach results in more-convenient closed-form expressions. Numerical values of the Hilbert transform can also be calculated in equidistant set of points by using discrete Fourier transform [7]. This approach is implemented in many signal-processing tools, for example in MATLAB [8].

Recently, the closed-form approximations of fractional-order Gaussian derivatives and their Hilbert transforms have been developed [9]. Latter, the fractional-order Gaussian derivatives have been expressed via integer Gaussian derivatives [10].

In this paper, we propose a closed-form approximation of the Hilbert transforms of Gaussian derivatives. The approximation is based on the weighted polynomial fitting. Such an approach has already been used in [1] for the Hilbert transforms of the second, third, and fourth order derivatives. Furthermore, in the paper referred to, only low-order polynomials were utilized. Here, we consider the derivatives of arbitrary orders and high-order polynomials. The polynomial coefficients are calculated by using the least-squares error criterion.

II. Hilbert Transforms of Gaussian Derivatives

A. Weighted Polynomial Fitting

An nth order Gaussian derivative is given by [5]

$$g_n(t) = \frac{d^n}{dt^n} e^{-t^2} = (-1)^n H_n(t) e^{-t^2} \tag{1}$$

where $H_n(t)$ is the Hermite polynomial of order n. It is given by [5]

$$H_n(t) = n! \sum_{m=0}^{\lfloor n/2 \rfloor} \frac{(-1)^m}{m!(n-2m)!} (2t)^{n-2m} \tag{2}$$

where $\lfloor u \rfloor$ denotes the greatest integer equal to or smaller than u.

The Hilbert transform of $g_n(t)$ is given by [6]

$$h_n(t) = \frac{1}{\sqrt{\pi}} \int_0^\infty x^n e^{-x^2/4} \sin\left(xt + \frac{n\pi}{2} \right) \mathrm{d}x \tag{3}$$

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The integral in (3) cannot be expressed in a closed form. Therefore, we estimate the transform by using weighted polynomial fitting. The derivatives in (1) can be considered as the Hermite polynomials weighted by the Gaussian function. Therefore, in our fitting we also use Gaussian as the weighting function. In particular, we define the approximation in the form

$$\hat{h}_n(t) = p_n(t)e^{-t^2} \tag{4}$$

where $p_n(t)$ is a fitting polynomial. Even-order Hermite polynomials are even functions, whereas odd-order Hermite polynomials are odd functions. Since the Hilbert transform of an even function is an odd function, and vice versa, it follows that $p_n(t)$ contains only odd or only even powers. Therefore, we deal with the fitting polynomials

$$p_n(t) = \sum_{m=0}^{M} b_m t^{2m+1} \tag{5}$$

for an even n, and

$$p_n(t) = \sum_{m=0}^{M} b_m t^{2m} \tag{6}$$

for an odd n, where b_m, $m = 0, 1, ..., M$, are polynomial's coefficients.

If the samples $h_n[k] = h_n(kT_s)$, $k = -K, ..., 0,..., K$, of the Hilbert transform are known, where T_s is the sampling period, we can define an error function

$$\varepsilon_n = \sum_{k=-K}^{K} \left(\hat{h}_n[k] - h_n[k] \right)^2 \tag{7}$$

where

$$\hat{h}_n[k] = p_n(kT_s)e^{-(kT_s)^2} \tag{8}$$

Since $p_n(t)$ in (5) and (6) differ for even- and odd-order derivatives, we consider these cases separately.

B. Hilbert Transforms of Even-Order Derivatives

By substituting (5) into (8), and then (8) into (7), the error function is obtained in the form

$$\varepsilon_n = \sum_{k=-K}^{K} \left(\sum_{m=0}^{M} b_m (kT_s)^{2m+1} e^{-(kT_s)^2} - h_n[k] \right)^2 \tag{9}$$

To find optimum polynomial coefficients, we first calculate the derivatives of ε_n in (9) with respect to b_i, $i = 0, 1, ..., M$, and then set the derivatives to zero. The expressions obtained are given in (10). After further manipulation, we obtain the system of linear equations in (11). This system can be written in a matrix form as

$$\mathbf{Qb} = \mathbf{c} \tag{12}$$

where matrix $\mathbf{Q}$ and column vectors $\mathbf{b}$ and $\mathbf{c}$ are given by

$$\mathbf{Q} = \left[Q_{u,v} \right] \ , \ \mathbf{b} = \left[b_{u-1} \right] \ , \ \mathbf{c} = \left[c_u \right] \tag{13}$$

$$Q_{u,v} = T_s^{2v-1} \sum_{k=-K}^{K} k^{2(u+v-1)} e^{-2(kT_s)^2} \tag{14}$$

$$c_u = \sum_{k=-K}^{K} k^{2u-1} e^{-(kT_s)^2} h_n[k] \tag{15}$$

$$u = 1, \ldots, M+1 ; \ v = 1, \ldots, M+1 \tag{16}$$

The solution of the system in (12) is found as

$$\mathbf{b} = \mathbf{Q}^{-1}\mathbf{c} \tag{17}$$

C. Hilbert Transforms of Odd-Order Derivatives

By substituting (6) into (8), and then (8) into (7), we arrive at

$$\varepsilon_n = \sum_{k=-K}^{K} \left(\sum_{m=0}^{M} b_m (kT_s)^{2m} e^{-(kT_s)^2} - h_n[k] \right)^2 \tag{18}$$

Similar to the previous case, the derivatives of ε_n in (18) are calculated with respect to b_i, $i = 0, 1, ..., M$, and then set to zero, resulting in (19). The corresponding system of linear equations is given in (20). Finally, the system in (12) and (13) is formed with

$$Q_{u,v} = T_s^{2(v-1)} \sum_{k=-K}^{K} k^{2(u+v-2)} e^{-2(kT_s)^2} \tag{21}$$

$$c_u = \sum_{k=-K}^{K} k^{2(u-1)} e^{-(kT_s)^2} h_n[k] \tag{22}$$

$$u = 1, \ldots, M+1 ; \ v = 1, \ldots, M+1 \tag{23}$$

$$\frac{\partial \varepsilon_n}{\partial b_i} = \sum_{k=-K}^{K} 2(kT_s)^{2i+1} e^{-(kT_s)^2} \left(\sum_{m=0}^{M} b_m (kT_s)^{2m+1} e^{-(kT_s)^2} - h_n[k] \right) = 0 \qquad i=0, 1, ..., M \tag{10}$$

$$\sum_{m=0}^{M} \left(\sum_{k=-K}^{K} k^{2(i+m+1)} e^{-2(kT_s)^2} T_s^{2m+1} \right) b_m = \sum_{k=-K}^{K} k^{2i+1} e^{-(kT_s)^2} h_n[k] \qquad i=0, 1, ..., M \tag{11}$$

$$\frac{\partial \varepsilon_n}{\partial b_i} = \sum_{k=-K}^{K} 2(kT_s)^{2i} e^{-(kT_s)^2} \left(\sum_{m=0}^{M} b_m (kT_s)^{2m} e^{-(kT_s)^2} - h_n[k] \right) = 0 \qquad i=0, 1, ..., M \tag{19}$$

$$\sum_{m=0}^{M} \left(\sum_{k=-K}^{K} k^{2(i+m)} e^{-2(kT_s)^2} T_s^{2m} \right) b_m = \sum_{k=-K}^{K} k^{2i} e^{-(kT_s)^2} h_n[k] \qquad i=0, 1, ..., M \tag{20}$$

TABLE I
EXAMPLES OF FITTING POLYNOMIALS FOR APPROXIMATIONS OF HILBERT TRANSFORMS OF GAUSSIAN DERIVATIVES OF UP TO 10TH ORDER

$p_1(t) = 1.12125 - 9.41254\text{e}{-1}\ t^2 - 8.76842\text{e}{-1}\ t^4 + 7.84587\text{e}{-1}\ t^6 - 4.08441\text{e}{-1}\ t^8 + 8.27436\text{e}{-2}\ t^{10} - 6.44755\text{e}{-3}\ t^{12}$
$p_2(t) = -4.55044\ t + 1.77862\ t^3 - 3.45750\text{e}{-1}\ t^5 + 3.49549\text{e}{-1}\ t^7 - 8.44322\text{e}{-2}\ t^9 + 8.59674\text{e}{-3}\ t^{11}$
$p_3(t) = -4.50680 + 1.33895\text{e}{+1}\ t^2 - 1.79524\ t^4 - 5.85115\text{e}{-1}\ t^6 + 1.36780\text{e}{-1}\ t^8 - 2.02637\text{e}{-2}\ t^{10}$
$p_4(t) = 3.60544\text{e}{+1}\ t - 3.57053\text{e}{+1}\ t^3 + 2.87238\ t^5 + 6.68703\text{e}{-1}\ t^7 - 1.21582\text{e}{-1}\ t^9 + 1.47373\text{e}{-2}\ t^{11}$
$p_5(t) = 3.63037\text{e}{+1} - 1.83513\text{e}{+2}\ t^2 + 9.57461\text{e}{+1}\ t^4 - 8.51077\ t^6$
$p_6(t) = -4.35645\text{e}{+2}\ t + 7.34054\text{e}{+2}\ t^3 - 2.29791\text{e}{+2}\ t^5 + 1.45899\text{e}{+1}\ t^7$
$p_7(t) = -4.34149\text{e}{+2} + 3.04951\text{e}{+3}\ t^2 - 2.56919\text{e}{+3}\ t^4 + 5.36178\text{e}{+2}\ t^6 - 2.55323\text{e}{+1}\ t^8$
$p_8(t) = 6.94638\text{e}{+3}\ t - 1.62641\text{e}{+4}\ t^3 + 8.22140\text{e}{+3}\ t^5 - 1.22555\text{e}{+3}\ t^7 + 4.53908\text{e}{+1}\ t^9$
$p_9(t) = 6.93801\text{e}{+3} - 6.25174\text{e}{+4}\ t^2 + 7.31884\text{e}{+4}\ t^4 - 2.46642\text{e}{+4}\ t^6 + 2.75749\text{e}{+3}\ t^8 - 8.17034\text{e}{+1}\ t^{10}$
$p_{10}(t) = -1.38760\text{e}{+5}\ t + 4.16783\text{e}{+5}\ t^3 - 2.92753\text{e}{+5}\ t^5 + 7.04692\text{e}{+4}\ t^7 - 6.12775\text{e}{+3}\ t^9 + 1.48552\text{e}{+2}\ t^{11}$

III. PRACTICAL CONSIDERATIONS

In (7), we assume that samples of Hilbert transform $h_n[k]$ are known. We obtain them by taking the imaginary part of analytic representation of sampled derivative,

$$g_n[k] = g_n(kT_s), \quad k = -K, ..., 0, ..., K \tag{24}$$

The analytic representation of $g_n[k]$ is calculated by using the discrete Fourier transform [7].

The samples in (24) represent $g_n(t)$ from the interval $-T \le t \le T$, where $T = KT_s$ is derivative's effective width. Clearly, T should be chosen high enough to ensure the neglected tails have sufficiently small amplitudes. Here, we use the value of T which ensures

$$\left| \frac{h_n(t)}{\max\limits_t h_n(t)} \right| < \delta_t, \quad t > T \tag{25}$$

where δ_t is a threshold. Figure 1 shows T estimated for various δ_t and $n \le 10$. Clearly, the largest T is required for $n = 1$. It is expected since the Hilbert transform of the first-order Gaussian derivative has a slow decay [6]. However, T decreases very fast with the increase of n. Acceptable values for T are obtained for δ_t as low as 1e–5.

The Fourier transform of Gaussian derivative in (1) is given by [12]

$$G_n(\omega) = j^n \sqrt{\pi}\omega^n e^{-(\omega/2)^2} \tag{26}$$

where ω denotes frequency. The highest significant frequency component, Ω, can be estimated as minimum value which ensures

$$\left| \frac{G_n(\omega)}{\max\limits_\omega G_n(\omega)} \right| < \delta_\omega, \quad \omega > \Omega \tag{27}$$

where δ_ω is a threshold. The amplitude of $G_n(\omega)$ reaches its maximum at $\omega = \sqrt{2n}$ [12] and decays exponentially with the increase of ω. The value of δ_ω as small as 1e–6 is reached at $\Omega = 13.5$ rad/s for $n \le 30$. Following the sampling theorem, the sampling period used in (24) is chosen as $T_s < \pi/\Omega$.

Accurate approximations of Hilbert transforms of the Gaussian derivatives are obtained by taking $M = 6$ for $n = 1$, and $M = 5$ for $n = 2$, 3, and 4. For $n \ge 5$, $M = n/2$ for an even n, and $M = (n+1)/2$ for an odd n are suitable. The examples of fitting polynomials $p_n(t)$ for $n \le 10$ are given in Table I. The polynomial coefficients are calculated with $\delta_t = 1\text{e}{-4}$, which requires $T = 70$ s for $n = 1$ and $T = 20$ s for $n > 1$, and with $T_s = 0.2$ s which is sufficient in all cases.

Figures 2 and 3 show the first and tenth order Gaussian derivatives, their Hilbert transforms calculated numerically by using (3), and the Hilbert transforms obtained by using proposed approximation. Clearly, the proposed approximations match closely the numerically obtained transforms. In Figure 2, a small difference between $h_n(t)$ and $\hat{h}_n(t)$ is visible, whereas in Figure 3 the difference can be encountered only in numerical values. Generally, the approximation is more accurate for higher n.

For convenience, we provide a MATLAB code for calculating the coefficients of the fitting polynomials. The code is given in the Appendix. The code supports calculation of the fitting polynomials for the derivatives of up to the 30th order. For higher orders, the matrix **Q** in (12) might become ill-conditioned, depending on the choice of T and T_s.

IV. SCALED AND FRACTIONAL HILBERT TRANSFORMS

A. Derivatives of Scaled Gaussian Function

An nth-order derivative of scaled Gaussian function is given by

$$g_n(t) = = \frac{d^n}{dt^n} e^{-(t/\tau)^2} = (-1)^n \frac{1}{\tau^n} H_n\left(\frac{t}{\tau}\right) e^{-(t/\tau)^2} \tag{28}$$

where τ denotes scaling factor. In this case, the approximation of the Hilbert transform is given by

$$\hat{h}_n(t) = \frac{1}{\tau^n} p_n\left(\frac{t}{\tau}\right) e^{-(t/\tau)^2} \tag{29}$$

Note that approximation in (29) utilizes $p_n(t)$ calculated in Sections II.B and II.C, which are here scaled to $p_n(t/\tau)$.

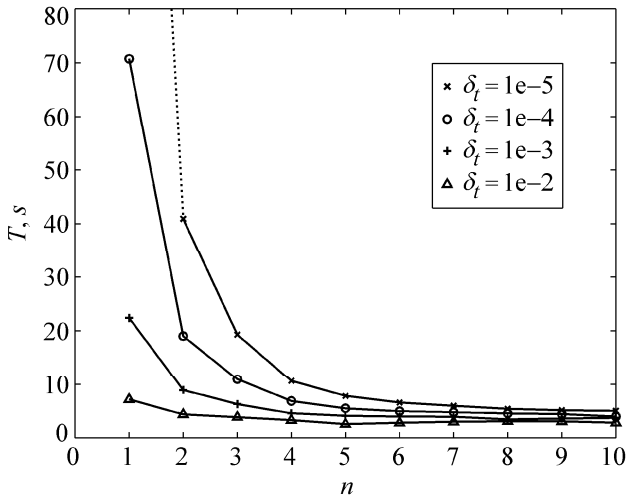

Figure 1. Effective widths of Hilbert transforms of Gaussian derivatives, calculated for various thresholds used in truncation of transforms' tails.

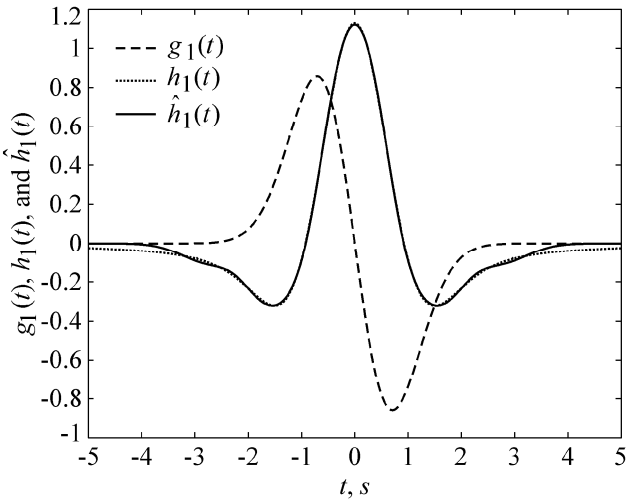

Figure 2. First order Gaussian derivative, its Hilbert transform calculated numerically, and Hilbert transform obtained by using proposed approximation with polynomial of 12th order.

B. Fractional Hilbert Transforms of Gaussian Derivatives

Hilbert transform introduces the phase shift $\pi/2 \cdot \mathrm{sgn}(\omega)$ to the Fourier transform of the original function. Fractional Hilbert transform is the generalization of Hilbert transform. It introduces an arbitrary phase shift $\varphi \cdot \mathrm{sgn}(\omega)$. In our case, the approximation of fractional Hilbert transform of the Gaussian derivative can be easily obtained by using Hilbert-transform pair $g_n(t)$ and $\hat{h}_n(t)$, as in [11]

$$\hat{s}_n(t) = g_n(t)\cos\varphi + \hat{h}_n(t)\sin\varphi \tag{30}$$

V. Conclusion

Closed-form expressions for the approximations of the Hilbert transforms of Gaussian derivatives were described. The approximations were obtained by using the weighted polynomial fitting. High-order fitting polynomials were utilized. The optimum polynomial coefficients were obtained using straightforward method based on the least-squares error criterion.

An example of MATLAB code for calculating the polynomial coefficients was provided. Finally, the fitting polynomials for the approximation of derivatives' transforms of up to the tenth order were tabulated.

Appendix
MATLAB Code for Design of Fitting Polynomial

In this section, we provide an example of MATLAB code for calculating the coefficients of the fitting polynomial. The function is called *wpolyfit*. Its input parameters are the order of Gaussian derivative, $n \geq 1$, parameter M, width T, and sampling period T_s. The function returns the coefficients of the fitting polynomial.

```
function b=wpolyfit(n,M,T,Ts)

% sampling points
K=ceil(T/Ts); k=-K:K; t=k*Ts;

% nth order Hermite polynomial
Hn=zeros(size(t));
```

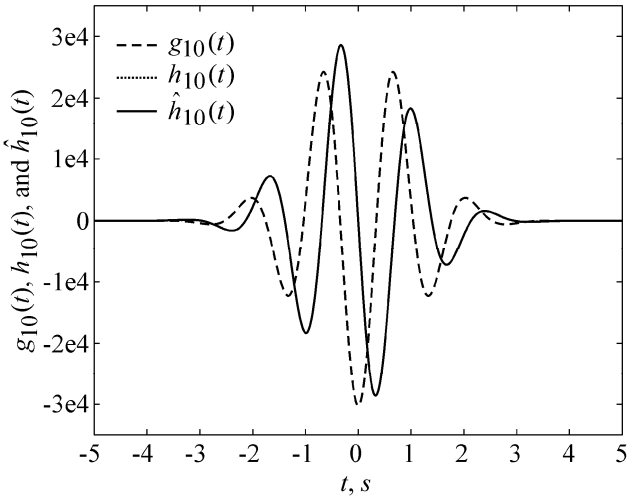

Figure 3. Tenth order Gaussian derivative, its Hilbert transform calculated numerically, and Hilbert transform obtained by using proposed approximation with polynomial of 11th order.

```
for m=0:floor(n/2)
 Hn=Hn+(-1)^m/prod(1:m)/prod(1:n-2*m)*...
       (2*t).^(n-2*m);
end
Hn=prod(1:n)*Hn;

% nth order Gaussian derivative
gn=(-1)^n*Hn.*exp(-t.^2);

% numerical values of Hilbert transform
Np=100*length(t); % zero padding
hn=imag(hilbert(gn,Np)); hn=hn(1:length(t));
% forcing the even or odd symmetry
hn=(hn-(-1)^n*hn(end:-1:1))/2;

% matrix Q and vector c
Q=zeros(M+1,M+1);
c=zeros(M+1,1);
if mod(n,2)==0 % even n
 for u=1:(M+1)
  for v=1:(M+1)
   Q(u,v)=Ts^(2*v-1)*...
          sum(k.^(2*(u+v-1)).*exp(-2*t.^2));
  end
  c(u)=sum(k.^(2*u-1).*exp(-t.^2).*hn);
 end
```

```
else % odd n
 for u=1:(M+1)
  for v=1:(M+1)
   Q(u,v)=Ts^(2*(v-1))*...
          sum(k.^(2*(u+v-2)).*exp(-2*t.^2));
  end
  c(u)=sum(k.^(2*(u-1)).*exp(-t.^2).*hn);
 end
end

% coefficients of fitting polynomial
b=Q^-1*c;
```

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Influence of Distributed Resistors in Integrated Active-RC Filters

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***Abstract*—In this paper a voltage mode active-RC simulation of a passive ladder RLC filter is investigated in the integrated circuit realization. It is shown that by integration there arises a problem: the parasitic capacitance of integrated resistors in active-RC on-chip filters cause that those filters become unstable and oscillate. On-chip resistors having parasitic capacitances can be described as distributed elements with RC-transmission-line nature. Therefore, we show how to model the on-chip resistors and find the causes of filter instabilities and possible solutions. The simulations are run using PSpice. It is shown that more carefully designed and/or compensated analog filter will be stable and realizable in analog integrated-circuit technology.**

Keywords: Parasitic capacitance in integrated resistors, distributed model of integrated resistors, RC-transmission line, simulated ladder-RLC active filter, low-pass filters, elliptic filters, low sensitivity, stability.

I. INTRODUCTION

The frequency response of a filter varies from the nominal due to tolerances of passive and active elements, aging, temperature, etc. Therefore, to design filters with reduced sensitivity to changes (tolerances) of passive element values the active simulations of passive ladder-RLC filters are designed. They have minimum sensitivity to component tolerances in the pass band as shown in [1]. In [2] a method of realizing finite zeros in elliptic filters using additional resistive networks instead of the additional capacitive networks is shown. Resistors are preferred over capacitors on a chip because they use less chip area, are easier to manufacture, and less prone to failure. Besides, the capacitance area on an IC chip is reduced considerably. It is beneficial to replace on-chip capacitors by on-chip resistors, wherever possible. The problem arises due to parasitic capacitance of the IC on-chip resistors, the filter becomes unstable and oscillates. In this paper we will find cause of the filter's instability, and possible solutions.

II. MODELLING INTEGRATED RESISTORS

In this Section we define a model of a distributed resistor in integrated form, that is, we represent the resistor with distributed parasitic capacitance. There exist two ways of modelling parasitic capacitance of integrated resistors:

- Version 1: $R_iC_{i\text{-parasitic}}$=constant, produces x degrees of phase shift at 300MHz ($C_{\text{parasitic}}$ is inversely proportional to resistor area).
- Version 2: $C_{i\text{-parasitic}}/R_i=C_{\text{parasitic}}/10\text{k}\Omega$ (capacitance density per resistance [fF/kΩ]) for x degrees of phase shift at 300 MHz ($C_{\text{parasitic}}$ is proportional to resistor area).

In this paper we present a signal-flow graph (SFG) filter with version-1 model of integrated distributed resistors. Cadence Pspice model of integrated resistor, which we are going to use, is presented in the form of distributed resistor with parasitic capacitance as shown in Fig. 1. The modelling of integrated resistors presented in this paper in Fig. 1 is according to the definitions described in the literature [3]–[9], with a common symbol in Fig. 2(a) [4]. Such distributed resistance model produces 5, 10, 20, 40, 60-degree phase shift at 300MHz. The same representation of distributed-parameters resistor model can be used to model the channel of MOS transistors [3]. Finding parasitic capacitance such that distributed resistor has 5, 10, 20, 40, 60 degrees phase shift at 300 MHz can be performed in Pspice using the circuit in Fig. 2(b). Phase response of a 10kΩ-distributed resistor as in Fig. 1, investigated by the setup in Fig. 2(b), is shown in Fig. 3.

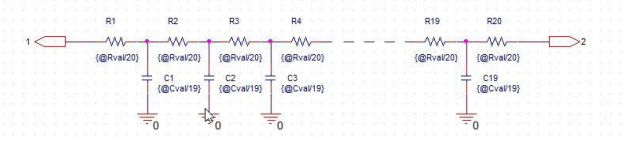

Fig. 1. Integrated resistors (distributed) in the form of RC-transmission line in Cadence Pspice. Its common symbol is shown in Fig. 2(a).

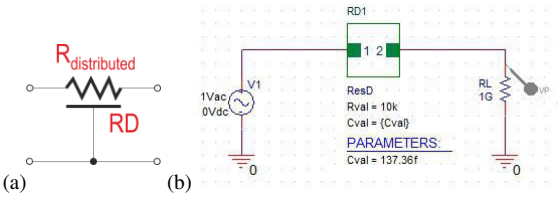

Fig. 2. (a) Common symbol of a distributed resistor. (b) Finding phase shift of the distributed resistor RD1 in Cadence Pspice.

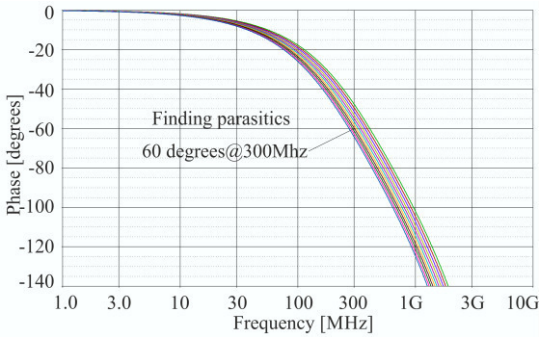

Fig. 3. Phase shift determination of distributed resistor in Pspice. For the on-chip RD1=10kΩ resistor, and the value of parasitic capacitance $C_{\text{parasitic}}$=137.36fF there is a phase shift of 60 degrees at 300MHz.

It is found that it is needed $C_{parasitic}$=137.36fF to produce 60 deg phase shift of 10kΩ resistor at 300MHz.

III. Fourth-Order BP Filter with One Tank Capacitor

As an example, we realize a fourth-order elliptic low-pass (LP) filter with cut-off frequency f_p=30MHz, maximum pass-band attenuation A_{max}=1.1dB, minimum stop-band attenuation of A_{min}=45dB, and with the transient band-width equal to Ω_s=2. The prototype realization of the filter is shown in Fig. 4, which is a doubly-terminated fourth-order LP elliptic passive-RLC ladder filter with element values given in tables [10][11]. As shown in [2], the original passive ladder filter in Fig. 4, using signal-flow graph in Fig. 5, can readily be converted into an active, inductorless ladder circuit consisting of only adders, subtractors, and integrators, shown in Fig. 6.

The circuit from Fig. 6 is realized in Cadence Pspice using distributed resistor models in Fig. 1 and is shown in Fig. 7. All capacitors in the circuit in Fig. 7 are chosen equal C_1=C_2=C_3=C_4=1.1pF, while calculated resistor values are in Table I. Besides resistor values, there are values of parasitic capacitance values for different phase shifts, in corresponding columns. Notice that the values of the product of each resistance and the parasitic Cs for a given degree are constants. This is according to the definition of version-1-model of parasitic capacitance of integrated resistors, above.

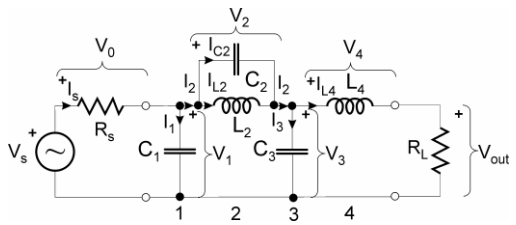

Fig. 4. Fourth-order passive-RLC ladder filter with designated voltages and currents.

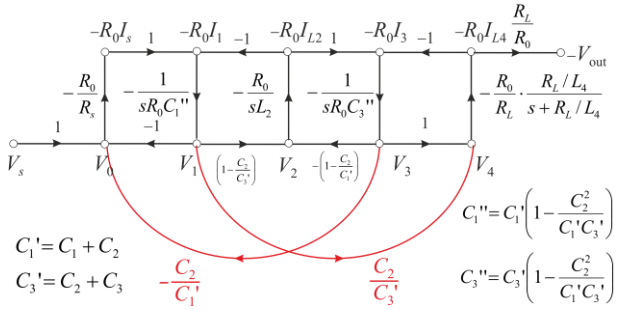

Fig. 5. Signal-flow graph of the fourth-order ladder-RLC filter in Fig. 4. Simulation with all negative integrators and two gain paths for realizing finite transfer function zeros.

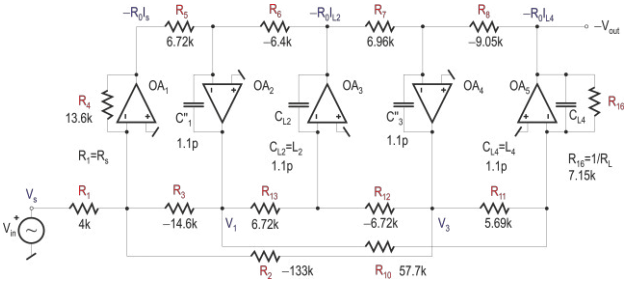

Fig. 6. Deriving the active-RC circuit from Fig. 5, with only negative integrators and some negative resistors.

TABLE I
Resistor values and parasitic Cs of active-RC filter in Fig. 7.

Rs	Ideal	0deg	5deg	20deg	40deg	60deg
R_1	4k	-	-	-	-	-
R_2	133k	0f	0.697f	2.85f	6.1f	10.24f
R_3	14.6k	0f	6.46f	25.95f	55.5f	93f
R_4	13.6k	0f	6.84f	27.85f	59.5f	101f
R_5	6.72k	0f	13.68f	56.35f	120f	202.6f
R_6	6.4k	0f	14.44f	59.15f	126f	212.8f
R_7	6.96k	0f	13.34f	54.4f	116f	195.6f
R_8	9.05k	0f	10.22f	41.85f	89.4f	150.4f
R_9	7.15k	0f	12.98f	53f	113.2f	190.4f
R_{10}	57.7k	0f	1.62f	6.55f	14f	23.6f
R_{11}	5.69k	0f	16.3f	66.5f	142f	239.3f
R_{12}	6.73k	0f	13.87f	56.2f	120f	202.3f
R_{13}	6.72k	0f	13.68f	56.35f	120f	202.6f

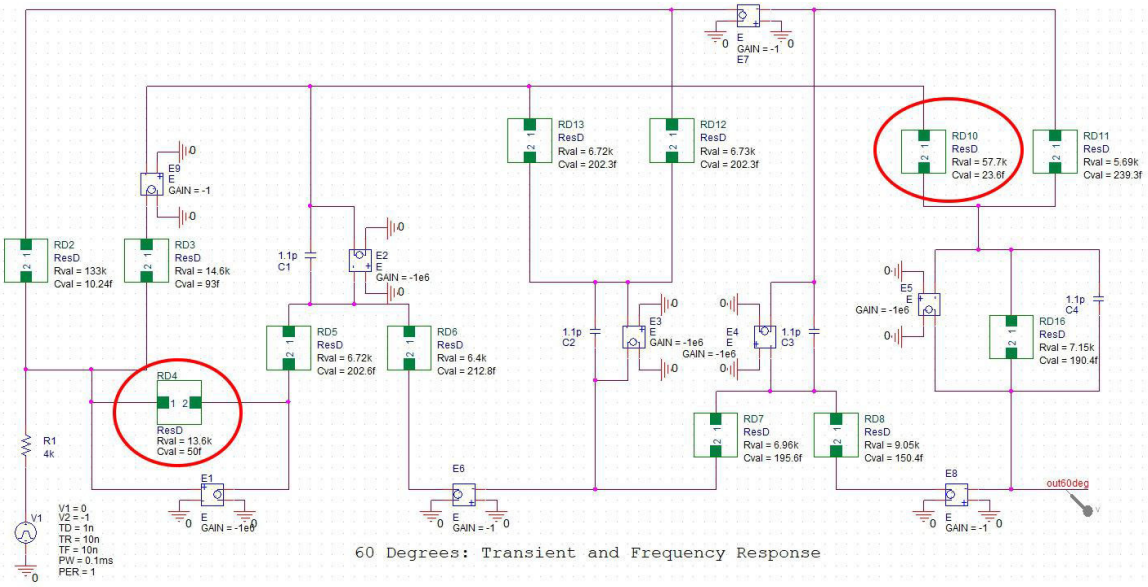

Fig. 7. Realization of 60-degrees active-RC circuit from Fig. 6, in Cadence Pspice Capture CIS, with distributed resistors as in Fig. 1.

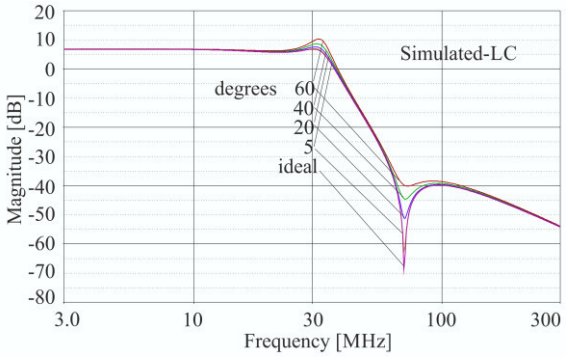

Fig. 8. Frequency response for distributed resistors with 5-, 20-, 40-, and 60-degree 'Version-1' parasitic capacitance.

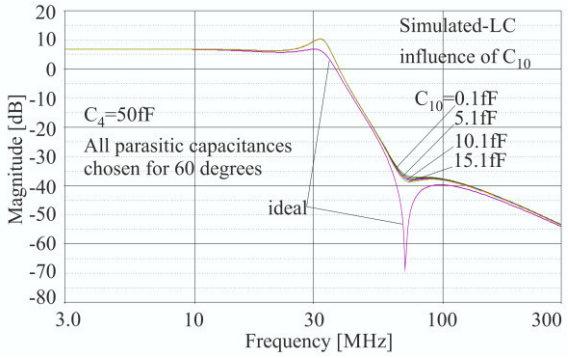

Fig. 10. Frequency response for 60-degree 'Version-1' resistances with parasitic capacitances and influence of C_{10} parasitic (C_4 < 50fF).

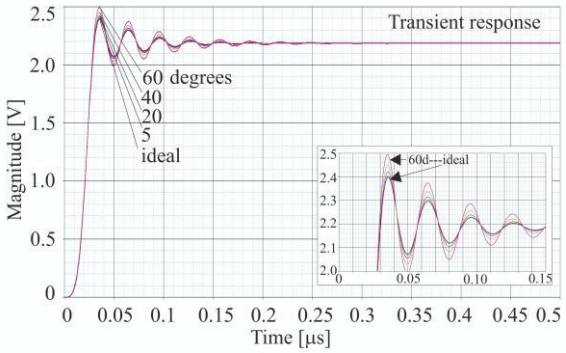

Fig. 9. Transient response for ideal and 5-, 20-, 40-, 60-degree parasitic capacitance. For 60deg C_4 is chosen smaller than 50fF.

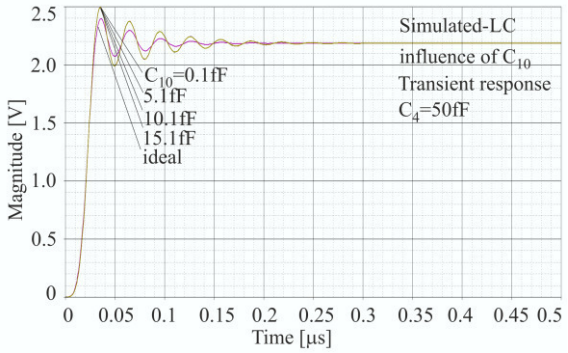

Fig. 11. Transient response for 60-degree 'Version-1' parasitic capacitances and influence of C_{10} parasitic (C_4 < 50fF).

Amplitude-frequency characteristics of the circuit in Fig. 7 with different values of phase degrees of distributed resistors are shown in Fig. 8. The transient response is shown in Fig. 9.

It was found using above AC-Sweep and Transient analysis in Cadence Orcad Pspice that for the value of 60 degrees resistors, the value of parasitic of 101fF in the resistance R_4 (see bold border in Table I) causes the circuit to become unstable. Therefore, to avoid oscillations, in our analysis we have assumed parasitic capacitance of R_4 to be 50fF. This upper-bound value of 50fF is obtained experimentally by Pspice simulations.

The above AC-Sweep and Transient analysis using simulations in Pspice showed that 2 capacitors have the most significant effect on the filter circuit performance:

- C_4 "destabilizing capacitor", which must be smaller than approximately 50fF to avoid instability.
- C_{10} "notch capacitor", which must be approximately 30fF to retain the notch in the filter response.

Both above capacitors, that are indeed parasitic capacitance values of distributed resistors R_4 and R_{10}, are designated in Fig. 7 (rounded by a red circle). The maximum values of both parasites C_4=50fF and C_{10}=30fF are obtained empirically by several simulations in Pspice using circuit in Fig. 7.

Effect of the capacitor C_{10} when C_4 is less than 50fF is shown in Fig. 10 (amplitude response), and in Fig. 11 (transient response). It can be concluded that C_{10} has significant influence on the depth of transfer function zero in the amplitude-frequency characteristics, whereas it has low influence on the transient response.

IV. Investigating Cause of In-stability

Before we find solution how to build stable integrated filter circuits, we must investigate why is the value of C_4 so critical for the stability of the filter. The parasitic capacitance C_4 is inside the distributed feedback-resistor R_4 which is a part of the only summing circuit of the filter Fig. 7, through which all loops are connected.

To analyze its effect, consider first the summing inverter shown in Fig. 12. From Fig. 12 can be concluded that the parasitic capacitance of the feedback resistor increases the gain and phase of the frequency response. The same feedback function has the resistance R_4 with parasitic capacitance C_4 shown in Fig. 7.

Furthermore, to understand more deeply the effect of distributed resistor we can, for the first approximation, replace the distributed-RC 'resistor' by an RC T-circuit. Therefore, it is convenient to compare amplitude and phase response of unity inverter with distributed-RC and RC-T feedback resistor which is shown in Fig. 13.

The feedback resistor of an inverter - with distributed parasitic capacitance - behaves just like an RC T-circuit, and even more so. In both cases the gain and phase of the inverter increases. As a result, the phase margin within the multi-loop circuit decreases to the point of instability. Thus, for stability, the parasitic capacitance C_4 of the summing feedback resistor R_4 in the circuit in Fig. 7 must be limited: in our case (empirically) somewhere below 50fF!

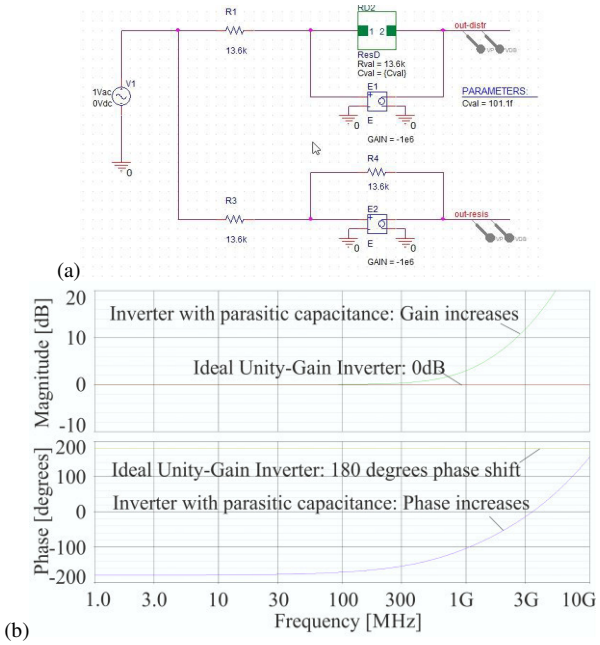

Fig. 12. Comparison of ideal unity-gain inverter to the inverter using a distributed resistor with parasitic capacitance, in the feedback. (a) Circuit. (b) Amplitude- and phase-frequency characteristics.

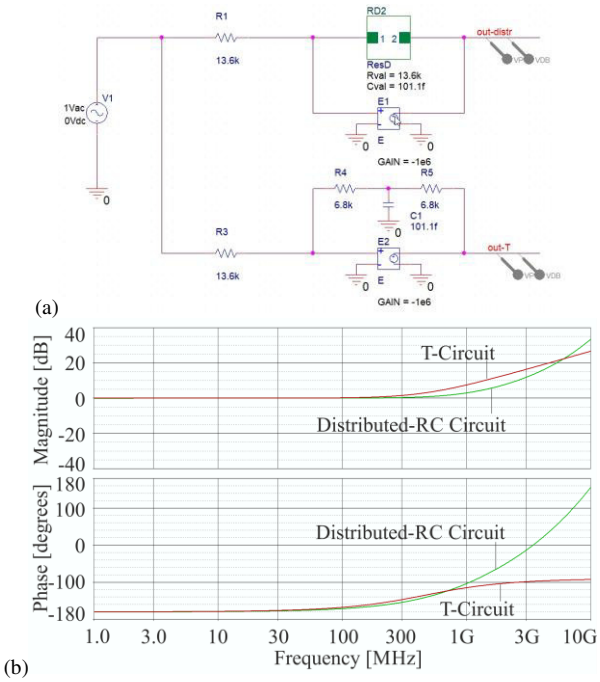

Fig. 13. Comparison of Distributed-RC and RC-T feedback resistor in unity-gain inverter. (a) Circuit. (b) Amplitude- and phase-frequency characteristics.

V. STABILIZING THE SFG-FILTER CIRCUIT

Before we proceed we must understand the T-Circuit which is shown in Fig. 14(a). According to delta-star transformation it can be converted to Π circuit in Fig. 14(b). The value of the transformed series impedance Z'_2 in Fig. 14(b) is then given by

$$Z'_2 = Z_1 + Z_3 + \frac{Z_1 Z_3}{Z_2}. \qquad (1)$$

Note that if parallel impedance in Fig. 14(a), i.e. Z_2 is a capacitance then for higher frequencies the transformed

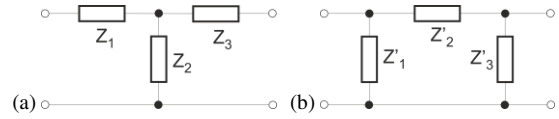

Fig. 14. Delta-star transformation. (a) T circuit. (b) Π circuit.

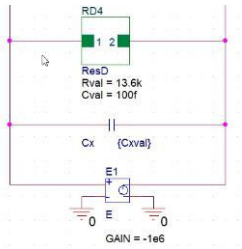

Fig. 15. Compensating capacitor C_x parallel to R_4 in SFG filter in Fig. 7.

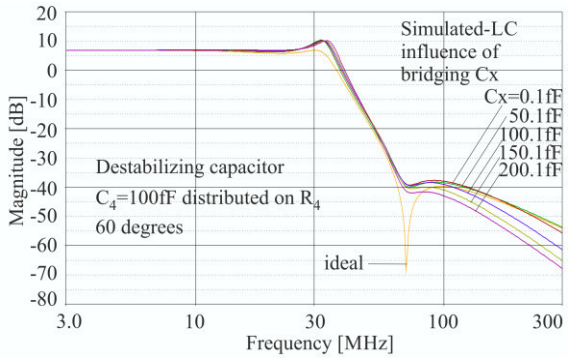

Fig. 16. Frequency response for 60-degree 'Version-1' parasitic capacitances and influence of bridging capacitor C_x (C_4 =100fF, i.e. larger than 50fF).

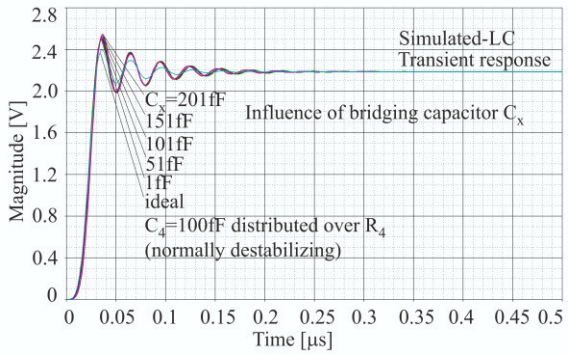

Fig. 17. Transient response for 60-degree 'Version-1' parasitic capacitances and influence of bridging capacitor C_x (C_4 =100fF, i.e. larger than 50fF).

series impedance Z'_2 in Fig. 14(b) is becoming very high, and is frequency dependent. To compensate its influence, it is possible to connect a capacitance C_x in parallel to Z'_2. In that way the compensating capacitance C_x is reducing the total (parallel) impedance $Z'_2 \,||\, 1/(sC_x)$ when the frequency is increased. Addition of C_x parallel to distributed resistor R_4 (in Fig. 7) is shown in Fig. 15 (see also [4]).

Thus, unlike in our above simulations, instead of limiting C_4 (the parasitic capacitance of R_4) to values less than approximately 50fF, R_4 (with full parasitic capacitance) can be bridged by a capacitor C_x. This prevents instability. The value of C_x is not critical but should not exceed approximately 300fF. The value of bridging capacitance C_x must be chosen by experimental procedure using simulations in Pspice with the goal that the filter becomes

stable. Maximum value of 300fF is suggested by comparison with other capacitance values of the circuit and a technology.

Effect of bridging R_4 with capacitor C_x is shown in Figs. 16 and 17, while R_4 is with full oscillation-causing parasitic capacitance of over 100fF. Effect, on frequency response, is not significant, and the transient response is stable (thus the value of C_x is not critical).

VI. Redesigning The SFG-Filter Circuit

In this Section we apply another approach to stabilize the above filter circuit. By more carefully redesigning the SFG in Fig. 5, we obtain a new SFG in Fig. 18, which possess two lossy integrators at the outer parts and lossless integrators in the inner parts of the graph.

TABLE II
Resistor values and parasitic Cs of active-RC filter in Fig. 20.

	R'_1	R'_2	R'_3	R_6	R_7
Ideal Rs	1.976k	65.72k	7.214k	6.4k	6.96k
60deg Cs	-	20.73f	188.7f	212.8f	195.6f
R_8	R_9	R_{10}	R_{11}	R_{12}	R_{13}
9.05k	7.15k	57.7k	5.69k	6.73k	6.72k
150.4f	190.4f	23.6f	239.3f	202.3f	202.6f

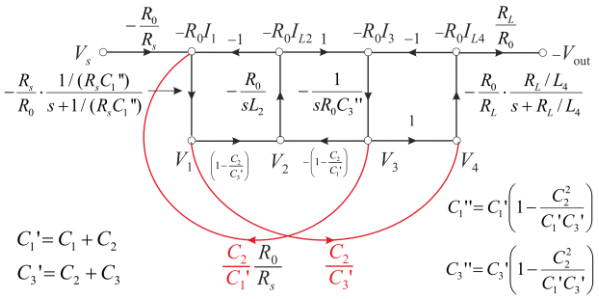

Fig. 18. Another signal-flow graph of the fourth-order ladder-RLC filter in Fig. 4. SFG in Fig. 5 is redesigned.

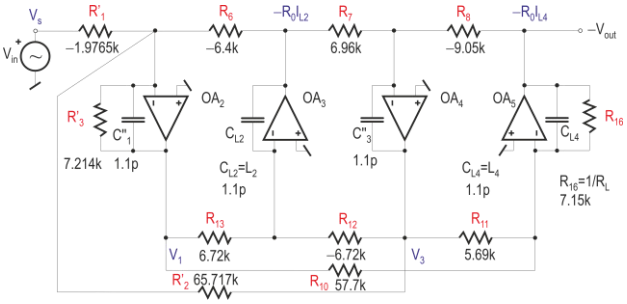

Fig. 19. Deriving the active-RC circuit from Fig. 18, with only negative integrators and some negative resistors.

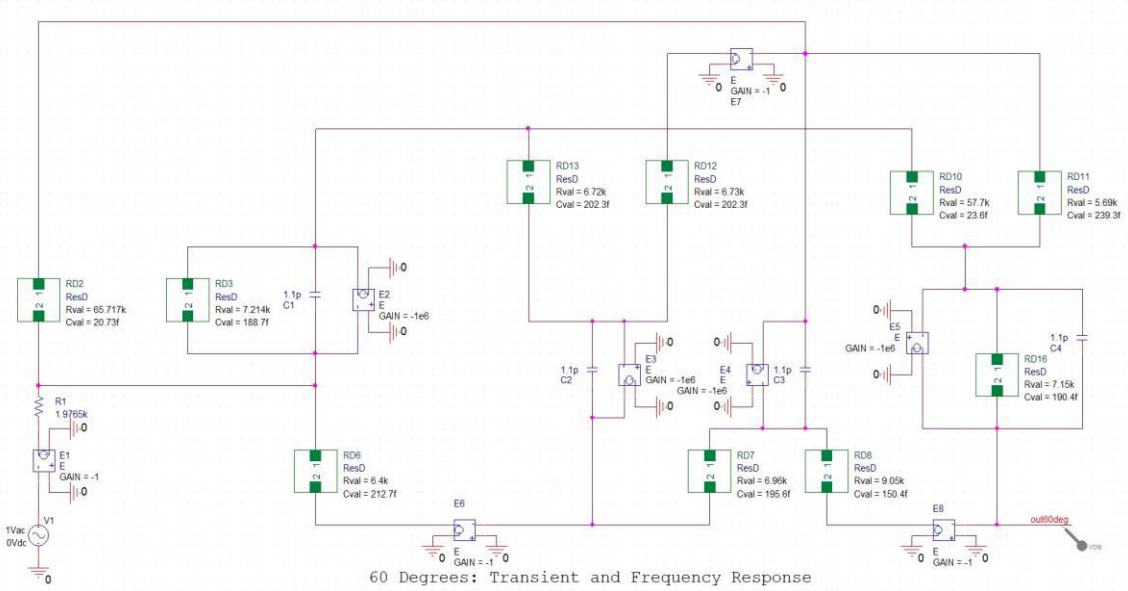

Fig. 20. Realization of 60-degrees active-RC circuit from Fig. 19, in Cadence Pspice Capture CIS, with distributed resistors as in Fig. 1. Circuit in Fig. 7 is redesigned. Parasitic capacitances of distributed resistors produce 60 degrees phase shift at 300MHz. This circuit is stable.

In that way the corresponding circuit which is shown in Figs. 19 and 20 is simplified compared to the initial circuit in Figs. 6 and 7. The component values of the new circuit are in Table II. The new circuit does not have operational amplifier OA_1 and R_4 and R_5 (they are all left out). The resistors R_1, R_2 and R_3 (grayed in Table II) are recalculated by

$$R'_1 = R_1\frac{R_5}{R_4}; R'_2 = R_2\frac{R_5}{R_4}; R'_3 = R_3\frac{R_5}{R_4}. \quad (2)$$

All other element vales are the same as those of the circuit in Fig. 7 (see the 60-deg column in Table I).

The redesigned circuit in Fig. 20 is stable because the critical parasitic capacitance of the resistance R_4 is not present any more (neither R_4 is present). The frequency and transient responses of the circuit in Fig. 20 are identical to those of the circuit in Fig. 7, that are shown in Fig. 8 and Fig. 9, respectively.

VII. Conlusion

In this paper we have firstly presented a model of integrated resistor with distributed parameters, when it is defined as RC-transmission line. We have then presented influence of the integrated distributed resistor model, having various amounts of capacitive parasitics, on the filter stability and performance. It was shown that under some circumstances the filter circuit can become instable (when some parasitic capacitances are too high). All

critical capacitance values are obtained by experimental simulations. This is very pronounced when negative feedback in the filter topology exists, which is the case for the simulated SFG filters, when they are realized in integrated circuit form. It is also presented in the paper how the stability of the filter can be achieved by an addition of one compensating capacitor. Finally, the redesigned circuit without critical capacitance is stable. This shows that careful design of the circuit is important for the stability.

ACKNOWLEDGEMENT

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Standardization as a Tool for Promoting Innovation and Commercialization of a Circular Economy for PV Waste - the Example of the European H2020 Project CABRISS

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***Abstract* - Focus of the research efforts is using Si waste for the high throughput, cost-effective manufacturing of hybrid Si based solar cells. The European H2020 project CABRISS ("Implementation of a circular economy based on recycled, reused and recovered Indium, Silicon and Silver materials for photovoltaic and other applications") http://www.spire2030.eu/cabriss demonstrates the re-usability and recyclability of end-of-life PV materials by associating together different sectors like the powder metallurgy (fabrication of Si powder based low cost substrate), the PV industry (innovative PV cells) and the industry of recycling (hydrometallurgy and pyrometallurgy) with a common aim: making use of recycled waste materials (Si, In and Ag). Proactive involvement in European standardization guarantees compatibility with the EU's WEEE directive. CABRISS proactively cooperates with SEMI's "TC Photovoltaics", CENELEC's CLC/TC 111X "Environment" and CLC/TC 10 "Energy-related Products". Thus, the consortium contributes to the interactions and benefits between research and standardization: raising awareness and fully exploiting the role of standards in order to increase the competitiveness of the EU.**

***Keywords* – photovoltaics, standardization, innovation, circular economy**

I. INTRODUCTION

Europe is paying increasing attention to innovation issues as well as commercialization of research findings. Aiming to enhance Europe's competitiveness through promotion of innovation, bridges between research and standardization were built within the last years [12]. While the outcomes of research projects constantly need to be regarded by standardizers, researchers are, vice versa, dependent on information on standards that are already applicable or currently being developed. The implementation of new standards itself may even necessitate additional research activity, for example when appropriate test methods are required.

II. STANDARDISATION AND INNOVATION

It is becoming more and more vital to raise awareness about standardization and to emphasize its importance as an opening key to the market for new technologies and research. The incorporation of up-to-date scientific discoveries and technological developments into new standards can provide a foundation for subsequent developments and research. A vivid knowledge circle of standards and research can be put into motion this way.

TABLE I. ISSUES CONCERNING STAKEHOLDERS AND RESEARCHERS AND THE SOLUTIONS PROVIDED BY STANDARDIZATION [2]

Issues	Solutions
Standardization processes take more time than the duration of the related research projects	There are different standardization processes; some can be finalized in shorter time. Though finding consensus can be time-consuming, the final outcome will be a more suitable standard with improved recognition and wider significance
Professional contribution of individual researchers is recognised neither in standards nor in academic careers	Potential solution: demonstrating authorship resp. granting standardization work comparable appreciation and credit as publishing
Researchers are unfamiliar with possible approaches towards involvement in standardization	Standardization bodies offer clear information how to get involved
Participating organizations do not have sufficient resources or funding for involvement in research projects	A range of funding resources can be applied for both on national and European levels and can be granted for standardization in research projects
Industry and especially SMEs do not see the benefits	There are benefits related to easier access to the market
Existing standards sometimes constitute a barrier to new technologies	Progress-inhibiting existing standards can be overcome by working on the development of new standards or by revising the old standards

Since the begin of European Framework Program 6 standardization has been a key factor in innovation and research, and has been of great relevance throughout Horizon 2020. Thus, researchers are encouraged by the EC to involve the aspect of standardization in their projects and in the development of proposals. Furthermore, the EC encourages researchers to take part in the work of Technical

Committees (TCs). Through engagement in research activity, National Standards Bodies and national Electrotechnical Committees can act as a bonding link between researchers and industry. This can be achieved by spreading the outcomes of research and by assuring communication and close cooperation between the key actors when standards are being developed. By participating in research projects and by close exchange with researchers in standardization the following benefits will be achieved:

- Networks and interaction with other communities will grow.
- New areas for standardization and new markets for commercialization and application of research findings will be identified.
- The number of competent researchers in Technical Committees and other technical bodies will increase.
- Competence will be gained through involvement in research projects.
- Awareness amongst policymakers and stakeholders about standardization organizations and their impact on innovation processes will increase.

International standardization is a highly social activity involving specialists, detailed observation of the written standardization process, and a clear strategic agenda. Often it is a highly organizational activity, and in many cases is a highly individual-dependent activity. Consensus building is an important process which demands the following skills:

- skills in communications, listening, persuasiveness, motivation, and facilitation.
- sharing awareness of each party's positions, expectations and backgrounds.
- sharing goals, costs, risks, quality requirements, measures, and alternatives.
- ability to foster compromises.

III. WEEE AND THE H2020 PROJECT CABRISS

A. *Impact of European legislation*

A target of European legislation is the development of environmental-friendly solutions which aim at the issue of Waste Electrical and Electronic Equipment WEEE [6] which also entails PV waste [4]. WEEE contains a broad variety of materials which act as a major potential threat to the environment if not handled appropriately. Additionally, rare and expensive materials are used in the production of state-of-the-art electronic devices (for instance, around 10% of total gold worldwide is used for electrical and electronic components). It is substantial for the world's transition to a sustainable energy future to improve the environmental handling of WEEE and to foster a circular economy, as well as enhancing the complete chain of collection, treatment, reuse and recycling of end-of-life electronics [5]. Since the recast Waste Electrical and Electronic Equipment (WEEE) Directive 2012/19/EU came into force on 13 August 2012, a legal framework for extended producer responsibility of PV modules is provided at a European level. Regulations regarding the collection, transport and treatment of photovoltaic panels are effective in every single European Union (EU) country as of 14 February 2014. The predominant majority of PV modules that have been collected result from large-quantity on-site pick-ups.

CABRISS [7] aims at stimulating a circular economy that manages the critical situation of recycling the significant volume of photovoltaic waste. The project aims to benefit also to electronics, metallurgy and glass industries by these means.

TABLE II. VALUE OF MATERIALS FROM END-OF-LIFE PHOTOVOLTAIC PANELS, SOURCE: RESIELP [19]

Materials	Indicative price [€/kg]	Weight [kg]	Value [€]
Ag	469.26	0.00889	4.18
Si	8.99	0.6	5.40
Glass	0.04	14.82	0.593
Al from cells	1.32	0.0275	0.0363
Cu	3.79	0.2	0.758
Al frame	1.36	2.5	3.40
		Panel value [€]	14.36

CABRISS' main objectives:

- Achieving a collection of up to 90% of the PV waste throughout Europe compared to the 40% rate in 2013.
- Retrieving up to 90% of the high value raw materials from the PV cells and panels: silicon, indium and silver.
- Establishing industrial symbioses by providing raw materials such as glass or silver as feedstock for other industries (e.g. glass, electronics or metallurgy).
- Lowering the cost (25% less) of manufacturing PV cells and panels from the recycled raw materials while achieving at least the same performances (i.e. cells efficiency yield) as the conventional processes thanks to the implementation of a solar cell processing roadmap, which uses Si waste for the high throughput, cost-effective manufacturing of hybrid Si based solar cell.
- Fostering Involvement of the EU citizens and industry into such a sustainable and financially viable new economy.

Generally, a variety of clusters, both at the European and national levels, are the relevant focal points for the European research and innovation community (for instance European Technology Platforms, National Contact Points

and Joint Technology Initiatives). At these clusters awareness can be raised about the significance of standardization in research projects among their members and proactive participation can be promoted. Insight into their respective purpose and background is needed for a successful involvement of these different channels and networks. Industrial symbiosis needs proactive coordination between a variety of stakeholders. The main target stakeholders of CABRISS which need to be addressed are:

- Standardization bodies: International standardization organization such as: (CEN/CENELEC, ETSI, IEEE, etc.) and national such as: AENOR, DIN, SFS, UNI, NEN they develop and establish product and/or process standards to be followed by project partners producers and application developers.
- Certification entities**:** (EEPCA - Professional Association of the European Certification Bodies, EECC - The European Certification Council, etc.) provide confidence to users that a certain element of the CABRISS project is produced and/or operated according to a defined set of best practices or standards.
- Photovoltaic systems suppliers, installers and service providers through national, European and international associations related with the technologies developed in the project.
- Training providers: provide training to qualify developers and other professionals to work with the CABRISS project results. Such as: Universities, RTD and devoted training organizations.
- Local authorities & national/regional public bodies are key players as policy makers, favorable legislative framework creation, public procurement, owners and promoters of their own buildings are also end users interested in cooperative working systems or applications. Such as: European housing ministries.
- European PV clusters represented by their cluster managements act as knowledge hubs and regional networks of trust for exchange on project results with relevant audiences related to the PV sector.
- Manufacturers and suppliers. To be provided with appropriate training, tools and guidelines for them to consider the integration of recycled photovoltaic materials in their products.
- Public and private real estate promoters. They can offer to their clients the advantage of the developed system therefore they should be informed about it and especially about new business models that could help to foster the adoption of the technologies.
- Clients and users (citizens): key actors interested in cooperative working systems or applications providing their perspectives in the formulation and assessment of the project results in aspects such as, design for all, adaptability for the future and value procurement through and new business models.
- Network operators: may act as a channel for offering and billing services and/or access devices to users. Such as: Eurelectric – Union of the electricity industry.
- Energy Management Agencies. Regional and/or national energy agencies are promoting efficient and innovative building-related energy technologies. IEA – International Energy Agency.
- Other related projects and platforms.

Figure 1. CABRISS consortium

The consortium of CABRISS (16 Institutions from 9 Countries Comprising 6 SMEs, 5 Industries and 5 RTOs) covers the whole value chain from the collection of end-of-life PV modules to the transformation into new modules following a dedicated process of extraction and recycling. All the partners of the CABRISS project were selected according to their complementary skills. PVCYCLE will be leading the collection of end-of-life PV modules and cells, and PV waste while LOSER and RESITEC will be in charge of dismantling and extracting materials from these collected modules. The transition to a more circular economy requires action throughout a product's life-cycle [8], production to the creation of markets for waste-derived raw materials. Especially in the field of waste management further improvements are needed and within reach: increasing waste prevention, reuse and recycling are main targets of both the action plan and the legislation on waste. Two technology steps are addressed in CABRISS: (i) collection of end-of-life modules, cells and PV waste and (ii) dismantling, extraction and recovery.

CABRISS has established contacts to SEMI [10] and CEN/CENELEC [11] for a closer cooperation and

knowledge exchange. SEMI is the global industry association which serves the manufacturing supply chain for the micro- and nano-electronics industries.

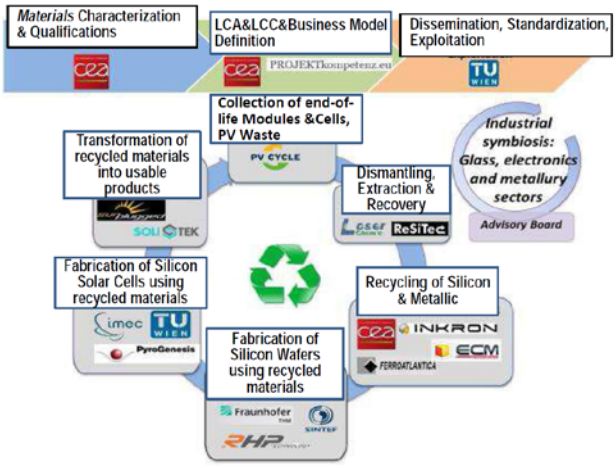

Figure 2. CABRISS value chain.

CABRISS proactively cooperates with SEMI's "TC Photovoltaics", CENELEC's CLC/TC 111X "Environment" and CLC/TC 10 "Energy-related Products". EC's standardization request M/543 requires "Definition of parameters and methods relevant for assessing durability, upgradability and ability to repair, re-use and re-manufacture of products". The CEN/CENELEC 45550 to 45559 series cover the aspects of recyclability, product durability, reparability, reusability, recycled content, ability to remanufacture, and product lifespan. Drafts of standard documents were made accessible to all CABRISS' partner institutions for commenting.

- prEN 45550 – Definitions related to material efficiency.
- prEN 45551 – Guide on how to use generic material efficiency standards when writing energy related product specific standardization deliverables.
- prEN 45552 - General method for the assessment of the durability of energy-related products
- prEN 45553 - General method for the assessment of the ability to re-manufacture energy related products.
- prEN 45554 - General methods for the assessment of the ability to repair, reuse and upgrade energy related products.
- prEN 45555 - General methods for assessing the recyclability and recoverability of energy related products.
- prEN 45556 - General method for assessing the proportion of re-used components in an energy related product.
- prEN 45557 - General method for assessing the proportion of recycled content in an energy related product.
- prEN 45558 - General method to declare the use of critical raw materials in energy related products.
- prEN 45559 - Methods for providing information relating to material efficiency aspects of energy related products.
- Involving the consortium from the begin gave the basis for having standards which are both in line with the requirements of industry and on the other hand are in line with the state of the art of technologies.

B. *Critical raw materials*

An additional generator for innovations is the Raw Materials Initiative [13] which addresses the challenges Europe is facing with regard to access to raw materials. This list's main aim is the identification of economically important raw materials to which reliable and unhindered access is a crucial necessity for the European industry and value chains, but whose steady supply cannot be relied on. The list follows an objective methodology and can be used as a basis for trade, innovation and industrial policy measures and thus increase Europe's competitive performance in line with its renewed industrial strategy [14], for instance by:

- identifying fields where investment is necessary to foster Europe's independence of imports of raw materials.
- supporting innovative projects which engage in raw materials supply under the EU's research and innovation programs.
- raising attention to the significance of vital raw materials for a shift towards a more circular economy.

The Raw Materials Initiative should help stimulate the European self-sufficiency regarding critical raw materials by improving their efficient use, extraction, recycling or replacement. Such critical raw materials are a main focus of the EU Circular Economy Action Plan [15]. The list may also be useful for reviewing foreign direct investments in the EU [16].

C. *Communication channels*

Reference [2] illustrates that standards serve as useful knowledge transfer tools which yield beneficial impact on product, service and process innovation. This effect can take place either as written input (such as knowledge in form of documents – codified knowledge), or as additional knowledge (tacit knowledge).

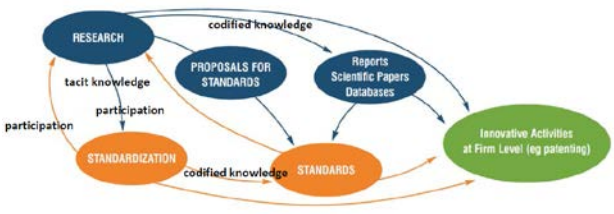

Figure 3: Knowledge transfer [2]

Fig. 3 illustrates the importance of written down knowledge, both in the form of standards, and in the form of scientific publications which act as a strong motivational incentive within the research community. Furthermore, Fig. 3 shows that knowledge exchange does not solely take place through scientific research publications or by involvement of researchers in standardization activity, but also through the firms themselves, which in their innovative developments combine knowledge stemming from both research and standardization.

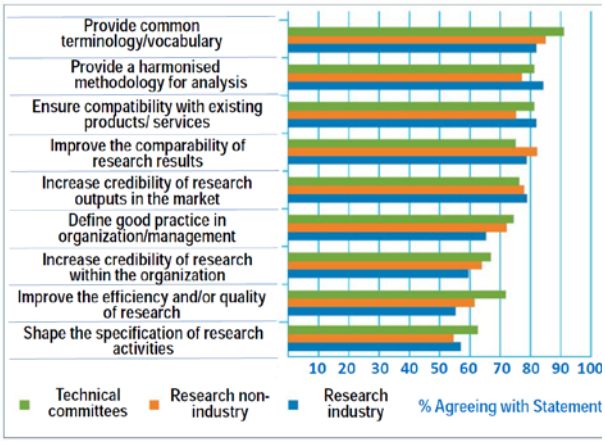

Figure 4. Benefits of Research by Using Standards [18]

The nine different terms contained in Fig. 4 can be categorized into the following three groups:

- Research methods: provide common terminology/vocabulary, provide a harmonized methodology for analysis, define good practice in organization/management.
- Research content: improve the efficiency and/or quality of research, shape the specification of research activities.
- The market acceptability of research outputs: ensure comparability with existing products/services, improve the comparability of research results, increase credibility of research outputs in the market, increase credibility of research within the organization.

This shows that the influence of standards is not the same throughout all different types of research. Standards have greater impact for innovation (especially through innovative technology and further developments) while it has smaller impact on fundamental research activities. When decisions are made about the organization of investment into finding new knowledge, standards can be a determining factor for the decision making. Thus, standards could be a basis for potentially ground-breaking innovation.

During early stages of innovation processes, standards may simplify the process of research by enabling effective communication between the different involved research facilities as well as by creating a shared basis for the common collection of data and results.

However, as we get closer to commercial applications, standards provide important elements of marketability and may also assist companies to show that they are meeting regulatory requirements. In this case, standards are therefore part of the 'demand pull' side of the innovation system – which in turn creates flows of knowledge from products and markets back into research and innovation.

The predominantly important topics can be summarized under the following terms:

- Management and control: point out cases where beneficial cooperation is hindered by barriers between the innovation and standardization actors.
- Awareness: raise awareness of standards, the processes behind standardization and emphasize how the innovation and research community can benefit from it (including funding agencies and government organizations); encourage innovators and researchers to take into account the role of standards and standardization.
- Improved linkages: develop improved tools to encourage the research community to participate in standardization and to simplify the processes behind it; implement appropriate mechanisms for supporting the provision of standardization expertise to relevant research projects.
- Coordination: strengthen bonds between H2020 and standardization activities.

D. IPR and Standards

While the aim of standardization is to share ideas with the public, patents have the purpose to protect an invention as the inventor's property for a limited time [17]. Due to the coexistence of IPR and standards, the consideration of protected IP of firms is just as inevitable in standard setting as in other fields. The systems of standardization and IP protection can potentially impair each other reciprocally in a manner that is detrimental for productive entrepreneurship. A case of such a collision are "essential patents". Patents are essential for a standard when a product/method needs to cause an infringe with the patent holder's IPR to fulfil the criteria of the standard. Such a constellation can deliberately be abused through "hold – up" or "patent ambush". In such a case the holder of a patent does not lay open the existing patent to the circle of addressees of a standard. After the standard has been implemented, those bound by the standard find themselves forced to pay royalty fees by the ambushing patent owner.

The CEN and CENELEC patent policy frameworks demand from those who participate in the technical work, especially from patent holders, early disclosures and identification of patents that may be considered, at the best of their knowledge, to be essential for the future use of the deliverables under development. The CEN/CENELEC Guide 8 [18], contain a statement form for this purpose. Holders of essential patents in standards, will be required to guarantee license negotiation under fair, reasonable and non-discriminatory terms and conditions (so-called FRAND conditions) with applicants internationally.

IV. CONLUSION

The focus of CABRISS lies on the collection, de-pollution and treatment technologies for end-of-life PV as prerequisites for recovery and recycling. By proactive involving European standardization, validity of results is guaranteed for the market. While growing photovoltaic (PV) panel waste embodies a new environmental challenge, it also bears unprecedented opportunities to create value and to open new economic paths. The European project CABRISS aims at the implementation of a circular economy based on recycled, reused and recovered Indium, Silicon and Silver materials for photovoltaic and other applications. On the one hand, this approach is in line with the European legislation which is fostering the development of a green solution to master the issue of Waste Electrical and Electronic Equipment WEEE including PV waste. On the other hand, the efforts are in line with the EU's philosophy on how to deal with critical raw materials

ACKNOWLEDGMENT

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Analysis of Real-Time Kinematic Samples Error for Sensor Fusion Applications

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***Abstract*— Recent developments in the fields of autonomous vehicles led to their widespread acceptance in many usage scenarios which include remote inspection, particularly in places not easily reachable or dangerous for humans. Global navigation satellite systems have become popular due to their convenience and low cost. The main disadvantages of typically used GNSS systems are relatively low refresh rate and low positional accuracy. The real-time kinematic method can be used to enhance the precision of GNSS but it still provides a relatively low refresh rate. Inertial navigation systems are based on inertial sensors, such as accelerometers and gyroscopes which provide high refresh rate. The main disadvantage of INS systems is the inherently present positional integration error of inertial sensors. The sensor fusion approach can be used to couple both the high positional accuracy brought by RTK and the high refresh rate resulting from the use of INS. However, coupling RTK and INS via sensor fusion approach is not a straightforward process due to challenges introduced by outliers and discontinuities in RTK positional data due to various factors affecting the GNSS signal reception. In this paper we present a static analysis of captured RTK data that can be used for further development of a method for compensation of unwanted side effects to enhance and stabilize the positional accuracy of the sensor fusion systems that incorporates both RTK and INS approaches.**

***Keywords*— GNSS, RTK (real-time kinematic), sensor fusion, inertial sensors, precision positioning**[1]

I. INTRODUCTION

In the last decade, GNSS (global navigation satellite systems) became widely available because of the emergence of low-cost and simple to use GNSS receiver modules and thus becoming acceptable as a default navigation system for low cost devices integrating those modules. GNSS positioning accuracy is within several meters range what is suitable for various applications where high accuracy is not required, particularly in applications where the open sky is available most of the time [1], [2]. These low-cost GNSS receiver modules use low power, are easy to interface with many microcontroller architectures and do not require any additional infrastructure or special permits that are regulated with subscription policies usually coupled with additional costs, despite the fact if they increase positioning accuracy or not [3]. There are some applications when the positioning accuracy of traditional GNSS systems is not acceptable. The example of such application is positioning of autonomous vehicles which size is comparable to the positioning error. If the vehicle is sized around 5 meters, which is a significantly larger than the positioning error, the impact of the positioning inaccuracy is not large. However, for small vehicles such as tiny drones such error could have a significant impact, depending on the target application. Control algorithms of autonomous vehicles that operate on high-speed basis require a relatively high frequency of the position update, usually in the range of 10 Hz, what is not always achievable with GNSS [4], [5]. To compensate for low refresh frequency of GNSS systems, INS (inertial navigation systems) are used. INS have a relatively high frequency of position update (in range of few 10 to 100 Hz) but they are used to calculate relative position instead of the absolute (global) positioning. Basic principles behind INS systems encompass signal processing using data from sensors that provide data about dynamic motion - accelerometers, gyroscopes and magnetometers [6]. By integrating acquired data through time, relative position can be calculated at higher frequencies than GNSS methods of positioning. The main disadvantage of INS systems in comparison to GNSS is the integration error that is inherently generated by the process of summation because it includes errors of input measurement chain along with useful signal from sensors [7],[8]. Navigation systems based on GNSS methods can provide continuous accuracy for long periods of time. Usually the accuracy gets better over the time because of the positioning algorithm convergence, but higher accuracy comes with lower response time [9]. Navigation systems based on INS methods lose the accuracy during the measurement because of integration error effects but they can output the position with higher frequency. The beneficial properties of both INS and GNSS can be combined by implementing sensor fusion algorithms that generate the output that is continuously highly accurate and that has a satisfactory position update frequency [10].

Typical sensor fusion algorithms [11], [12] include Kalman filter, Bayesian networks [13], Dempster-Shafer and convolutional neural networks [14], where Kalman filter is a preferred method of sensor data fusion represented as a series of measurements observed over the time. The main goal of Kalman filter is to produce an estimate of an unknown variable in statistical terms that tend to be more accurate than those based on individual sensor data. Kalman filters use unknown variables with normal distribution curve as inputs because of the natural tendency of values to the mean value. Sensors used

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in INS systems have behavior similar to the unknown variable with a normal distribution curve therefore by having these observable and measurable statistical properties they can be used in Kalman filters directly. GNSS methods of positioning do not produce output variables that have a normal distribution curve [15]. The situation gets worse with high tropospheric effects introducing various discontinuities in the otherwise continuous time-based data series.

II. GPS AND RTK POSITIONING

GNSS uses satellites for its operation and currently operational GNSS systems are American GPS (Global Positioning System), European Galileo, Russian GLONASS and Chinese BeiDou [1]. GNSS receivers calculate the position defined through the absolute global coordinates by calculating the time that the signal from multiple satellites passes from Earth's orbit to the receiver. Satellite position is precise and known beforehand. Typical precision of GPS is 5 m while Galileo has a precision of 1 m. Using encrypted channels for satellite communication the precision of Galileo system gets close to 10-centimeter values, but with the added cost and time-based subscriptions. Using this method of precision positioning is not economically viable now. There are other frequencies at which GNSS satellite communication is operating but those are reserved for military use and are not publicly available. When calculating the absolute geographic position traditional GNSS receivers first need to measure the distance to each of the satellites from which they receive GNSS signal. They do that by comparing the signal received from the satellite demodulated as a pseudo-random binary sample with locally stored reference sample they expect to receive. This method is also called comparison by model. There is some significant and measurable phase difference between these samples because it takes time for the signal to travel from the satellite to the receiver on the Earth surface. That phase difference is then used to calculate the distance between the satellite and receiver. Calculated distance accuracy depends mostly on the quality and signal processing capabilities of the receiver, environmental factors that affect the signal as it passes through the ionosphere and troposphere, refraction and interference of the signal and lastly real-time clock accuracy on the satellite and the receiver.

RTK (real-time kinematic) is a method used to enhance the precision of the regular GNSS. RTK method uses GNSS receivers that receive signals from the publicly available satellite network but they use special techniques enabling them to accomplish even the centimeter level accuracy of global positioning [16]. This is primarily achieved by using the data from the signal carrier and signal processing algorithms rather than signal binary data alone as it is used by traditional GNSS receivers. The signal noise of the carrier is much lower in value than the noise in the generated binary data received from the publicly available satellite network. Theoretical positioning error by using traditional GNSS signal processing is around 1 m, but when using the signal carrier phase difference positioning error can be as low as 5 mm. The main theory behind the RTK operation is to use two receivers (mobile and base station) that are not separated by a large distance. Both stations use the phase difference as a method of position calculation, where the base station has a well known position which is not varied over the time, meaning that it is statically positioned and the mobile station position can be accurately determined from the phase differences of received carrier signal on both receivers. Both stations share data using a wireless network where the base station sends correction data to the mobile station which uses that data to compensate for errors normally affecting the standard way of positioning by using GNSS networks [17]. Both stations receive the same signals which are affected by the same error sources. Using the RTK approach the error that is common for two closely positioned receivers converges to zero by mathematical processing of the received signals. RTK method has faster convergence when both receivers have good sky visibility because in that case the common error has maximum correlation. Increasing the distance between two receivers introduces a difference in error of the received signals mainly due to different tropospheric effects on the signal path which are more uncorrelated and thus can not be efficiently eliminated. Therefore, RTK algorithm loses the benefits of higher accuracy when separation between stations is about 20 km or more.

A. GPS convergence

GNSS systems rely on distance calculations between the receiver and satellites. These calculations are not readily available for the receiver users because of the Time To First Fix [18] (TTFF). TTFF[2] is a performance measure of a GNSS receiver that accounts for the time elapsed from the GNSS receiver power-on until the output of a navigation solution within a certain accuracy range. That time can be expressed as:

$$TTFF = T_w + T_{acq} + T_{track} + T_{NAVm} + T_{NAVs} \qquad (1)$$

where T_w is the receiver warm-up time, which includes software and hardware initializations and therefore is highly dependent of the receiver type and quality, T_{acq} is the time that takes the receiver to acquire a set of data that is large enough to give the first navigation solution, T_{track} is the time taken to achieve tracking stability (it is the time in which the tracking loops converge and data frames from multiple satellites are synchronized), T_{NAVm} is the time spent to decode navigation messages, and T_{NAVs} is the time in which the computation of first navigation solution is executed. There are several navigation solutions depending of the positioning quality, namely 2D and 3D fix. 3D fix means that the GNSS receiver outputs positioning data in three dimensions within the satellite system specified accuracy. Besides the clock time base difference between the satellite and receiver clocks, which creates phase ambiguity between them, the two factors that influence signal quality the most are ionospheric and tropospheric effects on the signal path.

The ionosphere is the part of the Earth's atmosphere that is located between 60 and 600 km above the Earth's surface. This part of the atmosphere is primarily influenced by the Sun whose UV and X rays ionize particles contained in this area.

[2] http://www.navipedia.net/index.php/TTFF

The density of ions varies with the Sun's activity. For example, during the day the Sun ionizes particles while during the night the free ions are recombined to form neutral atoms. It is difficult to predict the exact influence of the ionosphere to signal propagation because the density of ionized particles is constantly changing. The induced propagation delay to radio frequency signals is proportional to the signal's frequency. Geodetic grade dual band GNSS receivers use this fact to correct the effects of the ionosphere because they simultaneously receive two GNSS signals of different frequencies. The influence can be corrected by comparing the difference in propagation delays between the signals. Single band GNSS receivers have to rely on models of the ionosphere to make corrections [19].

The troposphere is the part of the Earth's atmosphere that is located up to 60 km above the Earth's surface. Most weather phenomena occur in the troposphere. Approximately 99% of the total mass of water vapor and 75% of the atmosphere's mass is contained in the troposphere. The tropospheric delay is influenced by humidity, temperature and air pressure. Unlike in the ionosphere, the influence is constant and does not depend on the frequency of RF signals. That means that even geodetic grade GNSS receivers can not compensate for tropospheric indulged delays. Single GNSS receivers use environmental short and long-term prediction models to compensate for the influence of troposphere [19].

B. *RTK covergence*

RTK algorithm is based on processing the raw GNSS data output to extract both the pseudo-random binary codes, like normal GNSS receivers, *and* the phase difference in carrier signals for two closely positioned terrestrial receivers, thus effectively bypassing the navigation signal decoding phase as it is implemented in normal GNSS receivers. Time to float is a measure of time that RTK takes to give stable and good navigation solution. Because RTK relies fundamentally on GNSS receivers, time to float is firstly influenced by a warm-up time, signal acquire time and signal tracking time of the receiver. Secondly, it is dependent on the time spent on the convergence of the RTK algorithm which uses some of the GNSS data that itself has convergence time. Observing this dependency relationship it can be concluded that RTK is very sensitive to the short-term effects of the ionosphere and troposphere. While ionosphere effects usually have significant changes in periods of 20-40 minutes and affect the signal continuously, tropospheric effects are more influential because they include short-term blockage (in a range of seconds to minutes) of the optical signal path thus generating disruptions in the received signal. These short-term disruptions consequently lead to the signal discontinuities and they can have an affect on the stability of the RTK navigation solution precision if they last long enough to disturb the RTK algorithm. Therefore, in this paper we analyze the performance of the RTK algorithm in static conditions (i.e. mobile and base stations not moving) to investigate the RTK algorithm behavior due to the disruptive stochastic influences of atmospheric effects to assess the viability of using the RTK as an input in sensor fusion system with INS based on Kalman filters due to the non-Gaussian nature of RTK signal [20], [21].

III. SAMPLE ANALYSIS

RTK algorithm fundamentally depends on calculations involving the signals acquired by two receivers, the mobile and the base station.

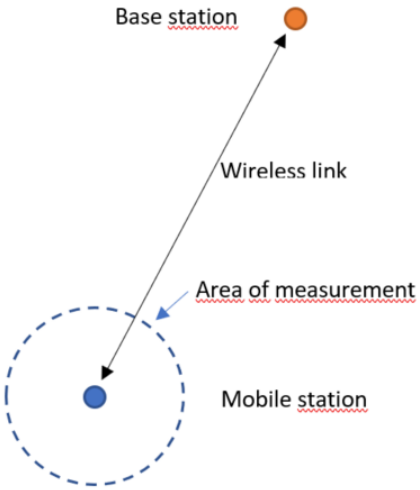

Figure 1. Experiment setup

Coordinates of the mobile station are calculated by RTK algorithm from signals acquired by two receivers, the base and the mobile station. Distance between the stations is 20 cm and unchanged during measurement procedure. Due to previously explained influences of atmospheric effects, obstructions in signal path and inherent receiver noise, errors are present in calculated coordinates of the mobile station. The goal of research presented in this paper was to assess the statistic properties of the mobile station coordinate errors obtained by RTK algorithm calculations. As was noted before, Kalman filter for sensor fusion applications assumes Gaussian error model of input variables while coordinates obtained by RTK algorithm exhibit different statistical properties. Area of measurement is a range in which the RTK is reporting position data. The idea behind the proposed static analysis is to place both receivers on fixed positions, without interfering with the signal path during the measurement time. In our static analysis give an input to the RTK algorithm that the position of the queried station (i. e. the mobile station) do not change over the time so that we isolate the uncertainty caused only by other error sources directly from calculations. Measurements were performed using two U-blox NEO-M8T[3] single band GNSS modules and U-blox ANN-MS antennas. The receivers were connected to a personal computer running RTKlib [22] software which is used to perform RTK calculations in a real-time. Measurements in a form of raw GNSS data were taken from U-blox NEO-M8T with a sample rate of 1 Hz. The measurement location situated on the top of the building provided a clear view of the sky without large buildings and

[3] https://www.u-blox.com/en/product/neolea-m8t-series

trees in the surroundings that would block the view and interfere with GNSS signal path. The duration of measurement was 1495 s (00:24:55). The weather was clear with good sky visibility. During the measurement there were at least 8 and at most 15 satellites in use (in 417 out of 422 data points). RTK convergence was achieved after 403 s (00:06:43). Coordinates that were determined by RTK algorithm for the measurement location are:

- latitude: (45,8002685431 ± 0,0000000951)°
  deviation: 10,17 mm
- longitude: (15,9710096676 ± 0,0000000907)°
  deviation: 10,08 mm
- height: (178,672 ± 0,041) m

RTKlib outputs various data, including GNSS time, latitude, longitude, height and ratio of certainty. To simplify data processing, instead of observing latitude and longitude the relative distance was analyzed and height was ignored as it is not relevant for planar positioning. Based on the acquired data, the center point of the position is expressed as the mean value of the whole dataset. Data is expressed using reference coordinate system WGS84, which includes Earth's ellipsoidal curvature, therefore distance cannot be calculated by a simple quadratic calculation [23]. The area of the measurement was less than 1 m which is by many orders of magnitude smaller than the Earth's radius, leading to the conclusion that in this case the Earth's ellipsoidal curvature can be simply considered as a spherical curvature what simplifies the distance calculation. The distance between that center point and every other point in measurement dataset is calculated as a great-circle distance using the Haversine function:

$$d = 2r\sin^{-1}\left(\sqrt{\left(\sin\frac{lat_2 - lat_1}{2}\right)^2 + \cos lat_1 \cos lat_2 \left(\sin\frac{lon_2 - lon_1}{2}\right)^2}\right) \quad (2)$$

where d is calculated distance in meters, r is Earth's radius (6371 km), lat_1 is the latitude of the first point, lat_2 the latitude of the second point, lon_1 the longitude of the first point, and lon_2 the longitude of the second point.

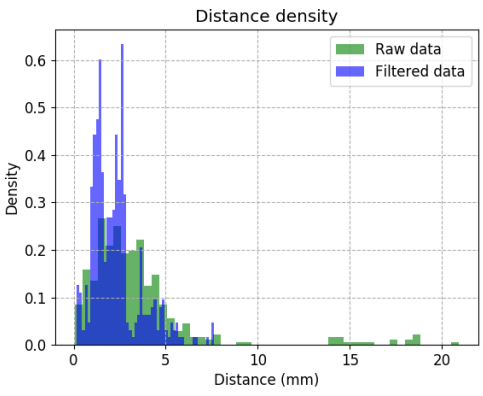

Figure 2. Distance histogram with outliers

Data in Fig. 2 is plotted as an approximation of the distance probability density function of the original dataset, where the acquired data was divided into 50 consecutive, non-overlapping intervals. It can be observed that the raw data histogram (green colored graph) displays a wide characteristic which includes discontinuities in the RTK signal output, resulting in the distance calculations of as large as 20 mm. These discontinuities, called outliers, manifest in rare cases and their contribution to the signal density is minor but still significant. If we consider their random occurrence in time in RTK input signal, our navigation solution would become unstable for a moment and, in case of RTK, it would break the quality of the navigation which consequently stretches the continued convergence time. Sometimes these discontinuities can alter and displace navigation tracking abilities, meaning that true vehicle path is not consistent. Using a simple Kalman technique to filter input coordinates, with the process variance of 10^{-5} and the Kalman gain in terms of estimated measurement variance of 10^{-3}, it can be observed that these outliers influence the filtered distance histogram by increasing the area of possible distance values (less than 20 mm) and thus delivering less precise navigation output.

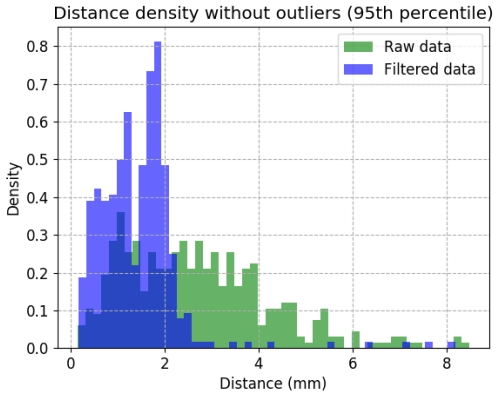

Figure 3. Distance histogram without outliers

If outliers are discarded, raw and filtered distance density histogram data are less dispersed and more consistent which can be seen in Figure 3. Because the raw RTK data before Kalman filer does not follow normal distribution, the 95th percentile is used as a discarding criterion for outliers, meaning that any data larger than 95% of the whole dataset is discarded and considered an outlier [24]. Observing the measurement system and RTK algorithm, the conclusion is that the outliers are possibly generated by tropospheric effects and possibly in a few cases by ionosphere or receiver and satellite clock drifts that last only for a brief period. If RTK algorithm is solely used for positioning, there is no certain method to acknowledge that data gathering in real-time is an outlier. If the measurement system consists of INS and RTK positioning methods, the INS system can acknowledge even the rapid changes in the position verifying that the change has, in fact, happened ensuring the measurement output integrity and even report the quality of positioning. This method is not using INS in a sensor fusion fashion but to enhance the positioning capabilities of RTK.

IV. Conclusion

In this paper an introduction on GNSS positioning systems was given, along with an explanation of global infrastructure and emerging low-cost GNSS receivers. Relative positioning using INS is introduced. Performance analysis of GNSS versus INS systems is given expressed using refresh rate and ability to provide continued positioning accuracy. Sensor fusion approach is introduced as a method of selectively using better characteristics of both positioning methods. RTK positioning method is introduced as a viable choice to eliminate low positioning accuracy if GNSS system is used. RTK positioning with its centimeter level accuracy is a better choice despite its relatively high convergence time and sensitivity to ionospheric and tropospheric effects. RTK static analysis is performed to analyze the consequences of discontinuities generated mostly by the tropospheric effects. Method of RTK positioning augmentation by using INS data to verify even the rapid changes in measurement system position. Further research and development would yield a sensor fusion method capable of utilizing INS and RTK positioning methods combined to not only enhance RTK positioning certainty but to increase positioning refresh rate [25], [26].

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Link budget analysis for a proposed Cubesat Earth observation mission

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***Abstract*—A Cubesat with payload for characterizing electromagnetic and geomagnetic field is proposed. We review the link budget requirements for this mission to enable high data rate communication between a low Earth orbiting satellite and an Earth station. Multiple frequency bands, typically used in Cubesat operations, are evaluated, including attenuation and other link impairments along the communication path. We also review the communication parameters in currently deployed and active Cubesat missions.**

***Index Terms*—Cubesat, satellite communications, satellite link budget, Earth observation.**

I. Introduction

Cubesats are a standard form of pico-satellites sent into low-Earth orbit (LEO) for space exploration and Earth observation. The elementary unit of a Cubesat has dimensions 10 cm x 10 cm x 10 cm, and a maximum weight of 1.3 kg. Such a unit can be a complete Cubesat, thus making up a 1U form-factor Cubesat, or it can be stacked to form a 2U, 3U, or larger satellite. In comparison to commercial satellites, Cubesats are low-cost due to the large number of commercially available components. These satellites are generally developed and built by students and faculty at universities; the primary purpose being engaging students in space-related activities and providing a comprehensive engineering project of building a complex electronic system. For the university, such a project will also include multidisciplinary collaboration, as other research groups (e.g. astrophysicists, geologists, etc.) could benefit from the payload data, i.e. the observations the satellite will conduct from Earth's orbit.

We propose a Cubesat equipped with detectors for monitoring and mapping light pollution, electromagnetic noise originating from both Earth and space, and Earth's geomagnetic field. The satellite is planned to carry multiple types of novel optical detectors, optical filters, magnetometers and highly sensitive RF receivers. The measurements are expected to produce a large amount of data, which would require a high throughput link to an Earth station.

A link budget of an RF communication link is a set of parameters that describe a link in terms of power levels required to establish reliable communication between the transmitter and the receiver. It includes power penalties and gains associated with antennas and phenomena that affect the signal to noise ratio (SNR) in a communication link. The term "link budget" also conventionally refers to the ratio of transmitter power to receiver sensitivity required to obtain a certain bit error rate or signal to noise ratio.

In section II of this paper, communication parameters and frequency ranges typically used by currently active Cubesat missions are presented. Adequate communication parameters are selected for this mission. A satellite orbit is suggested and described in section III, and most significant attenuation and other propagation effects causing link impairments are presented in section IV. Commercially available antennas and satellite-side transceivers for Cubesat communication are presented in section V. All the provided information is summarized in section VI to calculate the link budget for the proposed satellite link.

II. Link requirements

Most of the currently active Cubesats communicate with Earth station on frequency bands that are either specifically allocated for space communication, or correspond to amateur (HAM radio) satellite frequencies. Typically used HAM radio frequencies are 145.8 MHz – 146.0 MHz in VHF band, 435.0 MHz – 438.0 MHz in UHF band, and 2.400 GHz – 2.450 GHz in S-band. The use of the latter band is preferred in a 3 MHz sub-band beginning at 2400 MHz. These S-band frequencies are shared with local general permits and ISM band, while the bands in VHF and UHF are exclusive to HAM radio use, with limitations on total radiated power and produced interference levels. The narrow bandwidth available in VHF and UHF bands allows only for small datasets to be transmitted, containing satellite payload information (including scientific measurements), along with telemetry and commands. VHF and UHF bands are often duplexed in order to increase the overall bandwidth. To achieve larger throughput, many satellite operators turn to S-band communication. The use of 2.400 GHz – 2.450 GHz band is often limited, as the produced interference levels must comply with other systems using this band. Link performance for this band is therefore akin to that of VHF and UHF bands, as seen for a transceiver in [1]. To achieve larger data throughput, a licensed 2.000 GHz – 2.300 GHz can be used. This band is allocated for space research and Earth exploration satellites, and is further separated into 2.025 GHz – 2.110 GHz for Earth-to-space operations, and 2.200 GHz – 2.290 GHz for space-to-Earth operations [2].

The communication system discussed here will focus on VHF and UHF amateur bands, and the 2.000 GHz – 2.300

GHz band for high data rate transfer. Link parameters are defined by common communication protocols in VHF and UHF bands, as further discussed in this section. For S-band, communication parameters correspond to those implemented by commercially available transceivers presented in subsection V-D.

A. Bandwidth

Cubesats operating in VHF and UHF bands largely use a HAM radio derivative of the X.25 protocol: AX.25. It features full-duplex communication when duplexed in both VHF and UHF bands. Maximum bitrate is 9600 bit/s [3]. The available bandwidth is 20 kHz, following restrictions listed in [4]. For S-band, a QPSK-modulated system will be used. We will take the communication parameters used by a commercially available transceiver, such as the one seen in [1]. The bitrate is 3.4 Mbit/s. Forward error correction is employed with a factor of 0.75, using a typical block code, such as Reed-Solomon. The square root raised cosine filter with a roll-off factor 0.3 is used. The configuration assumes a Nyquist-limited representation of the signal. The bandwidth in Hz is then obtained as

$$B = \frac{R_b}{\mathrm{SE} \cdot \mathrm{FEC}}(1 + r)\,, \tag{1}$$

where R_b is the bitrate, SE the ideal modulation spectral efficiency; 2 bit/s/Hz in case of QPSK, FEC the forward error correction factor, and r the filter roll-off factor. The required bandwidth for S-band is thus $B = 2.95$ MHz.

B. Signal to noise ratio

The required signal to noise ratio for achieving the proposed bitrate can be obtained from established communication parameters and the required E_b/N_0 ratio for ensuring a certain bit-error rate of a particular modulation scheme. For BPSK, used in AX.25, and QPSK, the required E_b/N_0 for a bit-error rate of 10^{-5} is 9.6 dB [5]. To calculate the required signal to noise ratio, we use the relation

$$\frac{S}{N} = \frac{E_b}{N_0} \cdot \frac{R_b}{B} \tag{2}$$

For VHF and UHF transmission we get $S/N = 6.4$ dB, and for S-band $S/N = 10.2$ dB.

III. Satellite orbit

In order to estimate the effects a communication link between the Earth and a satellite will suffer from, one must first determine the location of the satellite relative to the Earth station. An example low Earth orbit (LEO) is defined, based on historic launch configurations presented in [6]. The satellite's altitude is $h_s = 600$ km above mean sea level. Orbital inclination is $52°$. The orbital period for a satellite in the proposed orbit is around 96 minutes[1]. With time, all objects in LEO suffer from altitude degradation, having a large amount of atmospheric drag as the main cause. For this reason, the actual orbit must be re-evaluated

[1]Orbit simulation performed with SaVi [7]

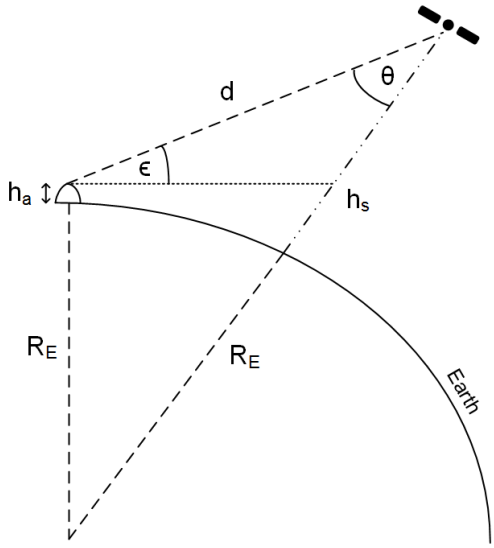

Fig. 1. Relative position of the satellite and the ground station at the farthest communicative distance

if a significant pointing loss is detected on Earth station antennas.

We also define the position of a ground station to be in broader Zagreb area in Croatia. The ground station is equipped with a number of high-gain parabolic dish antennas, enabling operations in VHF, UHF and S-band. The terrain configuration allows the ground station to observe the sky at minimum elevation of 20°, at an altitude of 120 m. In this configuration, a satellite following the suggested orbit would be visible to the Earth station around 12 times a day, in periods ranging from 8 to 12 minutes. Therefore, the satellite must be able to transmit all the prepared data in a number of bursts.

The link budget in section VI evaluates the worst-case scenario, in which the satellite is visible at a minimum elevation angle from the ground station. This angle will define the farthest position of the satellite relative to the ground station at which communication would be achievable. Relative position of the satellite to the Earth station, when viewed at the minimum elevation angle, is presented in Figure 1. Angle ϵ is the minimum elevation angle, here 20°, and θ is the angle between the satellite's orbital position vector (in geocentric coordinate system) and the shortest path to the ground station d. Lengths R_E, h_a and h_s are mean Earth radius, Earth station's ground level and satellite's height, respectively. From the geometry in Figure 1, the station-to-satellite distance is given as

$$\begin{aligned} d = &-(R_E + h_a)\sin(\epsilon) + \big\{(R_E + h_a)^2 \sin^2(\epsilon) \\ &+ 2R_E(h_s - h_a) + (h_s^2 - h_a^2)\ \big\}^{1/2}\ . \end{aligned} \tag{3}$$

For this Earth station configuration, the distance is $d = 1392$ km.

In this position, the ground station is visible from the satellite at an angle θ, which is found as

$$\sin(\theta) = \cos(\epsilon)\frac{R_E + h_a}{R_E + h_s}\,, \tag{4}$$

TABLE I
FREE SPACE LOSS

Frequency	L_{FS}
146 MHz	138.6 dB
446 MHz	148.3 dB
2200 MHz	162.2 dB

which, for this configuration, gives $\theta = 59°$. Radiation cones from antennas aboard the satellite will have to cover this angle to maintain communication. This is further discussed in subsection V-C.

IV. ATTENUATIONS AND PROPAGATION EFFECTS

The satellite link budget LB is distributed among the penalties, which include free-space propagation loss L_{FS}, rain attenuation P_R, depolarization penalty, expressed by *cross-polarization discrimination* (XPD), depointing penalty P_D, and antenna gains G_S [dBi] for the satellite antenna and G_E [dBi] for the Earth station antenna. Antenna gain is defined as the ratio of power density radiated in the maximum radiation direction to the average power density on a sphere containing the antenna. Comprising all above, and other possible penalties under a single coefficient P_P, the link budget can be expressed as

$$LB = P_{\text{tx}} + G_S + G_E - L_{\text{FS}} - P_P - P_M - N \quad (5)$$

where P_{tx} is the transmitted power, P_M the link margin; the amount of power left for random fluctuation in attenuation or degradation of the link, and N the overall noise on the receiver. Link margin should always be positive and preferably greater than 6 dB. The following subsections discuss the main penalties and antenna gains relevant to satellite communications. The link budget is generally computed for the worst-case situation.

After the link budget is met for the defined communication parameters, received power must be verified to be above the receiver sensitivity, which is defined as the received power, expressed in dBm, at which the receiver can detect a signal of a given symbol rate with specified bit-error rate. The total received power is expressed as

$$P_{\text{rx}} = P_{\text{tx}} + G_S + G_E - L_{\text{FS}} - P_P \quad (6)$$

A. Free space propagation

Major attenuation in satellite communications is caused by free-space propagation. At a distance d from the transmitter, the power density $S(d)$ drops to

$$S(d) = \frac{P_{\text{tx}}}{4\pi d^2}\,. \quad (7)$$

Relating the effective antenna area to the wavelength λ, free space loss L_{FS} can be expressed as

$$L_{\text{FS}} = \left(\frac{4\pi d}{\lambda}\right)^2\,. \quad (8)$$

For the frequencies of interest, free space loss for the farthest distance $d = 1392$ km is presented in Table I. In order to mitigate free space loss, highly directive antennas, high transmitter powers, and sensitive receivers must be used. These are discussed further in this paper.

B. Rain attenuation

Rain penalty is frequency-dependant, and generally higher for higher frequencies. Commercially used bands, notably Ku, K and Ka bands are much more effected than bands below 1 GHz [8]. Rain penalty is estimated by requiring that the rain-induced attenuation will not surpass the highest value expected during a certain percentage of time in one year. Typically, link availability during 99.99% of the year is required. ITU recommendations P.837, P.838 and P.839 provide a model for evaluating rain attenuation for a given Earth station site, in the frequency range from 1 GHz to 1 THz [9], [10], [11].

The specific attenuation can be presented as

$$\gamma_R = kR^{\alpha}, \quad (9)$$

and is expressed in units dB/km. Here, R is the rain rate in mm/h that is exceeded for 0.01% of time in one year at Earth station's geographical area. The value is obtained from maps in [9], by finding the location of the Earth communication site. Coefficients k and α are frequency- and polarization-dependant, and are provided by tables in [10]. They can also be well approximated by expressions given in [8] for frequency ranges 1 GHz – 40 GHz. Note that, for frequencies above 4 GHz, γ_R is often obtained by use of nomograms published in [12].

Rain attenuation is manifested through only a part of the communication path. The effective rain path length is calculated from expressions found in [11], and corrected by the sine of the ground station's antenna elevation angle.

For a ground station located in Croatia, R is equal to 42 mm/h. The rain attenuation is calculated for S-band communication around 2.2 GHz. Given an antenna elevation of 120 m above mean sea level, and the mean annual 0 °C isotherm height of 3.31 km, the rain-attenuated path is 9.82 km in length. The total rain attenuation is

$$P_R = 0.093\,\text{dB} \quad (10)$$

Therefore, rain attenuation at such low frequencies is negligible. For even lower frequencies in VHF and UHF bands, the rain attenuation is even less significant.

C. Polarization effects

Cubesats can be equipped with either linearly or circularly polarized antennas. In case of linear polarization, maintaining polarization across the communication path is required to receive the signal. Major problems in tracking the satellite antennas' polarization arise due to ionospheric effects [13], [14], notably *Faraday rotation*. This effect causes a linearly polarized wave to be rotated in the ionosphere, due to interaction with Earth's magnetic field. The effect is significant at frequencies lower than 2 GHz, and can be approximated as

$$\Delta\tau \approx 2 \cdot 10^{17}/f^2 \text{ [rad]}. \quad (11)$$

The coefficient in front of the frequency-dependent term depends on the current state of ionosphere above Earth

station's area. For frequencies around S-band, the total polarization rotation will be about 1°. For VHF and UHF, this turns into 320°, and 34°, respectively. This amount of rotation in VHF and UHF bands, along with the uncertainty of ionospheric model, makes polarization tracking difficult.

Depolarization is included in the link budget by XPD. Linearly polarized antennas may be used at Earth station if the current state of signal polarization can be well estimated. However, due to the very short visibility period of a satellite, polarization must be quickly measured, and the receiving antenna adjusted, so as not to miss the satellite or end up with a large pointing error. A common approach to solving the polarization uncertainty is using circularly polarized antennas at Earth station, thus eliminating the requirement for knowing the current state of linear polarization. This introduces a constant XPD of 3 dB.

If a satellite uses circularly polarized antennas, this loss is eliminated, as Faraday rotation will have no effect on signal propagation. This approach also eliminates the satellite attitude uncertainty that existed with earlier Cubesats that were not equipped with attitude control systems. The satellite system reviewed here will use circularly polarized antennas.

D. Ionospheric scintillation

For waves below 3 GHz, irregularities in the received amplitude, phase, polarization, and direction of arrival are caused by rapid fluctuations in ionization density [14]. The effect is more intensely observed in equatorial and polar regions. For latitudes between 20° and 60°, the effect is considered negligible [15]. Therefore, for an Earth station in Croatia, this penalty can be ignored.

E. Doppler shift

The satellite's high orbital velocity is the cause for the Doppler shift of the carrier frequency. In large communication satellites, compensation is implemented on the satellite itself. With Cubesats, correction is normally performed on the ground station, given a corrected orbital model. Therefore, no penalty from this effect is expected.

V. Antennas and transceivers

A. Satellite-side antennas

Cubesats are typically equipped with commercially available antennas for space applications. For S-band communication, patch antennas are used, such as the one found in [16]. This antenna has a gain of up to 8.3 dBi. The half power beam width $\theta_{3\text{dB}}$ is 71°, which meets the constraints set in section III. Patch antennas for Cubesat applications are designed to be integrated on one of the faces of the satellite. For VHF and UHF, this is not the case, as patch antennas for these frequency bands would be too large. Instead, monopole or dipole antennas are used, such as those found in [17], [18]. These antennas are extended out of the cubical structure of the satellite after launch. Their gain is presumed to be 0 dBd. According to datasheets [17], [18], their half power beam width $\theta_{3\text{dB}}$ is sufficient to meet the constraints set in section III. Antenna performance is reviewed in Table II. If the monopole antenna is used, circular polarization can not be achieved. All the other referenced antenna systems are capable of circular polarization. Therefore, no XPD is considered further.

TABLE II
Performance of satellite-side antennas

Frequency	$\mathbf{G_S}$	$\theta_{\mathbf{3dB}}$
146 MHz	2.2 dBi	80°
446 MHz	2.2 dBi	80°
2200 MHz	8.3 dBi	71°

TABLE III
Performance of a 5 m parabolic dish antenna

Frequency	$\mathbf{G_E}$	$\theta_{\mathbf{3dB}}$
146 MHz	14.7 dBi	28.8°
446 MHz	24.3 dBi	9.4°
2200 MHz	38.2 dBi	1.9°

B. Earth-side antennas

Satellites are predominantly communicated with using parabolic antennas, save for mobile applications such as basic navigation, hand-held communications, or portable radios. Such applications use a dense constellation of LEO satellites, or one-way transmission from satellites in medium Earth orbit (MEO), in conjunction with lower frequency bands, which enables simpler antennas to be used at ground terminals. As power levels from Cubesats are limited by available on-board power, interference levels, or regulations, high gain antennas, such as those with parabolic reflectors, are a logical choice for the Earth side of the communication link. Fly-over times of Cubesats are relatively short, so the antenna should be motorized and light enough to ensure tracking, and enable pointing corrections. The formula for parabolic antenna gain is given as

$$G_E = A_{\text{eff}} \left(\frac{4\pi}{\lambda^2}\right)^2 = \eta \left(\frac{\pi D}{\lambda}\right)^2, \tag{12}$$

where A_{eff} is the effective area of the antenna, η parabolic dish efficiency, and D the aperture diameter. Typical efficiency is $\eta = 50\%$ [19]. The half power beamwidth of such an antenna is given as

$$\theta_{3\text{dB}} = 70^\circ \frac{\lambda}{D}. \tag{13}$$

We intend to use a parabolic dish antenna, 5 m in diameter, for all frequency bands of interest. This will give antenna parameters as shown in table III.

C. Depointing penalty

Attitude control system aboard the satellite maintains the attitude so that the satellite's payload-carrying side always faces the Earth. As the satellite moves away from the position directly above the ground station, antenna

gain in the direction of the ground station deteriorates. In the position farthest from the ground station, as described in section III, the ground station is illuminated by edges of satellite antenna's main lobe. According to farfield characteristics found in datasheets [17], [16], this will induce a depointing penalty, relative to the maximum antenna gain, of $P_D = 6$ dB for VHF and UHF bands, and $P_D = 9$ dB for S-band.

A depointing loss is also considered for Earth-side antennas. For parabolic antennas, it can be calculated by estimating the main antenna lobe profile as a square function, yielding

$$P_D(\theta) = 12 \left(\frac{\theta}{\theta_{3\text{dB}}} \right)^2 \text{ [dB]}. \tag{14}$$

Given antenna's beamwidth presented in table III, the depointing penalty is discarded for VHF and UHF bands. For the S-band, it is presumed that the tracking mechanism will provide mechanical precision of at least 1°. Therefore, we include a 1.3 dB penalty for S-band, as seen in (14).

D. Transceivers

A number of commercially available VHF, UHF and S-band transceivers for Cubesats are reviewed here [20], [1]. The simplicity of obtaining a license makes the low bitrate amateur-allocated VHF and UHF bands a popular choice for Cubesats. All afore referenced transceivers for VHF and UHF bands use the AX.25 protocol, with the highest bit rate of 9600 bit/s, and BPSK, GMSK, or FSK modulation. In the licensed 2200 MHz – 2300 MHz band, transceivers can achieve up to 3.4 Mbit/s, as is the case with the one presented in [1]. Communication parameters of this transceiver will be considered for S-band calculation.

All the considered transmitters provide a maximum transmit power of 1 W. Typical values used in Cubesat missions are between 0.5 W and 2 W. Transmit power is limited by the available power on the satellite, especially if a satellite is expected to run while in seclusion to sunlight; i.e. if it runs on batteries for a part of time. The sensitivity of these receivers must be high in order to receive signal from the Earth ground station. The transceivers in [1] feature a -104 dBm sensitivity, while the one in [20] as high as -121 dBm.

For the ground station, power levels of up to 100 W can be utilized, as this is the maximum allowed power from the transmitter to the transmitting antenna system, as defined by [4] for HAM radio bands. The same power level is presumed to be available in the licensed S-band.

VI. Link budget

The link budget considers signal and noise levels on either ends of the communication system. Having presented all the system components in previous sections, we can now make an estimate of the overall SNR on the link.

To calculate the noise level, we use

$$N = kTB\,, \tag{15}$$

TABLE IV
Noise levels

At the Earth station

Frequency	B	T_{noise}	N
146 MHz	20 kHz	2000 K	-122.6 dBm
446 MHz	20 kHz	200 K	-132.6 dBm
2200 MHz	3.4 MHz	130 K	-112.8 dBm

On the satellite

Frequency	B	T_{noise}	N
146 MHz	20 kHz	290 K	-131.0 dBm
446 MHz	20 kHz	290 K	-131.0 dBm
2200 MHz	3.4 MHz	290 K	-109.3 dBm

with k being the Boltzmann constant, T the receiver system equivalent noise temperature, and B the used bandwidth, as calculated in section II.

It is presumed that the antenna will be immediately followed by a low noise amplifier, which will eliminate most of the noise factor of the receiver. The antenna noise temperature will now make the key contribution to overall system noise. A standard Earth surface temperature of 290 K can be taken as the noise temperature for the satellite-side of the communication system, as its antenna is always viewing the Earth [21]. For the ground station, the noise temperature is read from diagrams in [21] to be 2000 K for VHF band, 100 K for UHF band, and 130 K for S-band. These values give represent valid orders-of-magnitude for noise temperatures. However, for UHF and S-band we increase the equivalent temperature on Earth-side antennas due to the noise picked up in spillover areas of the parabola's radiating element. This noise is expected not to exceed 100 K. As the antenna will not be pointing directly towards the Sun or the Moon, the noise from these celestial objects is not included.

Finally, noise levels can be calculated. They are presented in Table IV. To calculate the received signal power, we start with the well-known Friis formula

$$\frac{P_{\text{rx}}}{P_{\text{tx}}} = G_E G_S \left(\frac{\lambda}{4\pi d} \right)^2 . \tag{16}$$

All the penalties, and the link margin of 6 dB, can be included as additional terms of the formula.

Finally, the link budget can be presented in Table V.

VII. Discussion

The presented link budget is calculated for the worst-case satellite position relative to the ground station. The quality of the Earth-to-satellite link is far superior to that of the link in reverse direction. The reason for this is that the ground station can provide a much larger transmit power level, constrained only by local regulations. The satellite, on the other hand, can only produce a low-level signal due to power consumption constraints. The received signal is large enough on both ends of the communication links, and it meets the sensitivity constraints set by the presented satellite-side transceivers, and typical ground station transceivers.

Several major effects, usually observed in satellite links, that were presented here were shown to be of little

TABLE V
LINK BUDGET

Frequency	146 MHz	446 MHz	2200 MHz
Bandwidth	20 kHz	20 kHz	2.95 MHz
Channel			
Free space loss	-138.6 dB	-148.3 dB	-162.2 dB
Depointing loss	6 dB	6 dB	10 dB
Earth-to-satellite			
TX power	100 W	100 W	100 W
RX level	-77.8 dBm	-77.9 dBm	-76.7 dBm
Noise level	-131.0 dBm	-131.0 dBm	-109.3 dBm
SNR	53.2 dB	53.1 dB	32.6 dB
Link budget	40.8 dB	40.7 dB	16.4 dB
Satellite-to-Earth			
TX power	1 W	1 W	1 W
RX level	-97.7 dBm	-97.8 dBm	-95.7 dBm
Noise level	-122.6 dBm	-132.6 dBm	-112.8 dBm
SNR	24.9 dB	34.8 dB	17.1 dB
Link budget	12.5 dB	22.4 dB	0.9 dB

interest in this communication budget. This is due to selection of lower frequency bands (less than 3 GHz), where some of the effects have little to no contribution to signal deterioration. For VHF and UHF bands, polarization is shown to deteriorate significantly. Therefore, the use of circularly polarized antennas on both sides of the communication link is recommended. Further losses can be caused by short-term atmospheric conditions, such as heavier rain, clouds, ice, etc. As the rain attenuation had proven insignificant for frequency bands of interest, these effects are also considered to be negligible. The S-band is shown to be a good communication window for satellite communication, as it mitigates the power penalties from all the frequency-dependant effects presented in this paper. However, the link budget calculation includes a 6 dB margin, which is expected to cover all unforeseen losses, both natural in origin, or those induced by excessive cable lengths, mismatches, etc.

For the ground station antenna, a simple parabolic dish was selected. The antenna produces high gains even with the lowest of the considered frequencies. Therefore, it is a comprehensive solution for all communication bands.

The noise temperature used in Earth-to-satellite direction is an estimate of satellite antenna's captured noise. This is essentially the Earth's atmosphere noise, and taken as a standard value. For the satellite-to-Earth direction, the noise temperature depends on the time of day, latitude, visible celestial objects, etc. The noise temperature presented in Table IV takes into account only the galactic noise, i.e. clear sky conditions.

VIII. CONCLUSION

The link budget is calculated for typically used Cubesat communication parameters. In VHF and UHF bands, as well as the 2.4 GHz unlicensed band, only small datasets can be transmitted. Therefore, a licensed 2.2 GHz band, enabling high bit rate transmission, is shown to be of interest. Link parameters are defined, based on current practice in Cubesat operator community, as well as the requirement for high data rate communication. A satellite orbit is suggested and spatial relations between the Earth station and the satellite are discussed. Major propagation effects observed in satellite communication links are presented and evaluated for given frequency bands and system configuration. Earth station and satellite system parameters are defined.

Finally, the link budget is calculated for VHF, UHF and licensed 2.2 GHz bands. The link budget is met, proving that the suggested communication parameters are valid.

ACKNOWLEDGMENT

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Automated System for the Measurement of AC Magnetization Characteristics

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***Abstract* - The paper presents a fully-automated system for the magnetic scalar hysteresis measurement of the ring core specimens. The system is based on the National Instruments PXI-4461 two-channel dynamic signal generation and two-channel acquisition cards. A power amplifier is designed and manufactured, based on the TDA2030 monolithic integrated circuit, and a computer code for controlling the measurement process is programmed in LabVIEW. The system applies the analog RC integration. The system allows graphical presentation of the measured hysteresis curves, and calculation and presentation of the first magnetization curve, approximated by locus points of the symmetric hysteresis cycles. The first magnetization curve can be exported in a format prepared for the importing in the finite element analysis (FEA) software.**

Keywords - magnetic measurements, hysteresis, PXI-4461, LabVIEW, Computer-aided measurement, Internet-enabled metrology

I. INTRODUCTION

Numerical tools like finite element analysis (FEA) afford a very precise alternative for the calculation in electromagnetics, when analytical methods are not possible or applicable. For the devices like ferromagnetic cores, which are the nonlinear materials, most of the numerical packages for the low-frequency steady-state FEA or magnetostatic FEA include the options for the analysis with the nonlinear materials. Such kind of analysis is usually based on Newton-Raphson method because of its fast convergence [1]. Most of commercial FEA software packages offer a database with a set of typical *B-H* characteristic for standard soft magnetic materials. In addition they allow the creation of custom magnetic materials. In all these cases, the nonlinear *B-H* characteristic of soft magnetic materials is approximated with the first magnetization curve, neglecting the hysteresis. The manufacturers of the cores for the small transformers and chokes as well as the manufacturers of the core steel sheets often give typical data of the power losses in their datasheets, omitting typical magnetization curves. Therefore, if FEA is applied in the design and the optimization of the device, the measurement on the actual core or on the ring specimens has to be performed prior the FEA. The standard procedure for the visualization of the hysteresis loop can be applied for the measurement of the first magnetization curve, using the approximation of the first magnetization curve by the locus points of the symmetric hysteresis cycles [2].

For the measurement of the peak values of the magnetization current, typically the digital storage oscilloscopes (DSO) are applied. As well, some of digital multimeters (DMM) like Keithley 2001 have the option to measure peak value of the AC signals. In both cases, if the process is not automated, there is a need for the manual measurement and setting of the excitation in many different points across the magnetization curve, which is extremely time-consuming. Furthermore, with manual setting and measurement it is not possible to effectively perform the averaging to eliminate the measurement noise, which can significantly corrupt the measurements of the small signals, especially the voltage at the capacitor of the RC integrator.

The automated measurement of the hysteresis curves is described in several references [3-5]. We have developed our own system and LabVIEW program with the main goal of the fully automated measurement of the first magnetization curve and its preparation in a format ready for the import in a FEA software. For the acquisition of the signals, the system is based on NI PXI 4461 digital acquisition (DAQ) cards. It also includes a custom manufactured power amplifier, to create the excitation voltages with the low total harmonic distortion. It appeared that even in the Rayleigh loops zone [6] it is possible to achieve very accurate results, and solve the noise issues associated with the measurement of the corresponding small voltages. As an example of the full process, an example of the measurements on an actual ring core specimen is presented, associated with the import of the measurement data into Infolytica MagNET FEA software package and the numerical calculation of a choke using the measured data.

The paper is organized as follows: in Section II the physical background is described. Section III presents the measurement system based on NI 4461 DAQ cards. Section IV describes the export of the results to the FEA software and the results of a FEA simulation using the measured *B-H* characteristic. Finally, Section V are conclusions.

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II. PHYSICAL BACKGROUND

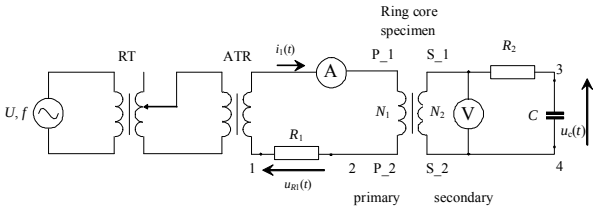

Fig. 1. The equivalent circuit diagram for the standard set-up

For the accurate FEA modeling of the transformer core, the *B-H* curve has to be experimentally determined. The standard procedure for *B-H* curve measurement is based on the measurement on the ring core specimens [2]. The actual *C*-cores can also be efficiently used for the determination of the *B-H* curve and core losses, because they have reasonably uniform flux density [7]. The measurement method and measurement set-up based on the IEEE standard procedures for magnetic cores, using the oscilloscope and peak-value measurement is presented in Fig. 1 (here the abbreviations RT and ATR denote regulation transformer and autotransformer, respectively). It is consisted of a shunt in series with the primary, a variable source of the sine voltage with low total harmonic distortion (THD), and an RC integrator connected on the secondary (search) coil. The peak values of the magnetizing current and induced flux are measured using a digital storage oscilloscope. The same system can be used for the calculation of the first magnetization curve, approximated by locus points of the symmetric hysteresis cycles.

If the primary coil has N_1 turns, using the Ampère's law we may write

$$H(t) = \frac{N_1 \cdot i_1(t)}{l_m} \tag{1}$$

where $H(t)$ denotes magnetic field, $i_1(t)$ denotes the primary current, l_m is the average length of the flux lines. If the current $i_1(t)$ is measured using the voltage drop $u_{R1}(t)$ across the shunt resistor R_1, the equation (1) becomes finally

$$H(t) = \frac{N_1 i_1(t)}{l_m} = \frac{N_1 u_{R1}(t)}{l_m R_1} \tag{2}$$

The magnetic flux density $B(t)$ can be measured indirectly, performing the integration of the induced voltage at the secondary winding. The preferred method for the integration of the induced voltage is by using an *RC* integrator [1], which gives the following relation for the measured magnetic flux density:

$$B(t) = \frac{R_2 C}{N_2 S} u_C(t)\,. \tag{3}$$

Here, S denotes the cross-section of the coil, R_2 is the resistor value of the RC integrator, C is the capacitance of the capacitor in the RC integrator, and $u_C(t)$ is the voltage across the capacitor C. N_2 is the number of turns in the secondary winding.

III. MEASUREMENT SYSTEM

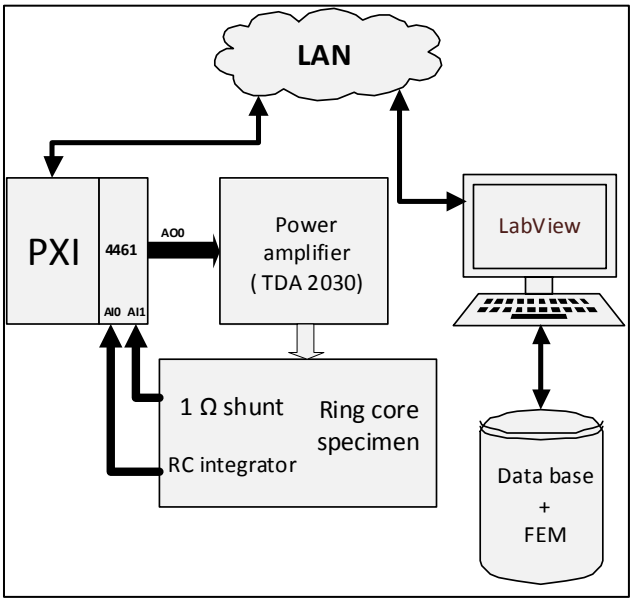

Fig. 2. Block diagram of the used measurement set-up

Based on the standard set-up in Fig. 1 we have made modified measurement set-up which contains the National Instruments PXI system, equipped with the acquisition cards NI PXI 4461. Fig. 2 presents the block diagram of the modified measurement system we actually used. All inputs of the cards were configured in the differential configuration.

The PXI system generates the stimulus signal, which is fed to the power amplifier based on TDA2030 monolithic integrated circuit. This is a hi-fi audio amplifier, capable to provide 14 W output power at a 4 Ω load. There are several reasons to choose TDA2030 for the generation of the excitation of the primary winding:

- As an audio power amplifier, it is well-suited to drive the inductive load
- It is capable to provide high output currents
- It has very low harmonic and crossover distortion
- It has an original short-circuit protection system to keep the operating point of the output transistors within the safe operating range, plus a conventional thermal shutdown system

The amplifier circuit is realized according to the manufacturer specifications for split power supplies. The resistors in the feedback branch were chosen in such a way that the voltage gain of the amplifier was 10. An original printed circuit board was developed, and placed in a suitable passively vented box. The split power supply is an electronically stabilized external commercial unit (Protek DF1731), which further improves the stability of the exciting voltage.

The software that controls the excitation, the signal acquisition, processes the signals and visualizes the results was entirely programmed in-house in the NI LabVIEW environment. The measurement process starts through the graphical user interface (GUI) with the definition of the excitation frequency, span of the

excitation signal magnitudes and number of data points within the magnitude span. The communication between LabVIEW application and the PXI system is accomplished using the Ethernet protocol and the institutional local area network (LAN), thus enabling distant start and control of the measurements. LabVIEW, as well as many of the commercially available software tools devoted to the implementation of virtual insruments (VIs) offers features for interactive control of instrumentation via Internet and, in that way, Internet-enabled metrology [8]. In addition to the remote control of instruments, in this way traceable measurements can be performed at distant location, and the access to measurement history and other related data can be achieved. At our laboratory, a single measurement set-up for the automated measurement of the first magnetization curve (Fig. 6) can be controlled by the LabVIEW applications installed at several PCs, thus enabling the control of measurements, exporting the results to FEA software and running the FEA simulation from the same computer. This approach allows easy sharing and control of the same hardware within a group of users.

Fig. 3 presents the GUI window for setting the parameters of the measuremets, together with the measurement data during the measurement. Fig. 4. presents the GUI window with visulizations of the *B-H* curve and the first magnetization curve, approximated by locus points of the symmetric hysteresis cycles. Fig. 5 presents the measured first magnetization curve, while Fig. 6 shows the measurement set-up. The excitation frequency during the presented measurements was f=18 Hz, while the value of the shunt resistor R_1 was 1 Ω. The parameters of the core were as follows: N_1=300, N_2=94, l_m=0.334 m, $S = 4 \cdot 10^{-4}$ m^2. The reactance of the capacitor in the RC integrator has to be neglibigle at the applied frequency in comparison to the resistance R_2, i.e. the ratio $\frac{1}{2\pi \cdot f \cdot R_2 C}$ has to be as small as possible, while R_2 must have relatively large value to ensure that the secondary current is negligible. The actual values of applied RC integrator were derived from the values applied in [7], were R_2 was 330 kΩ, and C was 0.6 μF, with the ratio of the reactance to the resistance equal to 0.0147. Thus, *RC* integrator presented in this paper was consisted of the resistor R_2=330 kΩ and the capacitor C=3 μF, ensuring ratio of the reactance to the capacitance equal to 0.0089, which is better than in [7].

The accuracy of the digitizer is defined with following parameters: For 1 V signal amplitude, 1 V input range and 51.2 kS/s sampling frequency and simultaneous sampling the temperature coefficients of the magnitude and phase of the digitizer NI-4461 are 7.4 μV/V/K and 0.000008 /K. The standard deviation of the magnitude of the voltage ratio is 2.3 μV/V. The deviation of the magnitude of the voltage ratio from the nominal value is within 3 μV/V. The phase deviation is less than 16 μ° [9].

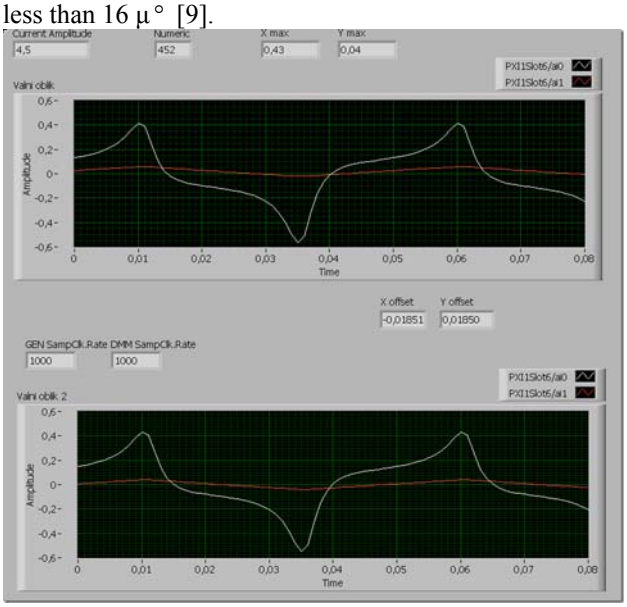

Fig. 3. The GUI window for setting the measurement parameters

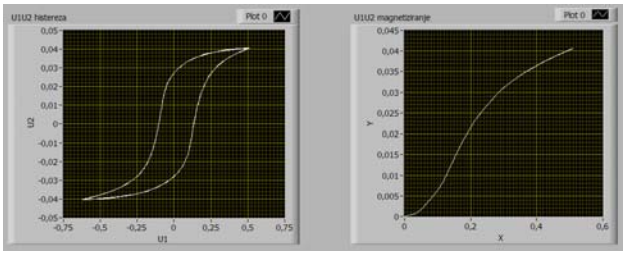

Fig. 4. The GUI window with the results

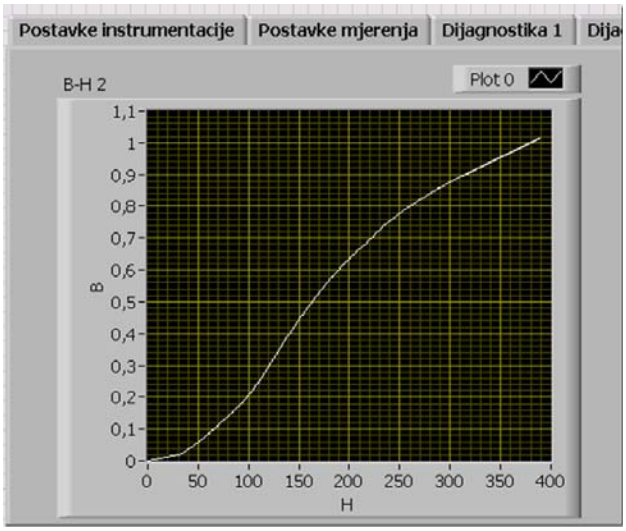

Fig. 5. The measured first magnetization curve

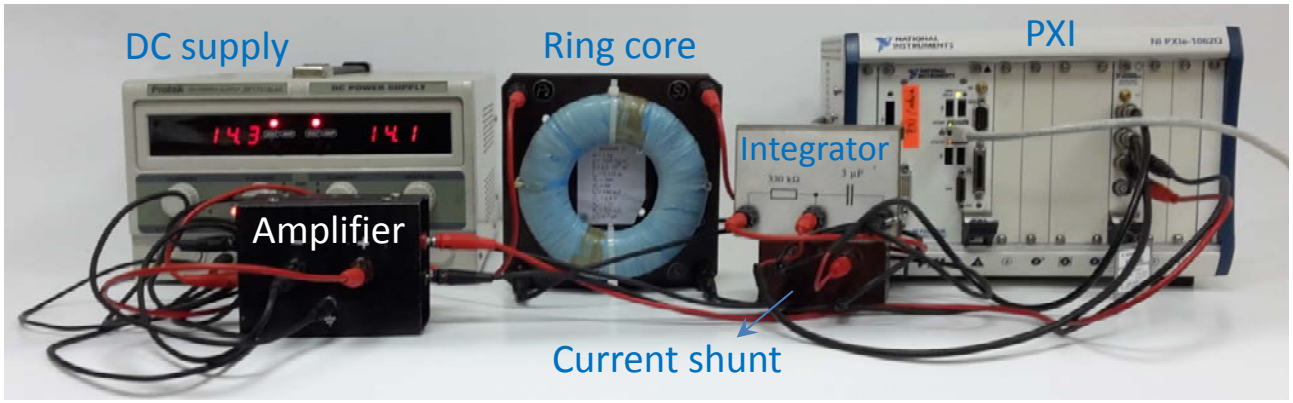

Fig. 6. Measurement set-up

IV. Export to FEM Software

The measured data of the magnetization curve of the ring core specimen was applied in the creation of a custom material in the Infolytica MagNet FEM software, running on a Dell Precision T5500 workstation at 2.67 GHz with 48 GB RAM installed.

The custom created ferromagnetic material was applied in the FEM analysis of a choke wound on a standard SU30 ferromagnetic C-core. The target application of the choke was the low-pass filtering in a power electronics application. Fig. 7 presents the custom-built former, and Fig. 8 presents the drawing of the core with the marked dimensions. The standard and measured dimensions of the core are tabulated in Table 1. The assumed number of turns in the winding of the choke is 36, based on the analytical calculation with a target inductance equal to 3.6 mH. In the analytical calculation, the core material was assumed to be linear with the relative permeability equal to 2671, which is extracted from the impedance measurement and the parameters of the test core specimen. Figs. 9 and 10 present the results of the FEM analysis. Fig. 9 presents the magnetic flux density within the choke with the choke current equal to 0.5 A. The inductance of the choke, extracted from FEM software is L=3.4853 mH. Fig. 10 presents the magnetic flux density within the choke with the choke current equal to 0.8 A. The inductance of the choke, extracted from FEM is L=3.4068 mH. As expected, the values of inductances, extracted from FEM software have lower values than those analytically calculated, since FEM is taking into account the leakage flux, the nonlinear core material and the non-uniform flux density distribution within the core.

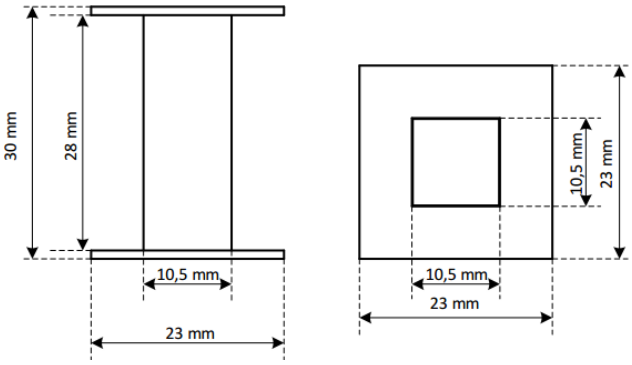

Fig. 7. Core former

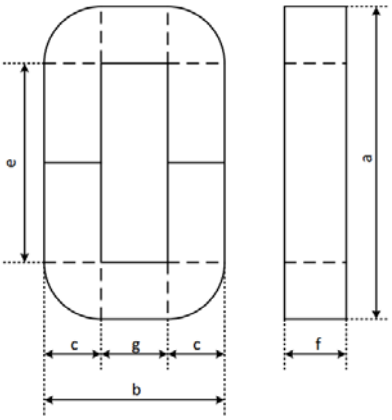

Fig. 8. C-core

Table 1. Dimensions of the core

Measured values [mm]		Standard values [mm]		Values applied in FEM [mm]	
b	29.5	b_{max}	30	b	29.5
c	9.3	c	9.9 (tol = -0.8)	c	9.3
f	10.2	f	10.1 (tol = 0)	f	10.1
a	49.6	a_{max}	52.7	a	51.1
g	10.9	g_{min}	10	g	10.9
e	30.6	e_{min}	32.5	e	32.5

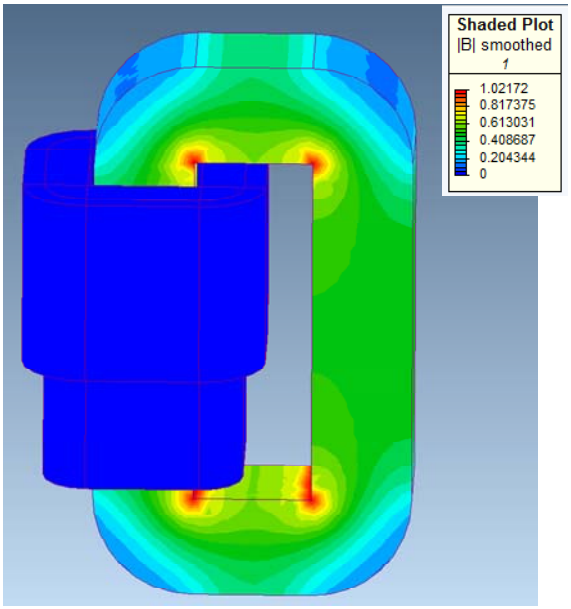

Fig. 9. Magnetic flux density distribution – *I*=0.5 A

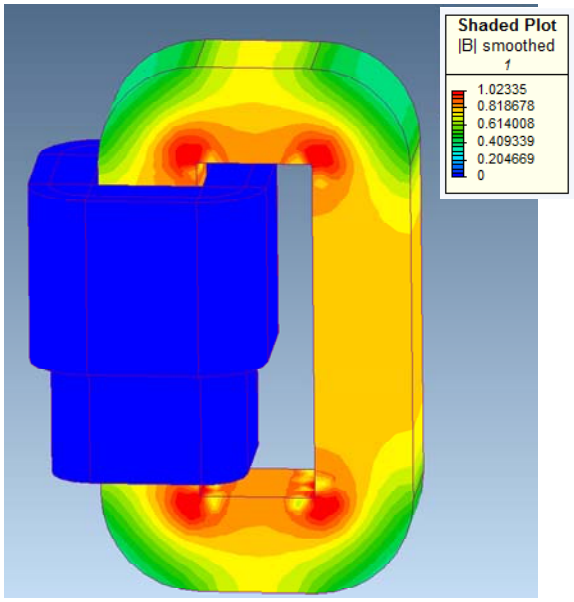

Fig. 10. Magnetic flux density distribution– *I*=0.8 A

V. CONCLUSION

We have developed a system for the fully automated measurement of the hysteresis and the first magnetization curve of ferromagnetic materials, based on LabVIEW and PXI NI 4461 acquisition cards. When using the FEA softwares, accurate determination of the actual characteristics of the ferromagnetic materials is very important in the design and modeling of the devices like electrical machines, chokes and transformers. The developed system allows for the user-friendly and fast measurement of the nonlinear characteristics of the ferromagnetic materials and its importation into FEA packages. It has very good characteristics when measuring the initial part of the first magnetization curves, associated with small magnetic flux densities and voltages highly influenced by the noise. The whole process of the measurement and importation into the FEA software is illustrated with an example of the choke with a ferromagnetic core. The numerical FEA analysis of the presented example is performed in Infolytica MagNET software, using the custom created ferromagnetic material data, imported from our fully automated measurement system. Within the framework of the Internet-enabled metrology, using the remote control of PXI NI 4461, the traceable measurements can be performed at distant location, and the access to measurement history and other related data can be achieved. At our laboratory, a single measurement set-up can be controlled by the LabVIEW applications installed at several PCs thus enabling the control of measurements, exporting the results to FEA software and running the FEA simulation from the same computer. This approach allows easy sharing and control of the same measurement set-up within a group of users.

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Implementation of a Low-cost Electrochemical Impedance Spectroscope

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Abstract – The paper describes an implementation of a low-cost electrochemical impedance spectroscope using a sound card on a computer. The main parts of the system are: PC's sound card used for signal output and data acquisition, a current source, two measurement channels, software module for battery parameter estimation. The sinusoidal signal with required amplitude and frequency is generated from the MATLAB and using the D/A converter of the sound card. The current source is implemented as a class AB amplifier with a PI regulator. Measurement channels are designed to prepare battery response signals for the A/D conversion. The implementation allows utilizing different algorithms for parameters estimation. The system performance is demonstrated when used to estimate the parameters of a Lead-Acid battery, test results are presented and discussed.

***Keywords*— electrochemical impedance spectroscopy (EIS); state of charge (SOC); state of health (SOH); sound card; battery testing;**

I. INTRODUCTION

More intensive use of chemical power sources requires development of methods and tools for their correct and economical usage. The essential parameters for battery exploitation are: state of charge (SOC), state of health (SOH) and internal resistance. These parameters can be estimated from the battery voltage, battery temperature, and impedance value [1, 2]. Voltage and temperature are quite easy to measure while measuring impedance is far more complex [1-9].

For measuring battery impedance there are several methods, which can generally be categorized into two groups: DC and AC [3, 10, 11]. In the DC method the battery is charged with a current pulse of certain amplitude and certain duration [3]. By recording the battery's response to this impulse, it is possible to estimate the impedance of the battery. The disadvantage of this method is the need for a high intensity current impulse which makes the method destructive. Also this method is primarily used for off-line testing and is not suitable for battery monitoring. In the AC method, the battery is treated with a sinusoidal current source of certain frequencies and certain amplitudes [3]. There are two approaches, the use of an active current source and the use of a passive current source. When using a passive current source, the current source is using power from the battery that is being tested. This method is also destructive. The advantage of this method is a more simple power supply of the system and the use of class A amplifier. This method it is not suitable to test empty batteries or with a charge of less than 20%. Testing the battery that is below 20% of charge will give incorrect results, because the voltage battery characteristic is extremely nonlinear in that area. When using an active current source, an external power supply system is required. This method is not destructive and it is considered as the most suitable method for battery testing. More information about battery testing methods can be found in [3]. The methods for estimating the state of SOC on the battery are described in [4].

Electrochemical impedance spectroscopy (EIS) belongs to the AC methods and is a general method to test electrochemical systems. The simple AC method for measuring the internal impedance of a battery uses a 1 kHZ frequency sine signal [12]. When using EIS a more complete picture of the state of the battery is formed (Nyquist diagram) because a wider frequency spectrum is used. Test systems for battery parameters identification using EIS are described in several papers. In [5], a prototype for battery testing using EIS is described. A low-cost prototype is designed based on a DSP processor, a sinusoid test signal generator, and measurement channels. In [6], authors analyze the performance of Lithium-ion batteries with aging, for different state of charge and temperatures, using Autolab® PGSTAT20 measurement unit, a current booster Autolab® BSTR10A, and the Autolab FRA software. A system based on fuzzy logic was used to estimate the parameters.

A practical battery diagnostic system and robust complex impedance measurement algorithm are described in [7]. The system is suitable for embedded systems as unmanned aerial vehicles. The measurement system is implemented using four low-cost 16-bit microcontroller circuit modules with 5 A/D converters with 12-bit resolution. The measurement module utilizes one control and 4 acquisition channels, providing for the system simultaneous battery impedance estimations on 16 cells. A system based on a function generator and an oscilloscope is used to generate signals and measure the amplitude and phase of the input and output signals [8]. A sinusoidal signal of 1 kHz frequency, 1.41 V amplitude and 0.7 V offset were generated and transmitted to the battery and the shunt through the NPN transistor with a feedback. In the paper, more details about the testing system itself were not provided.

Our research presented in the paper describes the implementation of an electrochemical impedance spectroscope with all relevant details. The system uses a standard PC, a current source, and two measurement channels. Sound card of the PC is used to generate input signals and for data acquisition of battery output signals. MATLAB is used for data processing, and parameter estimation. The system calculate battery parameters using EIS.

II. Description of the System of Electrochemical Impedance Spectroscope

To identify the battery parameters using the EIS, the device under test (DUT) is exposed to a sinus voltage of appropriate amplitude and frequency. On such a DUT, the current and voltage are recorded, from which the Nyquist or Bode diagram can be formed. The sine wave amplitude should be of such intensity that the system behaves linearly. The frequencies range should be wide enough to get all characteristic points on the Nyquist chart.

The structure of the electrochemical impedance spectroscope is shown in Fig. 1. The system consists of a current source, two measurement channels and a PC. With the use of the sound card A/D and D/A converters the required sinusoidal signal can be generated and the current and voltage of the DUT being tested can be measured. Afterwards, using MATLAB, the necessary parameters are estimated.

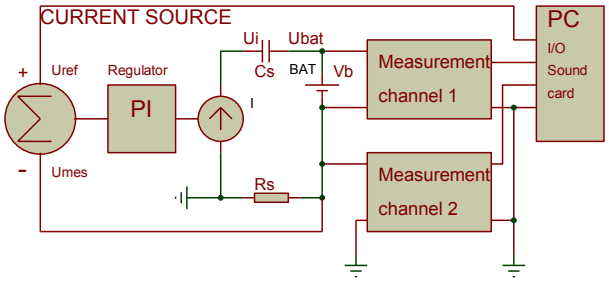

Figure 1. Block structure of electrochemical impedance spectroscope

III. Current Source

The current source is built with a current amplifier, a coupling capacitor, a PI regulator and a shunt. The input signal is generated on the computer using the sound card D/A converter and represents the input value to the regulator. This signal is connected to the (+) input of the error amplifier. Output signal from the shunt is connected to the (–) input of the error amplifier. This signal corresponds to the amount of current generated by the current source which passes through the DUT. The shunt resistance is 20 mΩ and at a current intensity of 1 A, on this shunt a voltage drop is 20 mV. This voltage is further amplified K times (K = 11) before connecting to the regulator. The output from the current source through the capacitor C_s is connected to the DUT.

A. Selection of coupling capacitor

The C_s coupling capacitor is selected to allow the flow of the current of appropriate amplitude and frequency and to separate the *DC* levels of the battery being tested and the current source.

The current through the capacitor is given by:

$$i_c = C_s \frac{dU_{Cs}}{dt} = C_s \frac{d(U_i - U_{bat})}{dt}. \quad (1)$$

The battery voltage, which is tested by injection of the current of the sinusoidal shape, is given with:

$$U_{bat} = V_b + U_m \sin(\omega t). \quad (2)$$

Because of the need to preserve the linear ratio of current and voltage on the battery, the amplitude U_m is chosen to range from 1 to 10 mV [9]. When the current of the current source is at its maximum, the value of the U_m voltage is much lower than the value of the voltage U_i. The voltage U_i is also a sinusoidal shape:

$$U_i = U_{im} \sin(\omega t). \quad (3)$$

Now the current is given by:

$$i_c = I_m \sin(\omega t + \varphi) = C_s \omega U_{im} \sin(\omega t + \varphi). \quad (4)$$

To ensure a current of 0.15 A at a frequency of 10 Hz and output amplitude of 5 V (U_{im}) the required capacity of the connecting capacitor is:

$$C_s = \frac{I_m}{U_{im}\omega} = \frac{1}{5 \cdot 10 \cdot 2\pi} = 477.7 \mu F. \quad (5)$$

Voltage on the output of the current source (U_{im}) below 5 V guarantees that the current amplifier works in the linear mode for the battery supply of ±9 V. The capacitor has capacity of 470 µF. If the current needs to be increased the capacitor needs to be replaced with a capacitor of higher capacity.

B. Power Amplifier

To ensure good tracking of the input signal for different types of loads, a power amplifier without voltage gain and significant power gain is used. The electrical schematic of the amplifier is shown in Fig. 2. The amplifier is implemented as a transistor power amplifier of class AB. The circuit is supplied by ± 9 V to generate a bipolar output signal. Transistors Q_1 and Q_2 are integrated Darlington transistors and they are selected to provide current ranging from 0 to 5 A and frequency ranges from 0.1 Hz to 20 kHz.

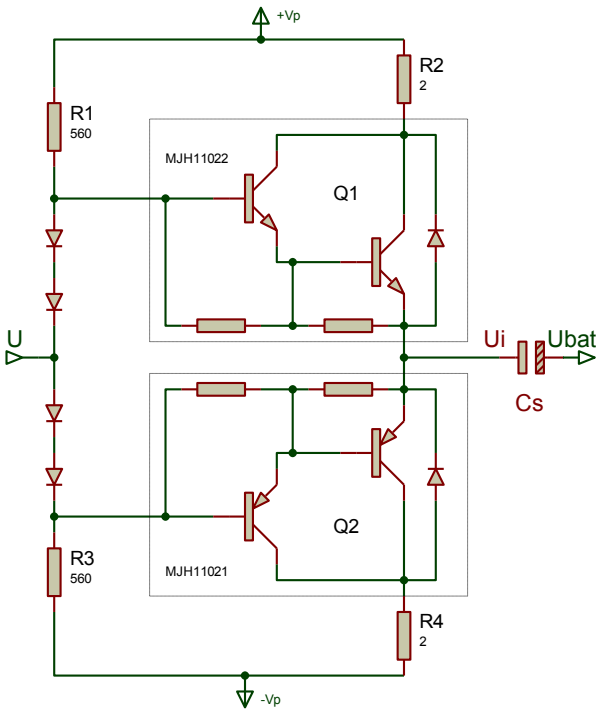

Figure 2. Electrical schematic of the amplifier
($R_1 = R_3 = 560\Omega$, $R_2 = R_4 = 2\Omega$)

C. Regulator

The current source is implemented with a negative feedback, and a PI regulator is used for control. The control signal from the PI regulator is given with:

$$U = U_{ref} + \frac{1}{R \cdot C_1} \int \left(2U_{ref} - K \cdot U_{mes}\right) dt, \quad (6)$$

$K=11$, $RC_1=10\ ms=T_1$.

The electrical schematic of the regulator is shown in Fig. 3.

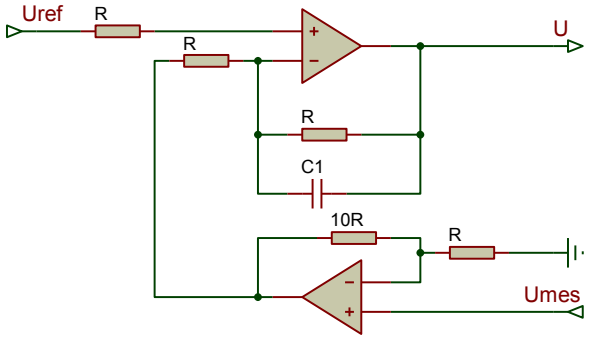

Figure 3. Electrical schematic of the regulator (R=10 k, C_1=1 μF)

D. Model of the DUT

The DUT is a battery modeled with the Randles circuit [9], as presented in Fig. 4.

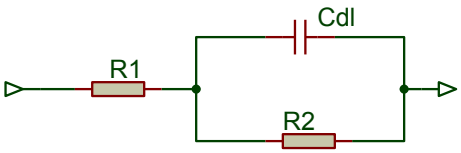

Figure 4. Simplified *AC* battery model

The DUT simplified AC electrical model parameters are:

- R_1 is the resistance comprising electrolyte resistance, resistance between cell bonds, resistance of metal electrodes, separator resistance;
- R_2 is a non-linear contact resistance metal-electrolyte;
- C_{dl} is the capacity of an electric double layer.

The model can be presented with the following impedance:

$$Z = R_1 + \frac{R_2}{1+\omega^2 C_{dl}^2 R_2^2} - j\frac{\omega C_{dl} R_2^2}{1+\omega^2 C_{dl}^2 R_2^2}. \quad (7)$$

The problem of the impedance identification is to determine the parameters of the simplified *AC* model: R_1, R_2 and C_{dl}.

E. Transfer function of the current source

An ideal current source should have a transfer function $A(j\omega)=1$. Due to RC elements, and due to the negative feedback, it is clear that the source is not ideal and that the transfer function has some limitations in terms of frequencies used and possible gain. In order to determine the transfer function, we will analyze the block structure of the system with the load as shown in Fig. 5.

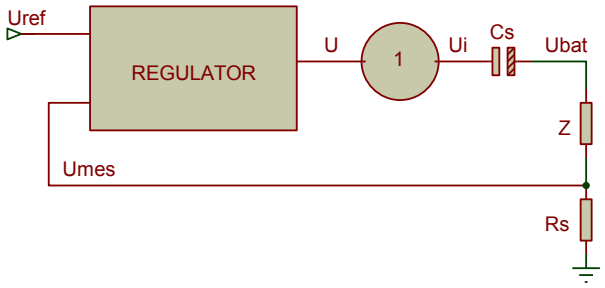

Figure 5. The block structure of the system with the load

The following equation can be obtained from the schematic in Fig. 3:

$$\frac{\left(1+\frac{10R}{R}\right)U_{mes}-U_{ref}}{R} = \frac{U_{ref}-U}{R} + \frac{U_{ref}-U}{-jX_{C1}}. \quad (8)$$

Further follows:

$$U = \frac{j2X_{C1}-R}{jX_{C1}-R}U_{ref} - \frac{j11X_{C1}}{jX_{C1}-R}U_{mes}. \quad (9)$$

The gain of the amplifier is 1, so the voltage $U_i=U$, and the current from the current source passes through the battery and through the shunt. The current through the regulator in the return branch is zero. Based on Fig.5:

$$I = \frac{U-U_{mes}}{Z-jX_{Cs}} = \frac{U_{mes}}{R_s}. \quad (10)$$

Further follows:

$$U = \frac{Z-jX_{Cs}+R_s}{R_s}U_{mes}. \quad (11)$$

Based on equations (9) and (11) and including the expression for the impedance with the corresponding time constants $T_2 = R_S C_S = 9.4\mu s$, $T_1 = RC_1 = 10ms$ the transfer function of the system is given in the form of:

$$A(j\omega) = \frac{U_{out}}{U_{in}} = \frac{U_{mes}}{U_{ref}}$$

$$= \frac{j2\omega T_1 - \omega^2 T_1 T_2}{1-(Z\cdot C_S+T_1)T_2\omega^2 + j\omega(Z\cdot C_S+T_1+T_2+11T_1)}. \quad (12)$$

Based on the transfer function of the system, the Nyquist diagram is shown in Fig. 6.

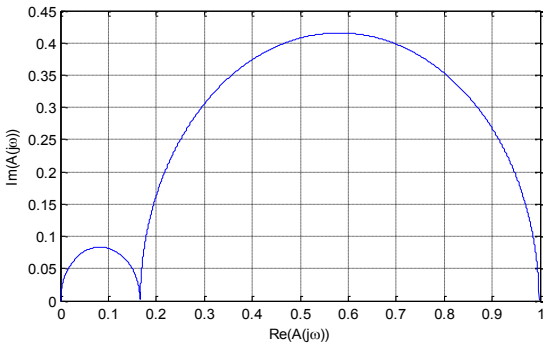

Figure 6. Nyquist diagram of the current source

Nyquist's diagram proves that the current source represents a stable system, since the closed contour does not include the critical point (-1, j0), i.e. the number of full rotations of the vector from the critical point is 0, and the number of zeros in the right half-plane is also 0. Based on

the Nyquist criterion of stability, it follows that the number of poles in the right half-plane is determined by the relation:

$$N_{Poles} = N_{Zeros} - N_{Rotations} = 0. \quad (13)$$

Hence, the system does not have poles in the right half-plane of the complex plane $\{s\}$, i.e. the system is stable.

IV. Measurement Channels

In order to preparation the battery current and voltage signals for the A/D conversion, two symmetrical measurement channels were implemented. The channels were designed as a cascade connection of a high-pass and low pass filter respectively, and an instrumentation amplifier, as shown in Fig. 7.

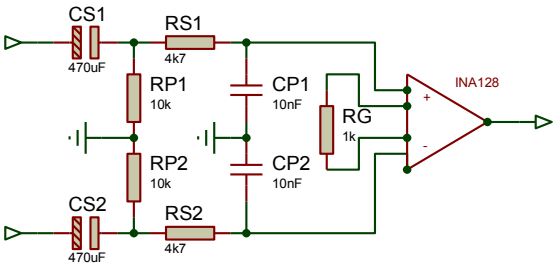

Figure 7. Measurement channel schematic

The transfer function of the measurement channel is given by:

$$A_F(j\omega) = 51 \cdot \frac{Z_{Cp1}}{\left(1 + \frac{R_{s1} + Z_{Cp1}}{R_{p1}}\right)\left(Z_{Cs1} + \frac{R_{p1}(R_{s1} + Z_{Cp1})}{R_{p1} + R_{s1} + Z_{Cp1}}\right)} \quad (14)$$

The amplitude-frequency and phase-frequency characteristic of the filter is given in Fig. 8.

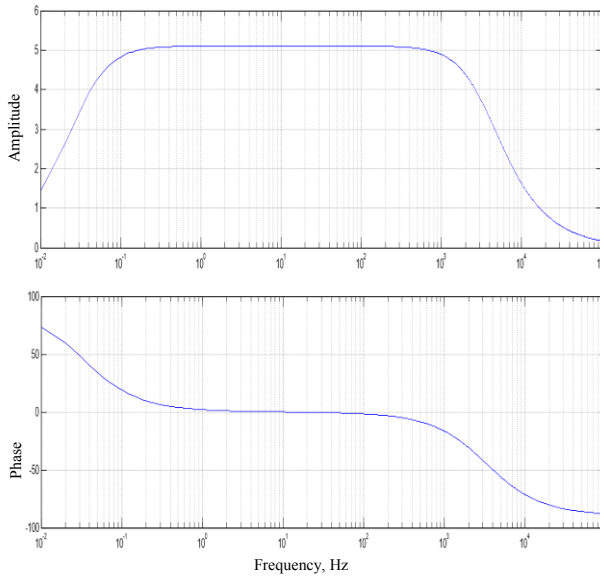

Figure 8. Amplitude and phase frequency characteristic of the filter

From the amplitude-frequency characteristic, it is evident that the frequency range is from 1Hz to 10 kHz. The signal amplitudes are significantly decreased for the frequencies below 1 Hz and above 10 kHz. The amplitude decrease that occurs at high frequencies, which are of interest to us, does not affect the measurement results, because the current amplitude of the current source at these frequencies is higher. The filter phase is almost constant at the high frequency range. In order to obtain a more accurate measurement, it would be useful to make the phase-frequency characteristic constant at the frequencies of interest. In this way we ensure that the phase shift error is avoided, the error caused by the asymmetry of two filters. This can be achieved by reducing the resistance of R_{s1} and/or by reducing the capacity of C_{p1}, but we should ensure that the parasitic resistance and capacities do not affect the measurement.

V. A/D and D/A Conversion

The sound card proved to be very suitable for recording and generating the harmonic signals required for the process of EIS. The sound card has two input and two output channels. It has two A/D converters which allows simultaneous recording of two signals, which helps avoiding the error of determining the phase shift. The sound card provides a sampling frequency between 1 kHz to 192 kHz, and 8, 16 and 24-bits resolution. It has been experimentally confirmed that good measurement results are achieved for signals up to 22.5 kHz without the need for additional software reconstruction of the signal.

Because the input of the sound card is capacitive, the *DC* component of the signal is removed, distortion occurs for complex harmonic signals, and it is possible to measure signals with maximum amplitudes from 40mV to 1000 mV depending on the frequency of the signal. For measuring signals of a higher amplitude, the signal should be further adjusted with a voltage amplifier. The output of the sound card enables generation of signals between -1 V and +1 V, which is enough for the EIS, however, in order to eliminate the impact of noise, it is better to use a voltage follower or amplifier that uses large-scale resistance. Electrical noise is a low-power signal and causes insignificant current on high resistance, so the voltage it induces is negligible.

VI. Data Acquisition

The acquisition of the data necessary for the calculation of the impedance (battery current and voltage, at the given frequency of the input signal) is implemented with MATLAB using the A/D converter on the sound card of the computer. The signals are prepared for the A/D conversion with two measurement channels, with filter characteristics designed to remove the *DC* voltage of the battery and to remove the noise signal to a significant extent.

VII. Parameter Estimation

Processing of digitalized current and voltage data in the MATLAB, allow for utilizing various algorithms for the estimation of the required parameters.

The estimation method described in the paper is based on the impedance module measurement. This method does not require angle measurements, and therefore is less sensitive to measurement errors. The parameters of an equivalent battery model C_{dl}, R_1 and R_2 can be calculated based on the expression for the impedance module:

$$|Z| = \sqrt{R_1^2 + \frac{R_2^2 + 2R_2R_1}{1+\omega^2 R_2^2 C_{dl}^2}}. \quad (15)$$

The following relations are derived to calculate specific parameter:

$$R_1 = \left(\frac{(Z_j\omega_j)^2 - (Z_i\omega_i)^2}{\omega_j^2 - \omega_i^2}\right)^{\frac{1}{2}} \quad (16)$$

$$R_2 = -R_1 + \frac{(R_1^2 A^2 - AB)^{\frac{1}{2}}}{A} \quad (17)$$

where A and B are:

$$A = Z_i^2\omega_i^2 - Z_j^2\omega_j^2$$

$$B = 2Z_i^4\omega_i^2 - Z_i^2 Z_j^2(\omega_i^2 + \omega_j^2) - R_1^2 Z_j^2(\omega_j^2 - \omega_i^2)$$

$$C_{dl} = \left(\frac{\left(R_s + R_p\right)^2 + Z_i^2}{\omega_i^2 R_p^2\left(Z_i^2 - R_s^2\right)}\right)^{\frac{1}{2}}, \quad (18)$$

and where Z_i represents the value of the impedance module at the frequency ω_i, while Z_j represents the value of the impedance module at the frequency ω_j.

The advantage of this method is that only the impedance module is used, so the final result is affected only by the error in measuring impedance module. Generally, measuring the impedance module is an easier task than measuring the phase shift.

The description of the algorithm for the battery parameter estimation: at the input of the measurement system described in previous chapters, a sinusoidal signal is supplied. The sinusoidal signal changes its frequency in time, over the range of values, and with predefined step. The response signals corresponding to input signal were measured. The frequency and impedance module are obtained based on the recorded response of the system. The frequency and impedance module values are written in two vectors. The frequency of the response signals are determined based on the sign of the recorded signal, by counting sequences of consecutive values of the same sign, and calculate the frequency as:

$$f = \frac{f_s}{N_p + N_n}, \quad (19)$$

where f_s is the sampling frequency, N_p is the number of consecutive positive values, and N_n is the number of consecutive negative values. Fig. 9 shows the result of this procedure when applied to the Lead-Acid battery.

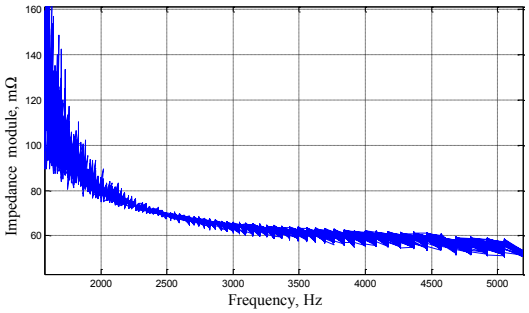

Figure 9. The impedance module versus the frequency

Further, values are averaged over the subintervals. Fig. 10 shows a chart for the values averaged over the subinterval of 100 Hz.

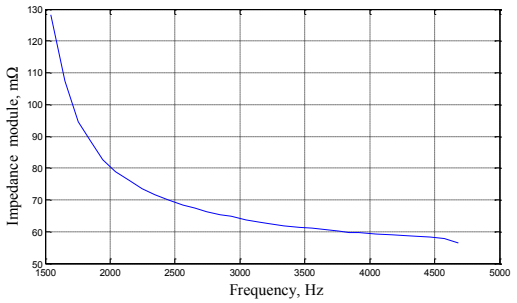

Figure 10. Impedance module versus frequency after averaging

Using the described algorithm, the following values for parameters are calculated:

$R_1 = 48.6403$ mΩ, $R_2 = 182.8740$ mΩ,
$C_{dl} = 4.3304$ mF.

Amplitude-phase characteristic for such parameters is shown in Fig. 11.

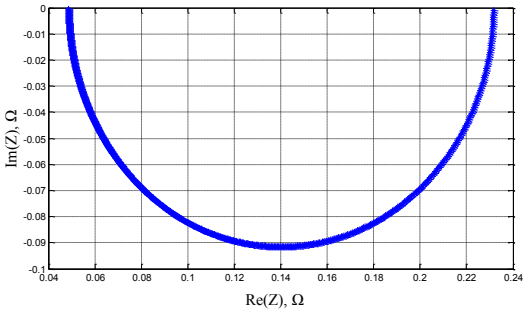

Figure 11. Amplitude-phase characteristic of the system

VIII. CONCLUSION

Implemented system provides for simultaneously recording of alternating voltage signal from the battery and the shunt. The input (excitation) signal is generated from a PC, using a sound card, but it can be generated from an external signal generator.

The MATLAB software tool was used for data processing and display of results, with advantage of a possibility of fast data processing, and ability to customize the existing and add a new algorithm for battery parameters estimation.

Using algorithm described in the paper, and based on the measured response signals, the parameters of the equivalent battery model were calculated, and the amplitude-phase characteristic of the Lead-Acid battery was formed. The approach can be used to analyze other systems of similar value of impedance, as well for precise measurement of low resistance (resistance of ducts, cables, wires, etc.).

The benefits of using the method is that any PC user can implement the system for battery impedance measurement. In addition to the standard PC hardware user needs simple external AC current source and two external measurement channels, as described in the paper.

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DATA SCIENCE

INVITED PAPER

Scalable Multi-cloud Platform to Support Industry and Scientific Applications

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***Abstract* - Cloud computing offers resources on-demand and without large capital investments. As such, it is attractive to many industry and scientific application areas that require large computation and storage facilities. Although Infrastructure as a Service (IaaS) clouds provide elasticity and on demand resource access, the challenges represented by multi-cloud capabilities and application level scalability are still largely unsolved. The CloudSME Simulation Platform (CSSP) extended with the Microservices-based Cloud Application-level Dynamic Orchestrator (MiCADO) addresses such issues. CSSP is a generic multi-cloud access platform for the development and execution of large scale industry and scientific simulations on heterogeneous cloud resources. MiCADO provides application level scalability to optimise execution time and costs. This paper outlines how these technologies have been developed in various European research projects, and showcases several application case-studies from manufacturing, engineering and life-sciences where these tools have been successfully utilised to execute large-scale simulations in an optimised way on heterogeneous cloud infrastructures.**

Keywords – cloud computing, application level scalability, container technologies, multi-cloud access.

I. INTRODUCTION

Cloud computing has the potential to offer computational resources on demand and dynamically scale these resources to fit the requirements of applications. Additionally, purchasing resources from public cloud providers eliminates the need to invest into expensive hardware, and to maintain these resources in-house that otherwise result in significant costs and requires expertise. Due to these features, cloud computing has proven to be rather attractive to both industry and the research community.

On the other hand, utilising cloud computing resources raises various challenges. Porting existing applications to cloud infrastructures and developing new applications that are able to fully utilise the dynamic and elastic nature of resources is not straightforward. The challenge is further increased if the application aims to be independent from the underlying cloud infrastructure. This feature may be required to avoid vendor lock-in and enable the migration of applications between various cloud providers. Additionally, more complex applications realising application workflows may also intend to utilise multiple heterogeneous cloud providers in order to further optimise execution time and costs. For example, some parts of a workflow may run on an internal private cloud and some other components may utilise a public provider to access large amount of resources.

Application developers are often facing the above described challenges when implementing industry and academic cloud applications. In order to address these issues, we developed a set of technologies within a string of European projects that supports application developers when creating flexible and scalable multi-cloud applications.

These technologies include the CloudSME Simulation Platform (CSSP) [1] that incorporates the multi-cloud CloudBroker Platform [2], the workflow-oriented WS-GRADE science gateway framework [3], and the CloudSME AppCenter. The CSSP was developed within the CloudSME (Cloud-based Simulation platform for Manufacturing and Engineering) project [4]. It represents a Platform as a Service (PaaS) solution that fastens up the development and deployment of complex multi-cloud applications (provided as SaaS – Software as a Service for the end-user), and also supports workflow execution and commercial accounting and billing. The CSSP was prototyped with eleven commercial applications from the manufacturing and engineering sector and was also used in several academic application scenarios. Currently, it is further developed in the CloudiFacturing [5] project where further 21 industry applications will apply the technology in near production quality demonstrators.

While the CSSP enables fast development and deployment of cloud applications, it does not optimise these applications either at deployment or at run-time. In order to address this issue, we are currently developing a generic pluggable framework, called MiCADO (Microservices-based Cloud Application-level Dynamic Orchestrator) [6] within the COLA (Cloud Orchestration at the Level of Applications) [7] project. MiCADO enables application developers not only to optimally deploy their applications in container-based cloud platforms, but also provides run-time monitoring and optimisation of these applications based on user defined quality of service parameters (e.g. deadline, cost, performance or security). MiCADO is fully integrated with the CSSP and provides cloud orchestration and optimisation in multi-cloud environments.

The rest of this paper provides a short overview of the above described technologies and also highlights some typical application examples and scenarios.

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II. THE CLOUDSME SIMULATION PLATFORM

The initial motivation when creating the CloudSME Simulation Platform was coming from the manufacturing domain. Large manufacturing companies widely utilise computer simulation to assist their design and manufacturing processes. Simulation can be used to analyse a wide range of physical and chemical processes, manufacturing systems, logistics, transportation networks and supply chains. On the other hand the take up of simulation by small and medium sized enterprises (SMEs) remains low. This is due to high hardware and software costs (simulation typically requires high performance computing capabilities and specialised software packages), and the lack of skills, technical expertise and in general low awareness of such technologies within SMEs. The aim of the CloudSME project was to utilise cloud computing and build a generic platform that supports independent software vendors (ISVs) and consultant companies when building simulation solutions for SMEs. The platform also enables the targeted end-user companies to utilise these solutions as services in the cloud and pay for it on a subscription or on a pay-as-you-go basis. Although the platform was originally built for the manufacturing sector, it was also successfully utilised in a number of academic and research oriented application scenarios.

Fig. 1 demonstrates a high level architecture of CSSP.

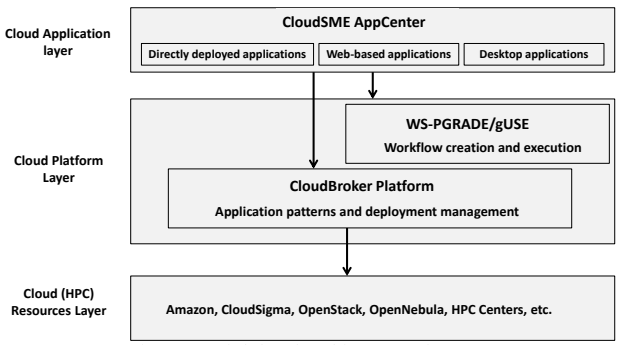

Figure 1. High level architecture of CSSP

The CSSP consists of three main layers. The **Simulation Applications Layer** allows software vendors deploying and presenting simulation products to end-users as SaaS in a wide range of scenarios and deployment models. The **Cloud Platform Layer** provides access to multiple heterogeneous cloud resources and supports the creation of complex application workflows. It is a PaaS to create and execute cloud-based simulations. Finally, the **Cloud Resources Layer** represents the IaaS clouds (and also high performance computing (HPC) resources connected to the platform.

When implementing the CSSP we concentrated on reusing, extending and integrating existing building blocks in order to speed up the development process and provide a robust and reliable solution. However, especially for the top layer that includes commercial components, some new modules also needed to be developed within the project.

The Simulation Applications Layer consists of the CloudSME AppCenter as a generic entry point to browse and execute various simulation applications. The AppCenter is a new component that was developed during the CloudSME project. The CloudSME AppCenter is a web-based one-stop-shop solution with the goal to provide software products and services by software vendors and service providers to end users that can utilise them via a single interface. For this, the AppCenter stores information about software products in an accessible way, provides usage scenarios for the software, and offers billing functionality that includes price setting, payment integration and tracking of users' spending.

The AppCenter supports three main deployment models: Directly Deployed Applications, Desktop Applications and Web-based Applications.

Directly Deployed Applications are published in the AppCenter using its native interface. End-users can access these applications directly from the AppCenter and execute them on the vendor selected cloud or HPC resources. Users will be billed based on software provider defined pricing policies, e.g. resource consumption-based pricing, fixed price per run, periodic subscription charge, etc.

Besides directly deploying and utilizing an application via the native user interface of the AppCenter, developers can also apply its API (Application Programming Interface) to embed accounting and billing functionality into existing web-based or desktop applications. Additionally, using the APIs of the Cloud Platform Layer they can also map these applications to various cloud/HPC resources or even combine then into complex workflows.

Desktop Applications are modified versions of the vendors' original software packages that include AppCenter and Cloud Platform Layer API calls, and redirect and charge for computation intensive simulations on the cloud. These applications can be downloaded from the AppCenter and executed on the users' local machine (but sending computation intensive jobs to remote computation facilities). Web-based applications are simply linked to the AppCenter and use the suitable API calls behind their web interface.

Fig. 2 shows a screenshot of the CloudSME AppCenter providing examples for each three categories. 3D Scan Insole Designer is a Directly Deployed Application that can be run from the AppCenter. TransAT is a Desktop Application that can be downloaded. Finally, CalculiX and OpenFOAM are Web-based Applications linked to the AppCenter.

The Cloud Platform Layer consists of the science gateway framework WS-PGRADE/gUSE and the CloudBroker Platform.

The CloudBroker Platform supports the management and execution of software on different cloud provider resources. The platform provides access to a wide range of resources including open source and proprietary clouds, and also various HPC resources. It can support non-interactive, serial and parallel batch processing

applications on both Linux and Windows operating systems. The Platform consists of a set of modules that manage processes, applications, users, finance (accounting, billing and payment), and runtime issues (process monitoring, queuing, resources, storage and images). Application "patterns" are deployed to CloudBroker in a form that allows the platform when instructed to run the application on a particular cloud and cloud instance type. Two typical patterns are direct installation (an application package and deployment script that allows the installation of the software on a cloud instance) or virtualisation (virtual machine image containing installed software that allows direct deployment to a cloud instance).

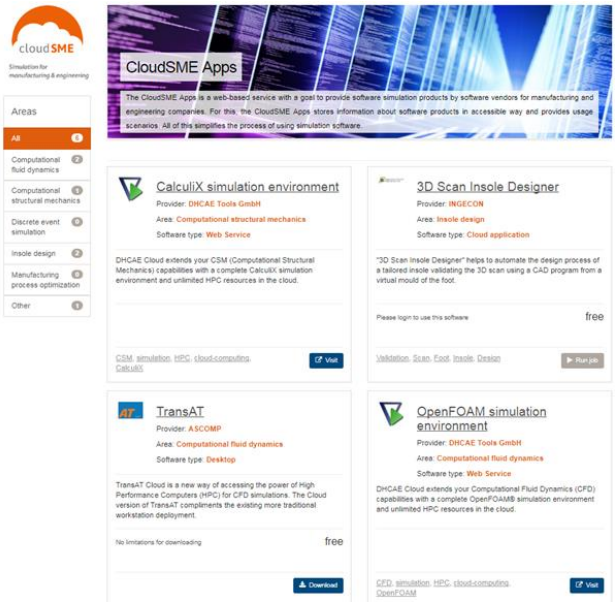

Figure 2. The CloudSME AppCenter

WS-PGRADE/gUSE supports the development and deployment of complex application workflows. It consists of three components: a workflow presentation layer, a workflow management layer and a workflow execution layer. The workflow presentation layer (WS-PGRADE) includes a set of Liferay portlets to create, start and control workflows, monitor their execution on various DCIs (Distributed Computing Infrastructures), and present results to users. The workflow management layer (gUSE) consists of services to support workflow management and execution (file storage, workflow repository, and workflow interpreter to manage the execution of workflows). The workflow execution layer manages job submission as specified in the workflow.

WS-PGRADE/gUSE and CloudBroker were integrated within the SCI-BUS [8] and CloudSME projects enabling the execution of WS-PGRADE workflows on multiple heterogeneous cloud resources supported by the CloudBroker platform.

The bottom layer of CSSP is the Cloud Resources Layer that consists of a range of clouds and HPC resources accessible via the CloudBroker Platform. These currently include Amazon and CloudSigma public clouds, various private clouds based on either OpenStack or OpenNebula, and HPC resources, for example the Cineca Galileo Cluster or the ETH Euler Cluster.

III. Applications on the CSSP

In order to prove the applicability of the CSSP, eleven near production quality demonstrators, in two waves, were developed in CloudSME. Altogether 24 companies, all of them SMEs, were involved in the project. These companies included cloud resource and platform providers responsible for the underlying resources and infrastructure, independent software vendors and software development/consultant companies providing various simulation software solutions, and manufacturing and engineering companies as end-users of the developed technology.

The strength of the CSSP is that it provides support for the fast and efficient development and deployment of a wide variety of applications. These application scenarios fall into three main categories.

Parallel multiprocessor applications use cloud instances or HPC resources to run massively parallel applications on multiple CPUs of one instance or on multiple instances of a computing cluster or HPC Center. Such CloudSME application example is described in [9] that presents TransAT (Transport Phenomena Analysis Tool), a computational fluid dynamics (CFD) application by ASCOMP GmbH [10], and analyses its performance speed-up when applying the CSSP.

The second category is parameter sweep applications that use multiple independent cloud instances to speed up experimentation. In this scenario large number of independent jobs has to be executed independently from each other typically followed by a shorter evaluation of results. A CloudSME application representing this scenario is also presented in [9] where Repast Simphony [11], an open source agent-based modelling and simulation tool was benchmarked on the CSSP.

The final category is scalable web applications where the challenge is the dynamically changing number of users and fluctuating load of the application that require a flexible amount of resources. A commercial application example where a custom web portal was implemented and connected to the CSSP for uploading and validating scanned images for custom foot insole design is presented in [12]. However, please note that this solution developed within CloudSME does not offer automated scalability and only scales up following operator intervention. This issue will be further addressed in Section IV.

Besides industry utilization, the usability of CCSP was also demonstrated in several academic and research application scenarios. The Raccoon2 [13] molecular docking desktop application was successfully extended with multi-cloud support as described in [14], and the automated setup and workflow-based execution of applications using Hadoop [15] was offered for users of the European Grid Infrastructure Federated Cloud (EGI FedCloud) based on the work in [16].

IV. Automated Scalability of Cloud Applications

One of the limitations of CSSP is that the resources utilized for the execution of applications are configured at the beginning of the experiment and cannot be

dynamically adjusted at run-time. However, many scientific and commercial applications require access to computation, data or network resources based on dynamically changing requirements. This challenge is addressed by the MiCADO Framework that is currently being developed within the COLA European project.

The concept of MiCADO is to provide application level scalability of cloud computing resources. The aim is to create a framework, where automatically adjusted cloud service supply can be arranged, based on application demands. Such framework allows cloud application developers to build cost and performance optimization mechanisms into their applications using a high level definition language. The suggested solution is based on microservices [17] and their dynamic orchestration in a cloud computing environment.

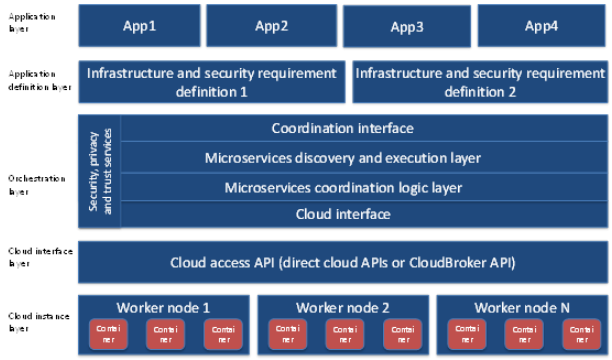

Figure 3. MiCADO Layered Generic Architecture

The generic layered architecture of MiCADO is shown in Fig. 3. The *Application layer* contains actual application code and data to make an application definition functioning in such a way that a desired functionality is reached. The *Application definition layer* forms the basis to define a functional architecture of the application using application templates. This layer describes the application topology and the deployment and scalability policies using TOSCA (Topology and Orchestration Specification for Cloud Applications), an OASIS standard [18]. The *Orchestration layer* is divided into four horizontal and one vertical sub-layer. The horizontal sub-layers include the *Coordination interface API* that provides access to orchestration control and decouples the orchestration layer from the application definition, the *Microservices discovery and execution layer* that manages the execution of microservices and keeps track of services running, the *Microservices coordination logic layer* that gathers and processes information in order to support decisions regarding scaling up or down the infrastructure, and the *Cloud interface API* that abstracts cloud access from layers above. The orchestration layer also includes a vertical sub-layer called *Security, privacy and trust services* that shields application developers from detailed security management. The *Cloud interface layer* provides means to launch and shut down cloud instances. Finally, the *Cloud instance layer* contains cloud instances provided by IaaS cloud providers.

As the cloud interface layer of the above described architecture can be implemented using the CloudBroker platform, MiCADO can seamlessly extend the CSSP when deploying and managing applications that require dynamic automated scalability.

The first prototype implementation of MiCADO, presented in [6] is based on the integration and extension of widely used open source container-based cloud technologies, such as Docker Swarm [19], Occopus [20], and Prometheus [21]. Docker Swarm is a widely used docker-based service where the Docker master node is responsible for the dynamic creation and management of Docker containers at the worker nodes of the Swarm cluster. In order to take the decision when the number of workers in the Swarm cluster should be increased or decreased, Prometheus is used as monitoring tool to observe the load of the worker nodes. The collected data is used to create alerts. These alerts are events which if triggered then they are sent out to other services of MiCADO. The alerts are generated by the Alert manager service. Prometheus provides only a framework to create the Alert manager service therefore it was our task to develop the alert conditions and code. Similarly the Alert executor service was developed by us based on the Prometheus framework concept. The Alert executor instructs the Occopus cloud orchestrator to deploy new Swarm worker nodes or remove existing ones depending on the information provided by the Alert manager service.

IV. APPLICATIONS OF MICADO

The two main targeted application categories for MiCADO are cloud-based services where scalability is achieved by scaling up or down the number of containers and virtual machines based on load, performance and cost, and the execution of a large number of (typically parameter sweep style) jobs where a certain number of these jobs need to be executed by a set deadline.

The first MiCADO implementations were primarily focusing on the first application category where the scalability of cloud-based services needs to be automated. Such application example is presented in [6] where the Data Avenue data staging service [22] was successfully extended with MiCADO based automated scalability. Data Avenue enables to transfer files or directories between different data storages having various storage access protocols (e.g. HTTP, HTTPS, SFTP, GSIFTP, SRM, iRODS, S3). Data Avenue is also used in gUSE/WS-PGRADE portals either as a portlet or inside WS-PGRADE workflows to enable file transfer based communication between workflow nodes. The original version of Data Avenue proved to be a bottleneck when a large number of users wanted to transfer large amounts of data. The MiCADO-based implementation overcomes this problem as it is highly scalable and can be automatically replicated whenever the usage of the service exceeds a pre-defined threshold. Similarly, once the load is reduced below this threshold, under-loaded replicas can be removed from the cloud.

The COLA project currently implements three large scale industry and public sector demonstrators to showcase the capabilities of MiCADO. One of these examples, Magician, an application for Social Media data mining by Spanish company Inycom, is described in [23]. Aragon Regional Government in Spain has set the goal to develop communication channels with citizens to become aware of their opinion about the local government's services, and how these can be improved. The authorities

also want to offer information to entrepreneurs and companies in the region that can be used to improve businesses or develop new ones. The local government already collects large amounts of data resulting from interactions with its citizens (e.g. applying for public services such as grants, aids, subsidies, and licenses). This data can be combined and extended with information publicly available in social networks. The aim is to set up a business gateway that is supported by the intelligent analysis and utilisation of all available information.

Two relevant aspects of such social media analysis tools are the ever increasing size of the amount of data available and, at the same time, the unpredictable fluctuation of computing load required due to the high level of uncertainty on how much information will be collected by the crawlers to be processed later. Additionally, databases and software processes may run on different Clouds requiring access to a heterogeneous set of resources in a dynamic way. In order to meet the above challenges, Magician is currently being prototyped within COLA to extend it with automated scalability.

V. Conclusion and Future Work

This paper presented an overview of technologies and solutions developed in a string of European research projects to address scalable multi-cloud deployment of industry and academic applications. The CloudSME Simulation platform has already been utilized for the development and cloud deployment of various applications from the manufacturing and engineering domain and also by the research community. In the currently running CloudiFacturing project the technology is expected to mature further and be used by up to 21 new industry applications.

In order to address the automated scalability of such cloud applications, we are developing the MiCADO framework that supports application developers to embed such capabilities into their applications without requiring low level custom development and cloud expertise.

Future work is twofold. We are further developing the CSSP based on the requirements of the CloudiFacturing application scenarios. On the other hand, MiCADO is being extended with policy keeper and optimiser modules in order support various application types and scalability parameters.

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PAPERS

Cross-correlation Based Detection of Contigs Overlaps

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***Abstract* - Increasing demand for genomic data stress the development of new sequencing techniques and assembly methods. While the sequencing techniques are the biologist domain, the genome assembly is bioinformatical task and development of new assembly algorithms responds to the new sequencing methods. The final part of the assembly process is merging the contigs and find their position in the genome. Contigs are almost the final product but they can contain errors and features induced by previous assembly process. The current methods use string algorithms based on dynamic programming computing with characters (A, C, G, T) representing nucleotides, but if applied to long sequences, e.g. contigs, they tend to be time-consuming. We applied another approach based on genomic signal processing to evaluate the further merging and overlaps between the contigs. The genomic signal form of DNA sequence can reveal hidden features of sequences and digital signal processing methods can be applied. Also, the computational complexity of task can be reduced by implementing massive downsampling. We use our own implementation of cross-correlation based on Pearson correlation coefficient to detect possible overlaps between contigs, when high positive correlation indicates possible shared regions of the contigs but also to denote the position of that region, without the alignment.**

Keywords - bioinformatics; genomic signal processing; assembly; correlation

I. INTRODUCTION

The current course in medicine, when the basis for treatment of diseases is searched more and more at the level of DNA sequences [1], together with new molecular biology methods [2], and gradual decrease of the price of a sequenced genome shift focus to newer sequencing techniques and related bioinformatical topics like genome assembly. As long as the DNA sequencing and following analysis is not as ordinary and easy to use as cell phones, there will probably be a requirement for lightweight and less demanding processing of sequencing data.

Until the sequencing methods are restricted in size of DNA molecule which they are able to read at once, there will be a process of the genome assembly. Depending on sequencing platform, the length of reads varies – PacBio thousands of nucleotides, Illumina up to 350bp, Oxford Nanopore up to thousands of nucleotides [3]. Many assemblers were already developed, usually suited for the length of reads the sequencing platform produces. The design of the assemblers is based on graph theory and uses overlap layout consensus algorithms suitable for long reads (Celera [4]) or de Bruijn graph for short reads (Velvet [5]). However, assembler does not produce a final product in all cases, instead, the partial output, the contigs, are produced. Contigs are longer sequences usually separated by gaps induced by sequencing errors, lower sequencing depth and genome repetitions longer than length of reads. Several tools called scaffolders were published: LINKS [6], SSPACE [7] etc, using different approaches, e.g. alignment, graph theory and greedy approach [8].

All assemblers and scaffolder are based on character-based sequences, as the natural form of DNA. However, the field of genomic signal processing (GSP) was developed as a merge between classical bioinformatics and digital signal processing (DSP) fields. Genomic signal processing includes the numerical representations which convert the DNA nucleotides in a letter form into a numerical form of the signal [9]. Thus, this enables us to use other approaches known to the field of DSP.

In this paper, we focused on the method for detecting overlaps between signals represented in form of genomic signals. The sequences representing contigs were converted into signals and the possible overlaps between them were detected using Pearson correlation coefficient implemented in our own algorithm. The Pearson correlation coefficient is computed incrementally across the two signals, so we acquire the signal of correlation. Detecting peaks in this signal together with their position should indicate the overlap between them. Optimization technique adopted from traveling salesman problem was then used to create a path and joining the contigs into the longer final sequence.

II. METHODS

A. Numerical representations

Numerical representations serve as a means to the acquisition of digital signal from DNA sequence. DNA sequence is represented by four letters representing nucleotides, numerical representation converts this sequence into a signal following a specific formula. Several numerical representations were already published [10-13]. Different representations have specific features.

From published representations, we focused on phase representations [11] which meet selected criteria: one-dimensionality, equidistant sampling (one nucleotide, one signal sample), low-computational demands to conversion. Each nucleotide in DNA sequence is converted into a genomic signal by getting the phase of the complex number according to mapping, e.g. (A = π/4; T = -π/4; C =-3π/4; G =3π/4). This simple assignment can be immediately used or the values can be cumulated across the signal (the cumulated phase representation), or corrected to produce smoother phase plot (unwrapped phase representation) [11-14].

B. Pearson Correlation Coefficient

The comparison of digital signals is main domain of correlation. Both covariance and correlation can be used. We employed our own implementation of Pearson correlation coefficient based on formula (1):

$$\rho(A,B) = \frac{1}{N-1}\sum_{i=1}^{N}\frac{(A_i-\mu_A)}{\sigma_A}\frac{(B_i-\mu_B)}{\sigma_B} \qquad (1)$$

where A, B denotes compared signals, N is observations, where μ_A and σ_A are the mean and standard deviation of A, respectively of B. Correlation techniques were already proven to be efficient for similar tasks [15]. Pearson correlation coefficient values are universally in the range from -1 to 1. A value of 1 implies a linear dependency between two A and B, a value of 0 no relation and value of -1 negative linear dependency.

C. Algorithm for computing correlation

Both numerical representation and correlation coefficient methods are merged in the proposed algorithm. The aim is to acquire a measure of similarity across both comparing signals representing DNA sequences, i.e. the cross-correlation. The peaks of correlation curve across the signals implies high similarity of those compared parts, i.e. possible overlap at that position.

The computing of correlation between two sequences is divided into three steps as displayed in Figure 1. and described by the formulas of Equation 2. Let's define two signals, *X [1: N]*, *Y [1: M] N>M*, the correlation signal *coef* is computed by implementing formulas:

$$\begin{aligned} coef_{a)} &= \rho(\,X\,[1{:}\,i], Y\,[M-i{:}\,M]\,) \\ coef_{b)} &= \rho(\,X\,[i{:}\,i+M)], Y[1{:}\,M]\,) \\ coef_{c)} &= \rho(\,X\,[N-i{:}\,N], Y\,[1{:}\,M-i]\,) \end{aligned} \qquad (2)$$

where ρ is the Pearson correlation coefficient and i is the shift between the signals, which is gradually increased and reset after computation of corresponding part of signal. Each step is described by corresponding formula and graphically illustrated in Figure 1. In Figure 1, the blue line represents the longer signal X, the black line the shorter one, signal Y. The red line denotes, which part of them serves for correlation computation (window).

Subsection a) on figure 1 captures the first part of the algorithm, the shorter signal is gradually moved to the right side and the correlation window is increasing in size. This part begins at the overlap of size 1 and ends when overlap has the size of the shorter signal. Then, during second part (subsection b) the windows have the same size as shorter signal and the whole window is moving to the right step-by-step. The process ends when the end of the longer signal is reached. The final part is similar to the first, the correlation windows decreases as the shorter signal shifts to the right side (subsection c).

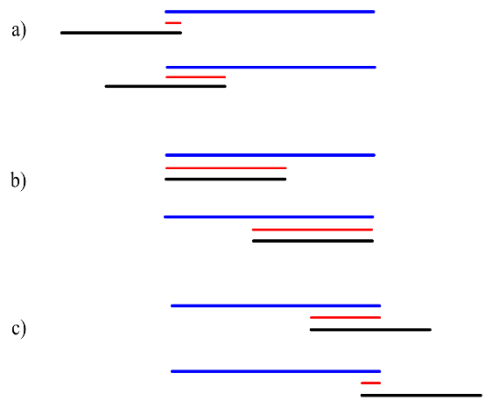

Figure 1. Algorithm for computing correlation. Blue and black lines represent contigs, red lines show what part of contigs are taken into correlation computation

In the case the signals have the same length, the middle part b) is omitted. The final correlation signal has the length of $L=L_A+L_B$, where L_A is the length of signal A, respectively, L_B the length of signal B. The signals are not zero-padded. The output of the computation between two signals is a vector of the size of the sum of lengths of those two compared signals. The maximum value of this vector is a score of similarity between those two signals. The final output is a matrix of dimensions N×N (N is the number of signals), where only the maximum correlation coefficients and corresponding positions are stored.

D. Travelling salesman problem – nearest neighbor algorithm

Travelling salesman problem emerged in the 20th century as one of most demanding topics and seconded increase of interest in optimization techniques. The basic formulation can be stated as searching for the optimal route between cities, with defined distances between them while visiting each city exactly once and returning into the original city. It is an NP-complete problem, still without a solution in polynomial-time. [16] Many optimization techniques can be used to solve this problem, heuristic approaches, genetic algorithms, neural networks etc. [16]

The background of TSP problem is a symmetrical matrix of distances between cities. The symmetrical distance matrix is the output of our proposed correlation computing algorithm. Thus, we can formulate the problem of connection contigs similarly to the TSP problem. Because of the smaller size of the dataset (in the order of dozens) we employed the heuristic approach – the nearest neighbor algorithm as the most intuitive. The algorithm starts with a random origin and at each step is choosing the

most scoring option (greedy-heuristic) and insert it into solution. Algorithm gradually cycles through all possible origins and creates set of solutions from which the most highly scoring solution is chosen. However, the heuristic method does not always produce the optimal results. [16]

E. Application

Both proposed algorithms were connected into the pipeline in Figure 2. The contigs taken from FASTA files are converted into the form of genomic signals and the Pearson correlation coefficient is computed each-to-each obtaining correlation signal. The acquired similarity matrix is an input of the nearest neighbor algorithm which tries to solve the optimal path between the contigs based on a sum of similarity score between the pair of contigs. The output

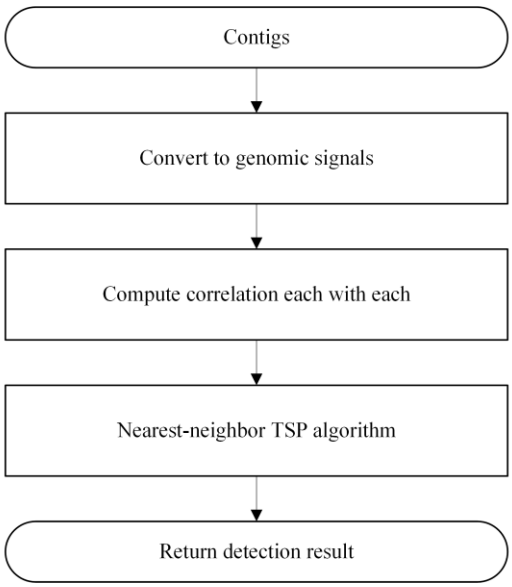

Figure 2. Algorithm process

is a path through the contigs.

F. Dataset

As the proposed algorithm is neither a complete assembler nor a scaffolder, the evaluation cannot be done as the one-to-one comparison of the outputs with other tools. Proposed algorithm does not take many features of DNA sequencing and assembly into account, e.g. dealing with DNA repetitions, gap introduced by pair-end sequencing, coverage. Thus, we established our own way to assess the output of algorithm in the way it was meant to work.

We created the synthetic data for testing the algorithm. Synthetics data are contigs of specified length, overlap, and percentage of erroneous nucleotides (representing sequencing errors). Contigs were created from the whole genome sequence of E. coli (GenBank ID NC_000913.3). The length of the contigs has not qualitative impact on results, only the impact on computational demands, thus all contigs are 3000 bp length. For assessment of Pearson correlation coefficient effectivity for the specific tasks of overlaps detection, the contigs were tested with different lengths of overlaps [20, 40, 80, 160, 250, 500] and errors percentage [0%, 0.5%, 1%, 2%]. That will show the reliability of implemented correlation algorithm under different circumstances. Each dataset contains 50 contigs, the total size of the dataset is 300 FASTA files leading to a 15000 contigs overall.

G. Evaluation metrics

The results of evaluation were considered in metrics of the confusion matrix. The output is essentially evaluated as correctly or incorrectly detected overlap. Thus, three metrics are used: accuracy (correctly detected (true and false) overlaps divided by the total number of overlaps in dataset), the percentage of correctly and incorrectly detected overlaps. Similar metrics were used in previous articles [12, 17].

H. Computational complexity

The analysis of code was performed based on time duration and operations performed, resulting in $O(n^2)$. For better insight, the table of time duration based on contigs number of constant length 3000 bp is inserted:

TABLE 1. Time duration of run

Contigs #	5	10	15	20	25	30	40	50
Time [sec]	3	13	30	53	86	123	220	346

III. RESULTS

The evaluation of algorithm performance is in Table 1. The results are divided by the length of overlap and percentage of induced errors.

TABLE 2. Table of results

0 % errors			
Overlap length	**Accuracy**	**% correct overlaps**	**% incorrect overlaps**
20	1	100	0
40	1	100	0
80	0,99	99,59	0,40
160	1	100	0
250	1	100	0
500	0,99	99,59	0,40
0.5 % errors			
20	0,99	86,93	13,06
40	0,99	79,79	20,20
80	0,99	80,61	19,38
160	0,99	81,63	18,36
250	0,99	81,83	18,16
500	0,99	88,16	11,83
1 % errors			
20	0,99	79,79	20,20
40	0,99	68,97	31,02
80	0,99	69,18	30,81
160	0,99	69,38	30,61
250	0,99	68,97	31,02
500	0,99	69,59	30,40
2 % errors			
20	0,99	59,86	40,13
40	0,99	55,10	44,89
80	0,99	60,54	39,45
160	0,98	46,93	53,06
250	0,99	54,42	45,57
500	0,99	56,46	43,53

IV. Conclusion

The aim of the paper was to introduce the proposed method for correlation computation across two signals together with the algorithm for joining the contigs together. Following the results section, there is clear statement that algorithms perform effectively at signals with no errors included. The Pearson correlation coefficient is very effective in these cases and is able to detect matching overlaps at almost 100%. The decrease in accuracy and other metrics in results for 80 and 500 overlaps is caused by one incorrectly detected overlap in dataset. However, the computation of correlation is not able to detect effectively overlaps with errors included. It tends to detect a higher correlation between signals which they do not share an overlap, thus decreasing overall accuracy and percentage of correctly detected overlaps. The results also emerged that the accuracy decreases as the length of overlap between signals increased. Again, Pearson correlation coefficient method tends to favour shorter overlaps by calculating higher correlation coefficient between shorter non-overlapping sequences than by longer overlapping sequences in some cases. The accuracy of the erroneous signals would probably increase when the number of the contigs in the dataset would be lower, respectively decrease more for higher number of contigs. Thus, the possible application dwells on focusing on already corrected data with less errors.

The proposed algorithm proved to be efficient, but very sensitive to the erroneous data as the results in the Table 1 imply. Also, the algorithm for creating the path between contigs implemented from TSP problematics demonstrated its usability and is a suitable replacement for a graph-based method for smaller number of contigs. It is convenient to mention that methods based on digital signal processing have generally lower computational demands than those based on string methods.

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Modular Supercomputing Design supporting Machine Learning Applications

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Abstract - The DEEP-EST (DEEP – Extreme Scale Technologies) project designs and creates a Modular Supercomputer Architecture (MSA) whereby each module has different characteristics to serve as blueprint for future exascale systems. The design of these modules is driven by scientific applications from different domains that take advantage of a wide variety of different functionalities and technologies in High Performance Computing (HPC) systems today. In this context, this paper focuses on machine learning in the remote sensing application domain but uses methods like Support Vector Machines (SVMs) that are also used in life sciences and other scientific fields. One of the challenges in remote sensing is to classify land cover into distinct classes based on multi-spectral or hyper-spectral datasets obtained from airborne and satellite sensors. The paper therefore describes how several of the innovative DEEP-EST modules are co-designed by this particular application and subsequently used in order to not only improve the performance of the application but also the utilization of the next generation of HPC systems. The paper results show that the different phases of the classification technique (i.e. training, model generation and storing, testing, etc.) can be nicely distributed across the various cluster modules and thus leverage unique functionality such as the Network Attached Memory (NAM).

I. INTRODUCTION

Traditional High-Performance Computing (HPC) systems have been mainly designed for scientific and engineering applications that often are based on numerical methods using known physical laws. Those class of applications are often summarized under the term 'simulation sciences' but are partly different from purely data-driven applications known as 'data sciences' today. Those latter applications use parallel and scalable machine learning methods, data mining algorithms, or statistical approaches in order to automatically discover information in large datasets (i.e. 'big data'), ideally following a systematic process such as the Cross-Industry Standard Process for Data Mining (CRISP-DM) [1]. As a consequence, current HPC systems design needs to support a much broader range of application requirements in order to enable performance improvements.

Another change in HPC systems design is driven by the ever expanding set of parallel technology hardware that becomes available such as a wide range of accelerator technologies like NVIDIA, General-Purpose computing on Graphics Processing Units (GPGPUs), or innovative memory technologies. While many paper contributions purely focus on the evolution of using particularly GPGPUs and accelerators in general in applications, there is less focus on innovative memory technologies that have very interesting capabilities especially when considering data-driven applications.

This paper, therefore, describes key approaches of using the innovative Network Attached Memory (NAM) [2, 3] from the HPC hardware manufacturer EXTOLL in a real data-driven application that employs machine learning algorithms that are used in a wide variety of applications, such as in the realm of life or earth sciences. The particular machine learning algorithm used to drive the HPC system co-design using the aforementioned NAM are Support Vector Machines (SVMs) [4] in the application field of remote sensing, but SVMs and their usage of the NAM are applicable to other application domains in the same way. The results of this paper have been implemented as part of the European Union's Horizon 2020 exascale project Dynamical Exascale Entry Platform – Extreme Scale Technologies (DEEP-EST) [5] and its HPC system prototypes that beside the NAM also offers other innovative modules.

The remainder of the paper is structured as follows. Following this introduction, Section II describes the technology background in the realm of the DEEP-EST project such as its various modules while Section II also includes a brief introduction to machine learning with a particular focus on the SVM technique. Section III describes the application problem domain and its need for parallel and scalable SVM implementations on HPC systems. Afterwards, Section IV technically describes how the NAM module and our SVM implementation in combination with other innovative DEEP-EST modules is particularly useful to improve application performance and HPC system utilization. The paper concludes with a summary and outline of future work.

II. BACKGROUND

This section provides a short background on machine learning and the various DEEP-EST hardware accelerator modules.

A. *Machine Learning with Support Vector Machines*

Machine learning techniques are used in a process of automatically discovering useful information or specific patterns in large datasets. We thus assume a pattern to be detected in the data and there is no mathematical formula or known physical law (cf. simulation sciences) that can be directly implemented to find those patterns with an

analytic solution. Instead, the focus on the dataset in question itself in order to discover the pattern with learning methods such as classification and clustering algorithms or regression methods.

The contributions of this paper are based on supervised learning using classification whereby groups of data already exist with labeled group identity and new data points are classified to those existing groups based on a learned classification model. In more detail, this learning process essentially follows the following three steps: (i) training, (ii) model generation and storing, and (iii) testing. We describe these three rather general classification steps in the context of a concrete model called Support Vector Machines (SVMs) [4], but they are valid for any other classification technique such as Random Forests (RFs), Artificial Neural Networks (ANNs), or, more recently, deep learning networks such as Convolutional Neural Networks (CNNs).

The (i) training process uses training data with a machine learning algorithm is often based on constrained optimization techniques that are solved with quadratic programming and sequential minimal optimization (SMO) in the case of SVMs. These computational demanding optimization techniques do not scale well and thus usually require a CPU with high single thread performance in order to perform proper model training and reach convergence in a reasonable amount of time. The result of step (i) is a model that was trained with a particular setup with respect to training parameters (e.g. regularization parameter C in SVMs) or the use of a kernel like Radial Basis Functions (RBFs).

In step (ii), the trained model from step (i) needs to be generated in a specific model format (i.e. SVM model file) and stored as a file, or transferred in some other way, to reach step (iii). The specific property of the particular step relevant for this paper (ii) is that the SVM model consists of an 'in-sample' property meaning that the support vectors [4] that support the decision surface to separate datasets of different classes is also part of the dataset. Hence, there is a likelihood that the bigger the dataset, the more support vectors are needed; as a consequence, the model file is getting larger, too. Thus dropping the model file to storage after step (i) in step (ii) to be loaded by step (iii) is something we refer to as 'model storage bottleneck' that is later addressed in this paper.

In order to predict new data items in step (iii) based on the model, the model file from step (ii) is again loaded into memory from file in the above case and used for inference. This prediction step is called testing and uses its own dataset or, when model building is finished, represents the way how a model is used in a final model deployment in daily applications. In contrast to step (i), the computational needs for step (iii) and its nature of inference is a process that requires only moderate CPU power. Finally, due to the page restriction of the paper, we can not go into details for another important element of the machine learning process that is validation that in turn is also used in conjunction with regularization techniques to combat overfitting.

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B. *Innovative DEEP-EST Modules*

The DEEP-EST project [5] performs research in new HPC system architectures using innovative hardware co-designed by a wide variety of applications. One of the research outcome of the DEEP-EST project is the creation and exploration of the Modular Supercomputer Architecture (MSA) [6] that in turn is adopted by the Juelich Supercomputing Centre (JSC) in Germany for production end users. The MSA is illustrated in Fig. 1 and consists of various modules with different HPC hardware characteristics in order to support different workloads of applications on one overarching HPC system. Each MSA module is tailored to fit the needs of a specific set of computations, storage, or communication tasks with the goal of reaching exascale performance, which is unlikely to be achieved using traditional and rather static non-accelerated HPC system designs with CPUs, storage, memory, and interconnects.

The Cluster Module (CM) offers a module with powerful Cluster Nodes (CNs) which consist of multi-core CPUs that offer fast single-thread performance and therefore makes is suitable for applications that are very computationally expensive. It offers a good amount of memory but enables only limited scalability being highly interconnected within the module itself but also to other modules using the Network Federation (FN).

In contrast to the multi-core CM module, the Extreme Scale Booster (ESB) module [6] is a manycore system for highly scalable application workloads whereby each of the many CPU cores in the system offers only moderate performance. As shown in Figure 1, the ESB module also includes the Global Collective Engine (GCE) integrated in its network fabric that leverages a Field-Programmable Gate array (FPGA) in order to speed-up common Message Passing Interface (MPI) collective operations in hardware such as MPI reduce operations.

The Data Analytics Module (DAM) offers accelerators like GPGPUs which are particularly useful for deep learning algorithms. Furthermore, the Scalable Storage Service Module (SSSM) offers a high capacity in storage using underlying parallel file system technologies, such as Lustre or the General Parallel File System (GPFS) from IBM at JSC. Finally, the NAM module [2, 3] is a special module that is the key focus of this paper and described in more detail in Section IV.

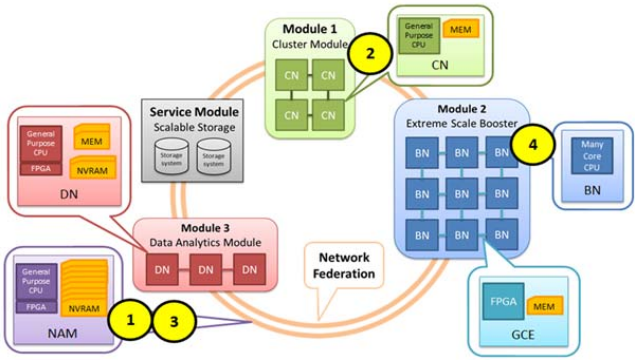

Figure 1. Utilizing the Modular supercomputer Architecture (MSA) for machine learning algorithms like Support Vector Machines

III. Parallel and Scalable SVMs in Remote Sensing using DEEP-EST Platform

This section describes our application and how we map it to the MSA of the DEEP-EST platform.

A. Parallel and Scalable Application Demands

The remote sensing application dataset used in this paper is the Indian Pines AVIRIS dataset [7] over an agricultural site composed of agricultural fields with regular geometry (200 spectral bands, 1417x617 pixels, spatial resolution of 20 meter, 52 classes of different land cover). Before the above phases of classification are performed the raw hyper-spectral data is used with feature engineering, which in this case is the Self-Dual Attribute Profile (SDAP) [8].

Progress in sensor technology leads to an ever-increasing amount of data which needs to be classified in order to extract information. This big amount of data requires parallel processing by running parallel and scalable implementations of classification algorithms such as the SVM introduced above on HPC systems. This paper uses our parallel and scalable PiSvM [9] that scales well across a large amount of CPUs and is an improved version of the original πSvM [10] implementation. As shown in Cavallaro et al. [11] this optimized version offers a good classification accuracy while at the same time being more efficient in using the MPI standard for parallel processing in HPC clusters enabling a speed-up for remote sensing applications.

B. Parallel Training and Model File Generation

The (i) training phase feeds the pre-processed remote sensing training data into the SVM algorithm which in turn calculates data-space coefficients using a particular set of hyper parameters. These coefficients identify support vectors that can then implicitly be used to classify arbitrary input data (e.g., new acquired hyper-spectral images) via a generated SVM model classifier.

In order to speed-up the (i) training phase outlined above, we use our parallel pisvm-train executable that in turn is based on the serial de-facto standard implementation libSVM [12]. As the optimization algorithm implementations that are part of the inherent libSVM are very computational demanding, it makes sense to use the DEEP-EST CM for the (i) training phase. This executable takes as input, alongside the training dataset location, several parameters related to the precise type of SVM to be used as they can also be used for regression. Another parameter for this executable is the type of the kernel function to be used in training and its associated parameters like gamma in the case of the RBF kernel.

The implementation of pisvm-train is executed on the DEEP-EST CM using a typical scheduler batch script for parallel processing. According to phase (ii) model file generation and storage, the parallel computing job on the CM creates an SVM model on the parallel file system to be used by step (iii). The PiSvM implementation from [9] uses non-optimized POSIX I/O for file handling. Our porting to the DEEP-EST MSA involves using MPI parallel I/O for for reading the initial input and writing the final output. Passing the intermediate data between the different steps and their executables is performed in a highly optimized way using the NAM as discussed in Section IV.

C. Use of the SVM Model File in Parallel Prediction

In the (iii) testing phase, we use the generated model file as input parameter alongside a test dataset location for the pisvm-predict executable that is used for prediction. The goal of this phase is to evaluate the SVM classifier's accuracy by comparing its output for a specifically selected testing dataset of input data with a correct classifications known beforehand and not used during the (i) training phase. This rather embarassingly parallel process is highly scalable and thus well suited for the DEEP-EST ESB module.

IV. Implementation using NAM

The preceding Section 3 outlined the standard use of the DEEP-EST modules with POSIX file I/O or potentially MPI parallel I/O for the involved file accesses. However, we observe a limitation in always storing an SVM model as a normal file during the phase (ii) model file generation and storage as performed by the executable pisvm-train and reading it again in as normal file in the subsequent phase by the executable pisvm-predict. This section describes how the NAM DEEP-EST module can be exploited in order to avoid this 'model storage bottleneck' which can be severe because SVM models tend to be very large.

A. Proposed Methodology

We exploit the MSA to enhance the training and testing phase of our PiSvM implementation focusing on the speed-up the NAM offers as an intermediary model storage target between the training and evaluation steps of the two involved PiSvM executables. This is depicted in Figure 1 with the following description of the steps marked in the figure with circles: (1) The remote sensing training and testing datasets are loaded into the NAM module, this reduces latency and bandwidth restrictions, compared with the standard storage module, when data is accessed; (2) Training a model is computationally expensive due to the inherent convergence process executed by PiSvM, it is therefore best suited for the DEEP-EST CM, which offers the most powerful CPUs as discussed in Section III (B); (3) The trained model is placed in the NAM module to speed-up access to it during the evaluation step, where the model is evaluated using another dataset; (4) The model is loaded from the NAM and its accuracy is evaluated. This is an embarrassingly parallel operation which is therefore best suited to take advantage of the ESB module that has the highest number of CPUs as discussed in Section III (C).

B. NAM Overview

The Network Attached Memory (NAM) is a device that can be described as a module which exists in the fast fabric interconnection between all other modules within the heterogeneous system. It has non-volatile high-

performance RAM which makes it extremely suitable for the role as a "faster than SSD" intermediary storage. Furthermore, it also has an FPGA integrated on its board that applications can utilize to perform near-data processing, independent and parallel to other modules, on data stored in the NAM.

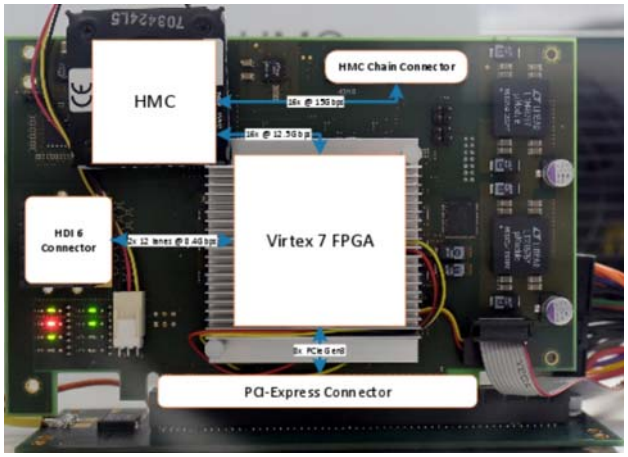

Figure 2. NAM Hardware Architecture [3]

Additional important use for the NAM is fast checkpointing [2] to improve the application's fault-tolerance, or modelselection, using inference to organize a set of trained models which can then used for transfer learning [13]. In this paper, however, we focus on its role as a fast storage target used by the PiSvM application for I/O performance gains.

C. NAM Architecture

The NAM hardware architecture, as depicted in Fig. 2, consists of a PCI-Express form factor card that is equipped with a Xilinx Virtex7 FPGA and Micron's Hybrid Memory Cube (HMC), which is a very fast DRAM stacked in 3D with integrated memory controllers. Multiple HMCs can be connected together using the HMC chain connector to extend the NAM's fast memory capacity. Finally, the NAM is accessible over the high-bandwidth and low-latency EXTOLL network1 via the HDI-6 connector depicted in Figure 2.

D. libNAM

The libNAM library [14], written in C, provides the API that developers need to use the NAM for their applications in DEEP-EST. Its API is modeled after the proprietary EXTOLL RMA API and its current implementation is indeed built on top of the same API, effectively limiting its usage to EXTOLL fabric interconnects at the moment. The usage of this API for speeding up PiSvM is described in the following two sections.

E. Using NAM for Training

Near the end of its execution, the training step of PiSvM has generated a model which can be used to classify unseen data in the prediction step. The model, however, must first be stored in the NAM where it can subsequently be accessed in the prediction step. This is demonstrated by the code snippet below: first, the NAM is initialized and then the fitting memory allocation is requested from it; thereafter the model is written into the allocation, and finally, a metadata file describing the allocation is produced.

```
#include <stdio.h>
#include "nam_util.h"

void saveModelNAM(Model* trained, char* path) {
   m_size = sizeof(trained);
   nam_initialize();
   nam_alloc = nam_malloc(m_size);
   nam_put(nam_alloc, trained);
   nam_write_metadata(nam_alloc, path);
}
```

Code Snippet 1. Storing the trained model in NAM

Note that nam_put in the above Code Snippet 1 stores the actual data whereas nam_write_metadata saves the allocation's metadata to a standard HPC file system with the given path using standard POSIX file I/O. The metadata includes the location and size of an allocation which enables other applications to access its underlying data on the NAM, as can be seen in the code snippet in the next section.

F. Using NAM for Prediction

A generated model must be evaluated to make inferences about its accuracy and suitability. The evaluation step loads the model from the NAM, as demonstrated by Code Snippet 2: first, the NAM is initialized, followed by the loading of metadata file from the standard HPC file system. The metadata contains the necessary information about the allocation made during the training step which enables the NAM API to load its contents, i.e. the model.

```
#include "nam_util.h"
Model* loadModelNAM(char* path) {}

  nam_initialize();
  nam_alloc = nam_read_metadata(path);
  model = nam_get(nam_alloc);
  return model;

}
```

Code Snippet 2. Model loaded from the NAM and evaluated

Using the same metadata file allows the PiSvM executables pisvm-train and pisvm-predict to exchange the model data in an extremely efficient way and thus minimizes idle processes by reducing waiting for I/O to complete.

V. Summary and Outlook

We presented the Dynamical Exascale Entry Platform – Extreme Scale Technologies (DEEP-EST) Modular Supercomputer Architecture (MSA) which is heavily based on hardware acceleration for all parts of an HPC system, i.e. not only computation, but also storage/memory and interconnects. These accelerated hardware modules are intended to serve as blueprints for tailoring future HPC systems towards exascale driven by the needs of the particular applications.

Our application that drives the co-design of the DEEP-EST MSA is parallel and scalable machine learning on huge datasets which includes deep learning [13], clustering [15], and classification. For the latter, we use

Support Vector Machines (SVMs) that are mapped on the hardware modules of the MSA as described in this paper: wherever possible, the benefits of these hardware accelerator modules are leveraged: massively parallel manycore processing of embarrassingly parallel processes is performed on the Extreme Scale Booster (ESB), whereas tasks that do not scale well are executed on the high-performance Cluster Module (CM), frequently used data is stored in the Network Attached Memory (NAM) including near-data processing via FPGA. This all is facilitated by a fast fabric interconnection and the Global Collective Engine (GCE) for MPI collective operations.

The focus of this paper is on exploiting the Network Attached Memory (NAM) for storing intermediate results of the different steps of an SVM classification chain, e.g: a model is trained and then its prediction accuracy is evaluated by another executable, i.e. the learned model needs to be stored persistently between runs of different executables. By using the fast NAM hardware and NAM API instead of the comparably slower Scalable Storage Service Module (SSSM) and standard POSIX I/O, a considerable speed-up of I/O is possible. In addition to using the NAM for intermediate data, using MPI parallel I/O for reading the initial input and writing the final output allows further I/O improvement. The potential for speed-up using the NAM has been identified by tracing the initial PiSvM implementation which gave valuable insights concerning idle hardware due to inefficient I/O and load imbalances that we mitigate with our approach.

The described accelerator modules are currently being developed as part of the DEEP-EST project and are still subject to change. For example, the current NAM prototype will be replaced within the life-span of the DEEP-EST project with an improved device that includes a more powerful FPGA, at least 128 GB of RAM, and much higher bandwidth. Because the hardware and its corresponding API implementation are not yet stable, we can currently not yet provide benchmarking results, but the first preliminary runs of our parallel PiSvM chain on the draft prototype hardware are very promising.

Future work, outside of porting our PiSvM implementation to the final DEEP-EST hardware, includes improving the scalability of parallel SVMs even further: we have started to implement the Cascade SVM approach where a dataset is split and then optimized separately using multiple SVMs; the subresults are finally combined again in a cascade of SVMs until the global optimum is reached [16]. Finally, we have started to investigate an alternative to using SVMs for hyperspectral image classification by applying deep learning with CNNs: first results look promising [17] and we intend to investigate its scalability on the DEEP-EST platform

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Information Entropy Measures and Clustering Improve Edge Detection in Medical X-Ray Images

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Abstract - Shannon information entropy measures and hierarchical agglomerative clustering were used to detect edges in digital images. The concept is based on communications theory with splitting of edge detection kernel into source and destination parts. The arbitrary shape of the kernel parts and the fact that information filter output is a real number with reduced problem of edge's continuity represents the major advantage of this approach.
The methodology was applied globally (the same information entropy parameters were used on a whole image), and locally (adapting edge detection algorithm to localized, kernel size computed information context). The results indicate that using local information context could reduce the noise.
The real life examples are taken from medical X-Ray imaging of series of femur bone in order to illustrate the algorithm performance on real data.

***Keywords* – information, entropy, image, processing**

I. INTRODUCTION

Development of information theory [1] was done for the analysis of communication channels. Shannon introduced the central concept in this theory, namely the concept of information entropy (1). Information entropy can be interpreted in various ways, but Shannon mainly thought of it as a measure for unpredictabilty of information.. The information entropy concept is so general that it was soon used in other fields besides communications. Examples are statistical inference, natural language processing, cryptography, evolutionary biology and all sorts of data analysis [2],[3]. There was also some work with entropy in digital images edge detection [4],[5],[6],[7].

II. THEORY

The information entropy H, is defined in (1) for n discrete states, each state i with its own probability p_i.

Information entropy

$$H = -\sum_{i=1}^{n} p_i \log_2 p_i \qquad \boxed{\lim_{p\to 0} p \log p = 0} \qquad (1)$$

$$\sum_{i=1}^{n} p_i = 1$$

In our previous paper [8], we suggested and tested various information entropy functions for the purpose of edge detection in digital images. These results will not be repeated here and only the information entropy H (1) and conditional entropy $H(X|Y)$ (2) will be used in this paper.

Conditional entropy

$$H(X \mid Y) = -\sum_{i=1}^{n}\sum_{j=1}^{m} p\left(x_i, y_j\right)\log_2 p\left(y_j \mid x_i\right) \quad (2)$$

Our main interest here is to see how determination of the number of states inside the kernel and in the whole image influences the edge detection results.

Our previous results suggested that reducing the number of states (pixel intensities) in image reduces the noise problem and gives more continuous, smooth edges [4]. However, collapsing the neighboring intensity pixels into single value could lead to artificial differences between the new states. For example, if 256 states which we typically see in a gray image are collapsed into 64 states, in some cases it would happen that the states which were initially closer then new digitization step (4 in this case) would be separated. For example, intensity values 15 and 17 would fall into different states although the original difference between them was only the half of new digitizing step.

III. RESULTS

One of the reasons for using information entropy kernels is that they are highly adaptable. Their size and/or shape can be very arbitrary. In contrast, the gradient operators like Laplacian and Sobel use kernels which are typically 3 by 3 pixels in size.

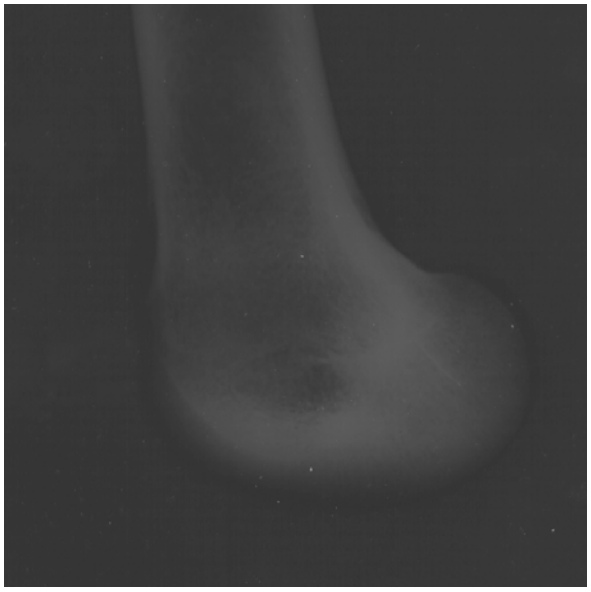

Figure 1. The femur bone picture

Our main interest here was to apply the methodology on X-ray images used in orthopedic medical practice. The first of two femur images is shown in Fig. 1

The Fig. 2 shows application of information entropy operator (1) on the first femur image. We can se continuous edges and detection of different density in bones which show as the consecutive edges. The Fig. 3 shows the same initial image with edge detection using conditional entropy operator (2). Both operators give very similar results, but having in mind that entropy operator H is simpler, we would argue it has an advantage in this case.

The number of states was deduced from histogram and clustering. We were able to improve the results further by local, inside the kernel adaptation of states by assigning values which differ for less then new digitization step to be in the same state. The images are shown as Fig. 4 and Fig 5 and are showing decreased noise level in comparison with Fig. 2 and Fig. 3, respectively.

Figure 4. The edges in the femur bone picture using the conditional information entropy $H(X|Y)$

The images shown here are just a sample from the pull of about thirty femur images, all from individual patients, belonging to the different age and sex groups. All the images have been processed, but the images are shown just for the single femur bone. The images are only shown for column-wise edge detection operator for kernel size 4 by 4 pixels. However, the results were consistent across the board.

The examples here also illustrate good flexibility of entropy algorithms which can be fine tuned and adjusted not only for individual images but also locally for different regions down to the each individual kernel.

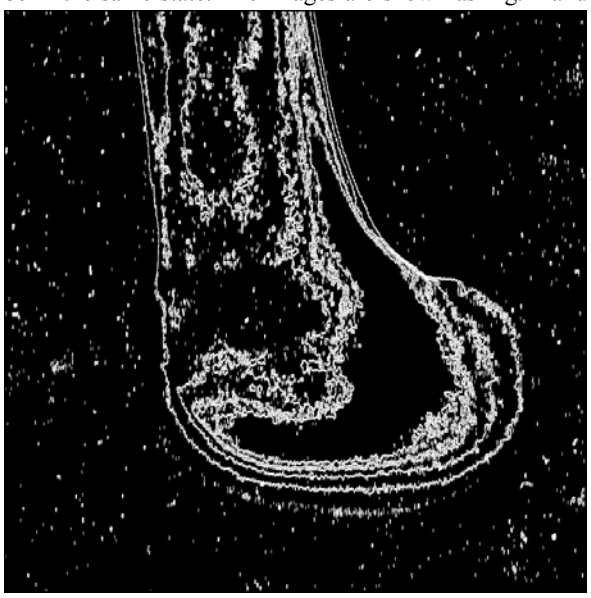

Figure 3. The edges in the femur bone picture using the information entropy H

Figure 2. The edges in the femur bone picture using the information entropy H after local states adaptation

Figure 5. The edges in the femur bone picture using the conditional information entropy $H(X|Y)$ after local states adaptation

IV. CONCLUSION

The information entropy based approach in combination with adaptation for number of states is used for detecting edges in X-ray digital images. The testing was done on a series of orthopedic images of femur bones. Our results strongly indicate that the better edge continuity and decrease of noise is achievable with entropy operators then with some classical approaches like Sobel operator. The better performance is due to considerable flexibility and possibility of local adaptation for entropy operators in sense of size, shape and orientation, as well as the fact that their result is a real number from predefined range. The noise reduction and edge continuity opens a possibility for automatic edge detection and bone shape extraction which can be passed on to the various software packages in orthopedic implant specification

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Using Local Binary Patterns in Speckle Image Analysis

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Abstract - **Firstly described by Newton in the 17th century, speckle is an optical phenomenon which can be translated into image patterns produced by wave interferences of diffused reflections. In fact, the speckle pattern is generated by the multiple interference phenomena that occur when a rough surface is illuminated with a coherent source of light, producing randomly distributed reflected waves of the same frequency but different phases and amplitudes. Although it has been known for a long time, capturing video sequences of speckle patterns was dependent on recent technological developments, in particular, related to laser technology and microsensors. The speckle acquisition setup comprises a light source, usually a laser, an optical beam expander and a CCD camera. The generated interference patterns are captured in series of video sequences, to further be processed. In previous works, several image processing algorithms have been applied to analyze video frames of speckle, aimed to capture the evolution patterns in dynamic processes. However, due to the typical high frequencies of the changing patterns, classical texture algorithms mostly fail this goal. In this work, speckle dynamics are evaluated using Local Binary Patterns (LBP) jointly with some of its main variants and a newly proposed algorithm, in a reactive hyperemia controlled test. The proposed methodology goes beyond the traditional implementations of LBPs, by considering an additional Gaussian filtering, a methodology thus coined as LBPg. The results, on one hand, confirm that the classical formulations of LBP are not sensitive to changes in the simulated patterns but, on the other hand, demonstrate that the newly proposed LBP-adapted algorithm successfully identify the dynamics of the processes under study.**

Keywords – Local Binary Patterns; Laser Speckle; Video Processing; Computer Vision.

I. INTRODUCTION

Speckle imaging is an optical intensity pattern produced by mutual interference of wavefronts scattered from a rough surface [1]. Whenever a coherent light source interacts with a medium, the surface geometry (static or dynamic) induces phase shifts in the scattered light, producing constructive or destructive interference. The temporal and spatial statistics of the varying pattern that is produced provides information about the motion of the scattering particles [2]. Although the physical phenomenon has already been described by Newton, the theory only gained a strong impulse in the 1960's and following of the last century, allied to the technological development of lasers and optical sensors.

When lasers were invented, the speckle effect was initially seen as a major limitation upon object illumination. In fact, in holographic imaging and in laser-based display systems (e.g. Laser TV) the speckle contrast reduction is highly desirable once as it tends to mask the image information [3]. Later on, it was proved that the granular effect was strongly correlated with the characteristics of the surface, either when a static surface is illuminated or when a dynamic process underneath the surface tends to deform the surface itself (i.e. by some type of motion). Accordingly, the so far artifact, became a useful feature to exploit in different scientific contexts and objectives, ranging from material sciences to medical applications.

The motion of the scattering induces front-wave interference, which will be further captured by a digital sensor in terms of pixel intensities, ranging from dark to white in a grayscale image. This type of changing pattern can be quantified through the image processing of the obtained grayscale images using spatial [4] or temporal statistics measures [5], spatiotemporal algorithms, or frequency derived algorithms [6]. Recently, unsupervised machine learning algorithms have been applied in the characterization of dynamic speckles to identify regions with the same activity pattern [7, 8].

The objective of this work is to present a comparison of methods based on Local Binary Patterns – LBP, when applied in laser speckle video processing. This comparison includes the results of LBP_g, recently proposed by our group to characterize skin perfusion profiles.

In the remainder of this paper, in Section II the methodology is presented and in Section III, the obtained results are shown. Section IV is dedicated to discussion and finally, in Section V, the conclusions are presented.

II. METHODOLOGY

A. Local Binary Pattern Algorithms

The LBP was first proposed in [9] as a 2D texture operator by integrating the local variations of the spatial pattern with a grayscale coding scheme. This method proved to be of easy implementation, invariant to

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monotonic illumination and having low computational complexity [10].

The LBP code of a given pixel is defined in (1);

$$LBP = \sum_{p=0}^{7} s(I_P - I_C)2^p, \quad s(x) = \begin{cases} 1 \; if \; x \geq 0 \\ 0 \; if \; x < 0 \end{cases} \qquad (1)$$

where I_p and I_C are, respectively, the intensity of the peripheral and central pixels and P de number of neighboring points. The definition can be generalized to a given radius R and a number of points P, as illustrated in Figure 1.

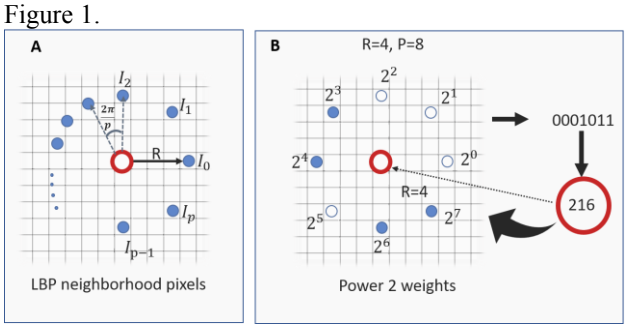

Figure 1: General LBP overview: A-neighborhood pixel geometry, B-LBP example using R=4 and P=8.

The original definition (1) has several variants, that have been proposed to overcome the identified issues when it is applied with distinct research purposes. In particular, LBP has limitations in detect large-scale textural structures and is sensitive to image rotation. Moreover, the methodology applies a fixed and coarse quantization using the sign of the differences between neighboring pixels thus being highly sensitive to noise [10].

The Local Binary Standard (CLBP) decomposes local differences into two complementary components: the signal (calculated in (1)) and magnitude (2);

$$CLBP_M = \sum_{p=0}^{7} f_2(|I_p - I_c|, T_{\Delta I})2^p, f_2 = \begin{cases} 1, x \geq T_{\Delta I} \\ 0, x < T_{\Delta I} \end{cases} \quad (2)$$

where, $T_{\Delta \bar{I}}$ is the average value of the difference in grey value between a pixel in the periphery and the central pixel. In addition to these two components, the CLBP also includes image intensity information:

$$CLBP_C = f_2(I_c, \bar{T}_I) \qquad (3)$$

where f_2 was previously defined in (2) and the threshold $\bar{T}_I$ is set as the average gray level of the whole image. The three code maps are combined to form the CLBP final histogram that allows characterizing the texture [11].

The local binary patterns in three orthogonal planes (LBP-TOP) is a spatiotemporal variant of the canonical LBP operator that allows to combine movement and appearance. LBP-TOP considers three orthogonal planes: XY, XT and YT and concatenates the local statistics of co-occurrence of binary patterns in these three directions. The final histogram of the LBP-TOP can be defined as:

$$H_{i,j} = \sum_{x,y,t} I\{f_j(x,y,t) = i\}, i = 0, \ldots, n_{j-1}; j = 0,1,2 \quad (4)$$

in which n_j is the number of different labels produced by the LBP operator in the j^{th}, $f_i(x,y,t)$ expresses the LBP code of central pixel (x,y,t) in the j^{th} plane, and

$$I\{A\} = \begin{cases} 1, & if \; A \; is \; true \\ 0, & if \; A \; is \; false \end{cases}$$

When the features to be compared are of different spatial and temporal sizes, the histograms must be normalized [12].

Regarding the multi-quantified local binary pattern scheme (MQLBP), it allows quantifying the gray level difference at a desirable number of levels (N), using a threshold parameter γ. Each level is quantified according to the function f_n, defined as:

$$f_n(x,y) = \begin{cases} 0, x < -(N-1)\gamma \\ 1, (N-1)\gamma \leq x < -(N-2)\gamma \\ \vdots \\ N-1, -\gamma \leq x < 0 \\ N, 0 \leq x < \gamma \\ N+1, \gamma \leq x < 2\gamma \\ \vdots \\ 2N-2, (N-2)\gamma \leq x < (N-1)\gamma \\ 2N-1, x \geq (N-1)\gamma \end{cases} \qquad (5)$$

producing $2N$ segments and the MQLBP code, corresponding to the i^{th} segment is calculated as follows:

$$MQLBP^i = \sum_{p=0}^{P-1} \delta(f_N(I_p - I_c, \gamma) - i)2^p, \qquad (6)$$

$$\delta(x) = \begin{cases} 1, & x = 0 \\ 0, & otherwise \end{cases}$$

The final histogram to characterize the texture results from the concatenation of the calculated histograms for each of the segments [13].

In (1) the gradient to the central pixel is not considered, but his signal. To overcome this constraint, the LBPg is also proposed in this work, whose definition for each pixel is presented in (7).

$$LBP = \sum_{P=0}^{7} s[g(I_P - I_C)]2^P \qquad (7)$$

where I_P and I_C are respectively the intensity of the peripheral and central pixels, s is a step function defined in (8) and g the Gaussian function.

$$s(x) = \begin{cases} 1 & if x \in FWHM_{g_{(\mu,\sigma)}} \\ 0, & otherwise \end{cases} \qquad (8)$$

where $\mu_{\bar{x}}$ and $\sigma_{\bar{x}}$ are respectively, the average and standard deviation of the absolute differences to the central pixel in a 3×3 neighborhood.

To obtain a relative measure of the activity a basal video sequence was selected (B) to further compare with the activity in other time intervals (S). To compare the dynamic patterns, four metrics relating the histograms of each video sequence H_B and H_S were implemented. These metrics (Chi-square - χ^2, Correlation - C, Intersection - I and Euclidian distance - E_d) were aplied to the normalized histograms H_B, and H_S as defined in (9).

B. Instrumentation and Experimental Protocols

For the purpose of this work, an acquisition setup was built, composed by a class III laser beam (633×10^{-9} m

wavelength and 5 mW Power). A beam expander and a CCD Camera (Sony, nxcam AVCHD, 50 fps) were also integrated into the setup as illustrated in Figure 2.

$$\chi^2 = \sum_i \frac{(H_B(i) - H_S(i))^2}{(H_B(i) + H_S(i))};$$

$$C = \frac{\sum_i (H_B(i) - \overline{H_B})(H_S(i) - \overline{H_S})}{\sqrt{\sum_i (H_B(i) - \overline{H_B})^2 \sum_i (H_S(i) - \overline{H_S})^2}} \quad (9)$$

$$I = \sum_i \min(H_B(i), H_S(i))$$

$$E_d = \sqrt{\sum_{i=0} (H_B(i) - H_S(i))^2}$$

where, $\overline{H_k} = \frac{\sum_i (H_k(i))}{N}$ and N is the number of bins in the histograms.

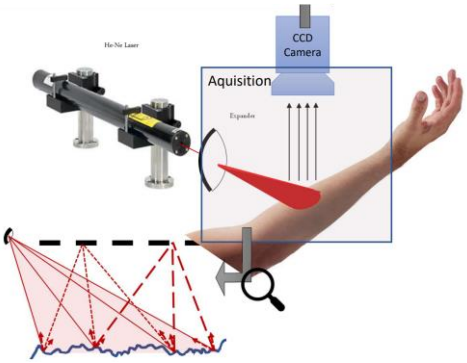

Figure 2 Acquisition Setup.

In order to compare the five LBP derived methodologies in distinct speckle dynamic patterns, an experimental protocol of skin microcirculation simulating hypoxia followed by perfusion (occlusion hyperemia test - OHT) was conducted in distinct ROIs at the upper limb. The OHT was performed in a controlled environment, in which the volunteers stay in a seated position for 5 minutes prior to the test. For each subject, distinct ROIs at the forearm and hand (dorsal and ventral) were tested in distinct perfusion conditions (basal, occlusion and hyperemia). The occlusion was simulated using a cuff pressure at the arm, inflated at 160 mmHg, during an occlusion interval of 60 seconds, followed by hyperemia and returning to basal conditions.

III. Results and Discussion

The perfusion profiles obtained during OHT for each LBP derived methodology and for each metric defined in (4) are presented in Figure 3. The opening instants of the cuff-pressure valve (i.e. the instants when the perfusion is restored) are marked with a vertical bar. This bar delimits the occlusion region, which is anterior, followed by a rapid increase of perfusion (i.e. hyperemia) and the return to basal conditions.

To test the consistency of the findings, additional tests were performed in which the perfusion profile was evaluated in different ROIs of the same volunteer under the same perfusion conditions. In this case, data was obtained from two regions of the hand (dorsal and ventral) in two volunteers (V1 and V2), as shown in Figure 4. In this case, the chosen metric for histogram caparison was the χ^2 metric.

The processing of speckle video frames is a challenging task. The type of features joint with their difficult perception to the human eye (even when the assessed phenomena have high-intensity variation) make it difficult to choose the image processing technique to be used as first choice. The patterns and textures that are perceived tend to put spatial methods of local analysis as a primary choice. Nonetheless, the results presented in this work clearly indicate the failure of the classical LBP method to detect dynamic changes in the speckle pattern (particularly in identifying the perfusion changes induced by the OHT). This result can be observed in the first column of Figure 3 for all the metrics used in this work, in which the perfusion pattern is slightly constant (even after the release of the cuff-pressure denoted by the vertical bar in Figure 3).

The CLBP methodology put forward a strategy to use the intensity gradient to the central pixel (instead of simply using the signal itself), preserving the information about local structures to be analyzed. Nevertheless, the results of CLBP in the OHT show rather limited sensitivity to identify the transition to the greatest activity period. It is interesting to note that in the case of E_d, when compared with χ^2 metric, the sensitivity is greatly reduced although the similarity of the definition (both are based on the difference of histograms, however the χ^2 metric is a normalized result).

The LBP-TOP is a simplified version of the Volume-LBP (built in terms of a cube of textons) aimed to capture the spatiotemporal dynamics in three orthogonal plans. According to the results in column 3 of Figure 3, the instants were the perfusion profile is changing are clearly identified, however it is possible to verify that (regardless of the applied metric) the LBP-TOP only identifies those where there is a high gradient in the activity. Regarding the analysis of MQLBP and the associated metrics, it is possible to verify the matching of the χ^2 and E_d derived profiles with the perfusion levels imposed by the experimental OHT protocol.

The LBP_g methodology, due to the combined ability to capture the differences between neighboring pixels and the local filtering approach (implemented through the Gaussian thresholding), allows an efficient characterization of speckle activity profiles. This methodology proved to be effective in identifying the instants where the perfusion profile is altered, regardless of the applied metric.

In what concerns the methodologies that proved to be sensitive to the changing of the perfusion patterns, the χ^2 metric is the one presenting consistent results, thus it was applied in the remaining tests. To test ROI texture dependence in LBP_g+χ^2 methodology, several perfusion profiles were experimentally simulated by OHT and measured at the hand. The results for the dorsal and ventral regions in two volunteers are shown in Figure 4. The perfusion profile allows to conclude that ROI texture has

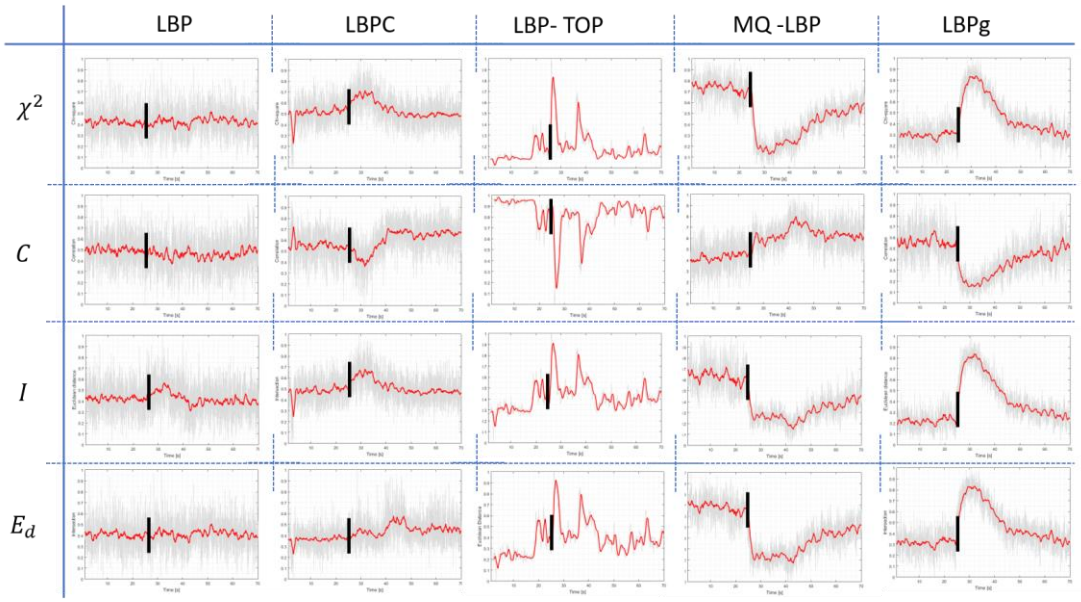

Figure 3: Perfusion profiles in OHT using LBPs methodologies and four metrics. The time of cuff release pressure is marked with a vertical bar

no significant influence on the identification of the perfusion trend.

Moreover, in the ventral region (due to the proximity of large vessels) the changes in the perfusion profiles were in fact highlighted on both cases. The results reported in this work clearly point out to the use a relative measure based on the suggested $LBP_g+\chi^2$ algorithm in Laser Speckle Imaging studies of skin perfusion. Indeed, the methodology proved to be sensitive to the changing of the perfusion profile and rather independend of the skin ROI texture.

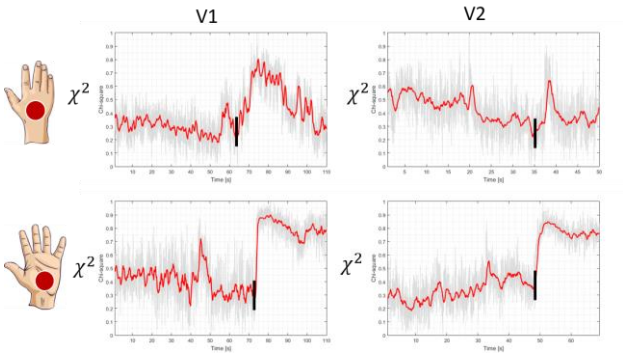

Figure 4: Qui-squared LBPg metric for dorsal (first row) and ventral (second row) perfusion profiles for two volunteers (V1 and V2)

IV. Conclusion

This work reports a comparative study of video speckle processing techniques based on LBP and some of its classical derivations. In particular, a new technique based on a Gaussian filtering was also tested, the LBP_g. Dynamic Speckle profiles were assessed by simulating upper limb perfusion conditions using the OHT test. Amongst the tested methodologies, the LBP_g proved to be sensitive to the changing of perfusion levels for any of the tested metrics.

To assess the influence of ROI texture on the perfusion results, different regions with the same perfusion profile were tested. The results show that the $LBP_g + \chi^2$ methodology is appropriate to identify perfusion changes regardless of the ROI texture.

The comparison results of LBP techniques allows concluding that classic aproach is not suitable for video speckle analysis. However, specific variations on the original methodology (which target the characteristics of the speckle images) allows us to obtain a low computational, noise sensitive methodology to track dynamic speckle activity.

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Parallel Coordinate Free Implementation of Local Meshless Method

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Abstract – This paper presents an implementation of a Meshless Local Strong Form Method that allows users to write elegant code expressed in terms of abstract mathematical objects, such as operators and fields, consequently avoiding working directly with matrix and array indices, which is tedious and error prone. This is achieved by using object oriented programming techniques for definition of abstract concepts and leveraging C++'s powerful templating mechanism. It is demonstrated that code written this way has little-to-no performance overhead compared to classical numerical code while being more expressive and readable, which gravely shortens model development and testing phases. The overall functionality of presented implementation is illustrated on numerical examples from classical thermodynamics, linear elasticity and fluid dynamics in one, two and three dimensions.

I. Introduction

The most cumbersome part of the implementation of numerical methods for solving partial differential equations (PDEs) is working with array and matrix indices for different differential operations, which is usually tedious, error prone, and hard to debug; enough so, that this aspect of programming numerical procedures has been studied before, especially in the context of choosing an appropriate programming language [1]. Traditional programming techniques require that the programmer keeps track of the meaning of all details in the code, which can be very hard to manage even for simple problems and becomes unmanageable for more complex systems of PDEs and constitutive relations. Another problem of such implementation is that it does not clearly reflect the problem at hand, making it hard to understand, change, and, maintain, when needed. Another problem is that in traditional implementation code changes with dimensionality of considered space, i.e. a 2D PDE solver is substantially different than a 3D solver. To wrestle this problem, a concept of coordinate free numerics was introduced by Haveraaen and Munthe-Kaas [2], postulating that software implementing numerical algorithms should abstract implementation details away from the user, exposing only an external interface that provides the necessary features. In such an implementation the user can think in terms of fields and differential operators instead of matrix indices and node enumerations. The difference in these approaches is illustrated in Figure 1.

The abstract approach is used extensively in almost all areas of mathematical programming, such as machine learning, network analysis and graphics, but implementations of numerical methods seem to lag behind the capabilities of modern programming languages.

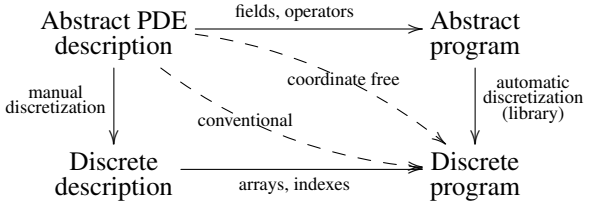

Figure 1. Comparison between coordinate free and conventional programming.

One of the often cited reasons for this lag is that abstractions make the code slower and cause unnecessary bloat. It has been proven that this is not necessarily the case when the library Eigen [3] for numerical linear algebra appeared in 2010, offering expressive object oriented syntax for matrix manipulation with speed comparable to LAPACK and BLAS.

In this paper we present an abstract implementation environment for solving systems of PDES with built-in parallelism. We use a Meshless Local Strong Form Method (MLSM) [4] as a numerical backbone, which seems to be an ideal numerical method for a coordinate free implementation due to its modular formulation. Similar approaches are already well established for the finite element method [5, 6] and particle-particle simulations [7], however no such implementations for meshless methods exist to the best of authors' knowledge.

The rest of the paper is organized as follows. In section II the numerical method along with a coordinate free parallel implementation concept is presented, in section III the numerical examples are demonstrated, and the conclusions are written in section IV.

II. Local Strong Form Meshless Method

Consider a boundary value problem of form

$$\mathcal{L}u = f, \text{ in } \Omega \tag{1}$$
$$\mathcal{R}u = g, \text{ on } \partial\Omega, \tag{2}$$

where $\Omega \subseteq \mathbb{R}^d$ is a domain u is an unknown scalar or vector field, $\mathcal{L}$ and $\mathcal{R}$ are linear partial differential operators and f and g are known functions. To obtain a discrete approximation of PDE, N points, also called nodes, are chosen in the domain Ω, of which N_i are in the interior and N_b on the boundary. Every point is also assigned a set of neighbors, called support domain.

For all N_i internal points p, the operator $\mathcal{L}$ at point p is approximated over support domain of p as

$$(\mathcal{L}u)(p) \approx \boldsymbol{\chi}_{\mathcal{L}}(p) \tag{3}$$

where $\boldsymbol{\chi}_{\mathcal{L}}$ is called a shape function for operator $\mathcal{L}$ at point p and only depends on the local geometry of the domain. For details on how to compute $\chi_{\mathcal{L}}$ the reader is referred to [4]. An important observation is that these shape functions can be computed beforehand and stored. A similar procedure is used to discretize any boundary conditions, in case they contain differential operators.

After computing the shape functions, two main approaches to obtain a numerical solution exist. Steady state problems will be solved implicitly, by approximating the equation

$$\mathcal{L}u = f \tag{4}$$

with a linear equation

$$\boldsymbol{\chi}_{\mathcal{L}}(p) \cdot \boldsymbol{u} = f(p), \tag{5}$$

where $\boldsymbol{u}$ is the vector of unknown function values in support domain of point p and $\cdot$ denotes the dot product. Adding equations for boundary conditions in boundary nodes, all equations can be gathered in a $N \times N$ sparse system

$$\begin{bmatrix} \boldsymbol{\chi}_{\mathcal{L}}(p_1) \\ \vdots \\ \boldsymbol{\chi}_{\mathcal{L}}(p_{N_i}) \\ \boldsymbol{\chi}_{\mathcal{R}}(p_{N_i+1}) \\ \vdots \\ \boldsymbol{\chi}_{\mathcal{R}}(p_{N_i+N_b}) \end{bmatrix} \begin{bmatrix} u_1 \\ \vdots \\ u_N \end{bmatrix} = \begin{bmatrix} f(p_1) \\ \vdots \\ f(p_N) \end{bmatrix}. \tag{6}$$

This system can be solved to obtain an approximation for function u at points p_i.

For transient problems, time derivative can be discretized using any standard procedure, such as explicit or implicit Euler method or Runge-Kutta methods, while spatial derivatives are again approximated using shape functions.

The presented formulation is convenient for coordinate free implementation, since in case of using RBFs for construction of shape functions all involved building blocks require only awareness of distances to surrounding nodes, which can be implemented at the lowest level. The reader is referred to [4] for more details.

A. *Coordinate free implementation*

The main purpose of coordinate free implementation of numerical methods is to abstract as many parts of the code as possible in order to present a flexible and readable interface between numerical operations and the user, e.g. to present concepts such as fields and differential operators. Naturally, the implementation of those concepts is still done in coordinates, however, it is done only once and only at the lowest level and it is not visible to the user, who is dealing with a complex physical model.

In our implementation vector and scalar fields are implemented as plain arrays using a well developed linear algebra library [3]. Domains are discretized with a list of points along with a list of neighbours for each point as described in section II. For boundary nodes, outside unit normals are stored, as well. The main concept that is usually problematic to abstract is the concept of a linear partial differential operator. However, equation (3) offers a way to compute and store different operators. Every linear partial differential operator $\mathcal{L}$ of order k at point p in an arbitrary number of dimensions can be written in standard basis using multiindex notation as

$$\mathcal{L}|_p = \sum_{|I| \leq k} a_I(p) \left. \frac{\partial^{|I|}}{\partial x^I} \right|_p, \tag{7}$$

and approximated as

$$\mathcal{L}|_p \approx \sum_{|I| \leq k} a_I(p) \boldsymbol{\chi}_{\left. \frac{\partial^{|I|}}{\partial x^I} \right|_p}. \tag{8}$$

This approach requires the computation of shape functions to be done only for derivatives of form $\frac{\partial^{|I|}}{\partial x^I}$ to approximate any linear operator. Examples in this paper use operators up to the second order and therefore one needs to compute and store shape functions for first and second derivatives over all combinations of coordinate directions for every point in the domain. This enables us to construct any operator of order two via (7), such as ∇^2 or $(\vec{n} \cdot \nabla)$. For example, Laplacian in two dimensions is computed as

$$\nabla^2|_p = \left. \frac{\partial^2}{\partial x^2} \right|_p + \left. \frac{\partial^2}{\partial y^2} \right|_p \approx \boldsymbol{\chi}_{\frac{\partial^2}{\partial x^2}}(p) + \boldsymbol{\chi}_{\frac{\partial^2}{\partial y^2}}(p). \tag{9}$$

The above expression can be easily generalized to a d dimensional space as

$$\nabla^2|_p = \sum_{i=1}^{d} \left. \frac{\partial^2}{\partial x_i^2} \right|_p \approx \sum_{i=1}^{d} \boldsymbol{\chi}_{\frac{\partial^2}{\partial x_i^2}}(p), \tag{10}$$

where x_i stands for i-th coordinate. The implementation of the shape functions computation is independent of domain dimensionality, making approximations of type (8) work seamlessly in all dimensions. The drawback of such approach to solving PDEs is the cost of preparing the shape functions, which has to be done every time nodal positions changes. On stationary domains, which will be considered in this paper, the shape functions need to be computed only once. Furthermore, this computational burden can be eased with parallel execution due to complete independence between different shape function computations.

Implementations of operators usually accept a matrix, a point index i and a scalar value α, and write shape coefficients, multiplied by α in the i-th matrix row, to build the system of equation described in (6). For explicit operators, they instead take a vector or scalar field and return the result directly. For example, user can use `op.lap`, representing the Laplacian operator, on a scalar field in 1, 2 or 3-dimensions with the same function name. The return value depends on the input parameters: if the input field is a 3-dimensional scalar field, the explicit `op.lap` will return a 3-dimensional scalar field, and an implicit `op.lap` will fill appropriate elements of the given matrix.

Implementations of described concepts are done using templated C++ classes, which are loosely coupled only by a mutual agreement to expose and expect the same interface. This is similar to duck typing in e.g. Python, but with the benefit of static type checking.

III. Numerical examples

A. Heat equation

First case stems from classical thermodynamics and asks for a steady state heat distribution in a homogeneous heated medium. It is governed by the equation

$$-\alpha\nabla^2 u = q, \tag{11}$$

where q is the volumetric heat source and α is thermal diffusivity. Dirichlet boundary conditions $u|_{\partial\Omega} = u_0$ and Neumann boundary conditions $\frac{\partial u}{\partial \vec{n}} = j$ will be considered.

First, a simple one dimensional case is tackled to assess basic properties of presented solution method. Consider the problem

$$\begin{aligned} u''(x) &= \sin(x), \quad x \in (0,1) \\ u(0) &= 0, u'(1) = 0 \end{aligned} \tag{12}$$

with analytical solution

$$u(x) = x\cos 1 - \sin x. \tag{13}$$

We solve the problem with MLSM using 3 support nodes and 3 monomials $\{1, x, x^2\}$ as basis functions on a regularly distributed nodes. This setup of MLSM is theoretically equivalent to the Finite Difference Method (FDM) and therefore it is worth implementing also standard FDM to compare results and execution times. The error between the actual solution u and the approximate solution $\hat{u}$ is measured in ℓ_∞ norm,

$$\|u - \hat{u}\|_{\ell_\infty} = \max_{x\in X} |u(x) - \hat{u}(x)|, \tag{14}$$

where X is the set of all points in the domain.

Coordinate free code for solving this problem is shown in listing 1, compared to classical code shown in listing 2. Both listings use variables `M` and `rhs` for the matrix and right hand side, respectively. The difference in readability is very pronounced. The user does not need to know almost anything about the method to understand the code in listing 1, while full working knowledge of FDM is required to understand code in listing 2.

```
for (int i : domain.internal()) {
      op.lap(M, i, 1.0);
      double x = domain.positions[i][0];
      rhs(i) = std::sin(x);
}
op.value(M, left, 1.0);
rhs(i) = 0;
op.neumann(M, right, {1}, 1.0);
rhs(i) = 0;
VectorXd solution = M.lu().solve(rhs);
```

Listing 1: Coordinate free code for solving problem (12) with MLSM.

The error analysis of MLSM and FDM methods with respect to number of nodes N is shown in Figure 2. Both methods converge regularly with order 2 as predicted by the theory. The error stops decreasing when the theoretical limit $\sqrt{\varepsilon}$ for second derivative approximation is reached, where ε represents the machine precision. Slightly lower final precision of MLSM is attributed to numerical errors during calculations of the shape functions.

```
vector<Triplet<scalar_t>> ts;
for (int i = 1; i < N-1; ++i) {
    ts.emplace_back(i, i, -2/h/h);
    ts.emplace_back(i, i-1, 1/h/h);
    ts.emplace_back(i, i+1, 1/h/h);
    rhs(i) = std::sin(i*h);
}
rhs(0) = 0;
ts.emplace_back(0, 0, 1);
ts.emplace_back(N-1, N-3, -1./2/h);
ts.emplace_back(N-1, N-2, 2/h);
ts.emplace_back(N-1, N-1, -3./2/h);
rhs(N-1) = 0;
M.setFromTriplets(ts.begin(), ts.end());
VectorXd solution = M.lu().solve(rhs);
```

Listing 2: Classical code for solving problem (12) with FDM.

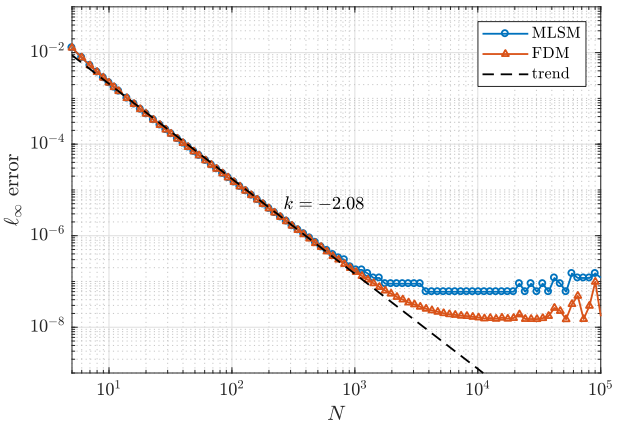

Figure 2. Convergence comparison of MLSM and FDM method.

Figure 3 represents the time spent by both methods.

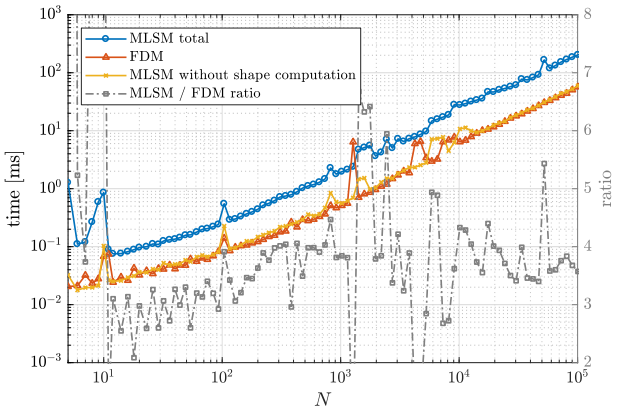

Figure 3. Comaprison of execution time of MLSM and FDM method.

As expected, MLSM is slower due to computation of shape functions, which are known in advance in FDM. However, counting that as part of the preprocessing and measuring only the part equivalent to FDM, it can be seen that the execution times for FDM and MLSM are the same for all practical purposes. This means that the abstractions discussed in section II.A and shown in listing 1 exhibit no measurable slowdown.

Next, a 2-dimensional case is considered with $\alpha = 1$ and $q = -2\pi^2 \sin(\pi x)\sin(\pi y)$ on a square domain $\Omega = [0,1]\times[0,1]$ with Dirichlet boundary conditions $u|_{\partial\Omega} = 0$. The analytical solution is given by

$$u(x,y) = \sin(\pi x)\sin(\pi y), \tag{15}$$

and error is again measured in ℓ_∞ norm given by (14). The problem was solved using MLSM in two setups: first, using monomial $\{1, x, y, x^2, y^2\}$ and 5 support nodes and second, using monomials $\{1, x, y, x^2, y^2, xy\}$ with 9 support nodes and Gaussian weight with $\sigma = 1$. These two setups are commonly used, because they mimic FDM and shall be referred to as MON5/5 and MON6/9, respectively. The code, describing the problem in shown as listing 3.

```
for (int i : domain.internal()) {
    op.lap(M, i, 1.0);
    double x = domain.positions[i][0];
    double y = domain.positions[i][1];
    rhs(i) = -2*pi*pi*std::sin(pi*x)
             *std::sin(pi*y);
}
for (int i : domain.boundary()) {
    op.value(M, i, 1.0);
    rhs(i) = 0;
}
VectorXd solution = M.lu().solve(rhs);
```

Listing 3: Code for solving two dimensional heat equation.

Plots of error of the method are shown in Figure 4. The order of convergence matches the theoretically predicted order 2.

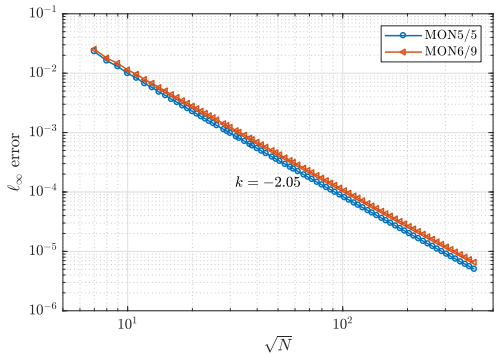

Figure 4. Error measured in ℓ_∞ norm of MLSM solving two dimensional heat eqation using MON5/5 and MON6/9 setups.

Finally, a 3-dimensional case is solved with $\alpha = 1$ and with heat source $q = -3\pi^2 \sin(\pi x) \sin(\pi y) \sin(\pi z)$. The analytical solution is

$$u(x, y) = \sin(\pi x) \sin(\pi y) \sin(\pi z). \tag{16}$$

The code needed to solve this problem is very similar to listing 3, with only right hand side being altered to reflect the new heat source. To solve the problem numerically, MLSM with basis $\{1, x, y, z, x^2, y^2, z^2\}$ and 7 support nodes and with basis $\{1, x, y, z, x^2, y^2, z^2, xy, xz, yz\}$ with 19 support nodes was used. These two setups are referred to as MON7/7 and MON10/19, respectively. The convergence in ℓ_∞ norm is shown in Figure 5. Once again the order of convergence matches the theoretical predictions.

The main benefit of using MLSM is, however, relatively simple consideration of complex geometries. Therefore, in a next example we present a more interesting 3-dimensional example, where a CAD model for aluminium heatsink (see Figure 6 left) is discretized to obtain the domain description.

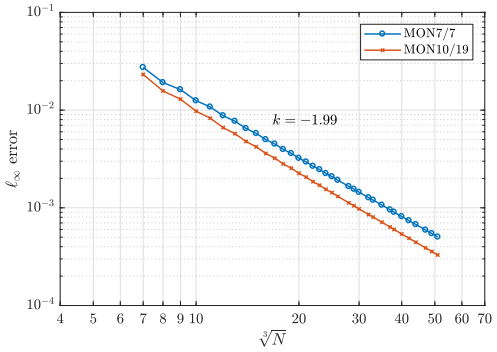

Figure 5. Error in ℓ_∞ norm of MLSM solving two dimensional heat eqation using MON7/7 and MON10/19 setups.

Heat equation (11) with $\alpha = 9.7 \cdot 10^{-5}\,\mathrm{m}^2/\mathrm{s}$, with no heat generation, i.e. $q = 0\,\mathrm{W}/\mathrm{m}^3$, with Dirichlet boundary conditions $u = 100\,^\circ\mathrm{C}$ on the bottom surface and $u = 20\,^\circ\mathrm{C}$ everywhere else.

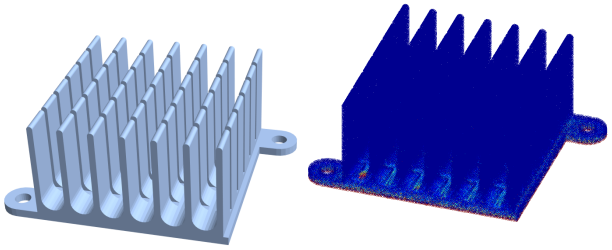

Figure 6. The CAD model for common aluminum heatsink (left), obtained from GrabCAD [8] and its steady heat distribution (right).

The solution is shown in Figure 6 (right), with a central cross section shown in Figure 7.

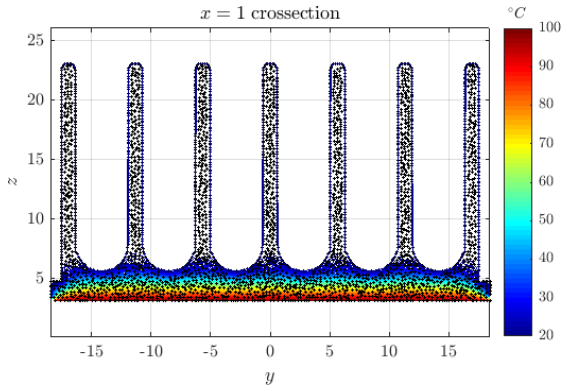

Figure 7. Contours of heat distribution in a crossection of considered heat sink.

B. *Cantilever beam*

The second problem arises from the theory of linear elasticity, dealing with deformations of solids under loading. The governing equation for elastic homogeneous isotropic materials is the Navier equation

$$(\lambda + \mu)\nabla(\nabla \cdot \vec{u}) + \mu\nabla^2\vec{u} = \vec{f} \tag{17}$$

describing displacements $\vec{u} = (u, v)$ and stresses σ, computed from $\vec{u}$ as

$$\sigma = \lambda(\mathrm{tr}\,\varepsilon)I + 2\mu\varepsilon, \quad \varepsilon = \frac{\nabla\vec{u} + (\nabla\vec{u})^\mathsf{T}}{2}. \tag{18}$$

Constants λ and μ are called Lamé parameters, I is the identity tensor and tr denotes the trace operator. Lamé parameters are usually expressed in terms of Young's modulus E and Poisson's ratio ν as

$$\lambda = \frac{E\nu}{(1+\nu)(1-2\nu)},\ \mu = \frac{E}{2(1+\nu)}. \tag{19}$$

A standard example from solid mechanics is the cantilever beam problem, where an ideal thin beam of length L and height D covering the area $[0, L] \times [-D/2, D/2]$ is bent with a force applied at one end while fixed at the other. Timoshenko beam theory offers a closed form solution for displacements and stresses in such a beam under plane stress conditions and a parabolic load on the left side. The solution is widely known and derived in e.g. [9], giving stresses in the beam as

$$\sigma_{xx} = \frac{Pxy}{I},\ \sigma_{yy} = 0,\ \sigma_{xy} = \frac{P}{2I}\left(\frac{D^2}{4} - y^2\right), \tag{20}$$

and displacements as

$$\begin{aligned} u &= \frac{Py\left(3D^2(\nu+1) - 4\left(3L^2 + (\nu+2)y^2 - 3x^2\right)\right)}{24EI}, \\ v &= -\frac{P\left(3D^2(\nu+1)(L-x) + 4(L-x)^2(2L+x) + 12\nu x y^2\right)}{24EI}, \end{aligned} \tag{21}$$

where $I = \frac{1}{12}D^3$ is the moment of inertia around the horizontal axis, E is Young's modulus, ν is the Poisson's ratio and P is the total load force.

The problem is solved numerically using MLSM with traction boundary conditions $\sigma\vec{n} = \vec{t}_0$ given by (20) prescribed on the top, left and bottom boundary, while displacements $\vec{u} = \vec{u}_0$ given by (21) are prescribed on the right boundary. Code for solution of this problem is shown as listing 4.

```
for (int i : domain.internal()) {
    op.graddiv(M, i, lam + mu);
    op.lapvec(M, i, mu);
    rhs(i) = 0; }
for (int i : domain.bottom()) {
    op.traction(M, i, lam, mu, {0, -1});
    rhs(i) = 0; }
for (int i : domain.top()) {
    op.traction(M, i, lam, mu, {0, 1});
    rhs(i) = 0; }
for (int i : domain.left()) {
    double y = domain.positions[i][1];
    op.traction(M, i, lam, mu, {-1, 0});
    rhs(i) = Vec2d(0,
                   -P*(D*D - 4*y*y)/(8*I)); }
for (int i : domain.right()) {
    double y = domain.positions[i][1];
    op.valuevec(M, i, 1.0);
    rhs(i) = Vec2d((P*y*(3*D*D*(1+v)-
                        4*(2+v)*y*y))/ 24.*E*I),
                   -(L*v*P*y*y) / (2.*E*I)); }
VectorXd solution = M.lu().solve(rhs);
```

Listing 4: Code for solving the cantilever beam problem.

Errors of displacements and stresses are measured using analogues of the ℓ_∞ norms

$$e(\vec{u}) = \frac{\max_{x\in X}\{\max\{|u(x)-\hat{u}(x)|, |v(x)-\hat{v}(x)|\}\}}{\max_{x\in X}\{\max\{|u(x)|, |v(x)|\}\}}, \tag{22}$$

$$e(\sigma) = \frac{\max_{x\in X}\{\max|\sigma(x)-\hat{\sigma}(x)|\}}{\max_{x\in X}\{\max|\sigma(x)|\}}, \tag{23}$$

where $\max|\sigma(x)|$ represents the largest element in σ by absolute value. The convergence of MLSM in MON9/9 and MON9/13 setups is shown in Figure 8.

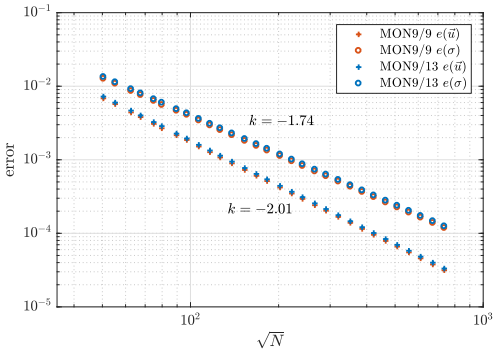

Figure 8. Error of MLSM solving cantilever beam problem using MON9/9 and MON9/13 setups.

To further demonstrate the generality of the method, a domain with arbitrarily positioned holes is considered, subjected to the same boundary conditions as a cantilever beam with traction free conditions on the inside of the holes. A comparison of von Mises stresses (a commonly used yield criterion) in ordinary cantilever beam and a cantilever beam with holes is presented in Figure 9.

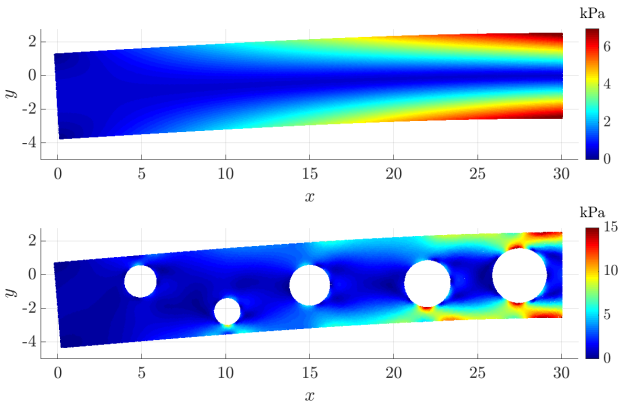

Figure 9. Comparison between solutions of ordinary and drilled cantilever beam problems, colored by von Mises stress.

C. *Lid-driven cavity*

The last example comes from the Computational fluid dynamics (CFD), where the core of the problem lies in solving the Navier-Stokes equations or its variants, e.g. Darcy or Brinkman equation for flow in porous media. The Navier-Stokes equations for incompressible flow are

$$\frac{\partial\vec{u}}{\partial t} + (\vec{u}\cdot\nabla)\vec{u} = -\nabla p + \frac{1}{\mathrm{Re}}\nabla^2\vec{u} \tag{24}$$

$$\nabla\cdot\vec{u} = 0 \tag{25}$$

where $\vec{u} = (u, v)$ is the flow velocity, Re is the Reynolds number and p is the pressure. A standard test for assessment of numerical methods attempting to solve the Navier-Stokes equations is the *lid driven cavity* problem. It has been proposed in 1982 [10] and since then solved by many researchers with wide spectra of different numerical

methods. The test is still widely studied and used for validation of novel methods and numerical principles. In lid driven cavity test a 2-dimensional domain is considered, where all boundaries except for the top boundary are of no slip type, while the top boundary is set to the constant velocity. More details on the case can be found in many papers, recently also in meshless context in [11]. There are different algorithms for addressing the pressure-velocity coupling. Here, we will use a pressure correction iteration [12], where a Poisson pressure correction equation

$$\nabla^2 p^{\text{corr}} = \frac{\rho}{\Delta t} \nabla \cdot \vec{u}^{\text{iter}} \tag{26}$$

with normal boundary conditions

$$\frac{\Delta t}{\rho} \frac{\partial p^{\text{corr}}}{\partial \vec{n}} = 0 \tag{27}$$

and regularization that ensures a unique solution

$$\int_{\Omega} p d\Omega = 0 \tag{28}$$

is used to project velocity towards solenoidal field to ensure mass continuity.

The intermediate velocity is, with present MLSM coordinate free implementation, computed as

```
for (int i : domain.internal()) {
    op.valuevec(M, i, 1 / O.dt);
    op.lapvec(M, i, -O.mu / O.rho);
    op.gradvec(M, i, v1[i]);
    rhs[i] = -1 / O.rho * op.grad(p, i)
             + v1[i] / O.dt;
}
for (int i : domain.boundary()) {
    op.valuevec(M, i, 1);
}
rhs[domain.boundary()]= Vec2d(0, 0);
rhs[domain.top()] = Vec2d(1, 0);
v_iter = solver.solveWithGuess(rhs, v_1);
```

In a next step a pressure correction Poisson equation is solved

```
for (int i : domain.internal()) {
    op.lap(M, i, 1.0);
    rhs_p(i) = O.rho/O.dt*op.div(v_iter, c);
}
for (int i : domain.boundary()) {
    op.neumann(M, i, domain.normal(i), 1.0);
    rhs_p(i) = 0;
}
for (int i = 0; i < N; ++i) {
    M.coeffRef(N, i) = 1;  // Regularization.
    M.coeffRef(i, N) = 1;
    rhs_p(N) = 0
}
P_c = M.lu().solve(rhs_p);
```

Finally, the velocity is corrected to fulfill the divergence free criterion.

```
for (int i : domain.internal()) {
    v[i] -= O.dl*O.dt/O.rho*op.grad(p_c,);
}
```

The example velocity magnitude contour plot of Re $=$ 3200 case is presented in Figure 10. The comparison against reference solution [13, 10] along with convergence information is presented in Figure 11. MLSM solution converges regularly to the same values as the reference solutions for all cases.

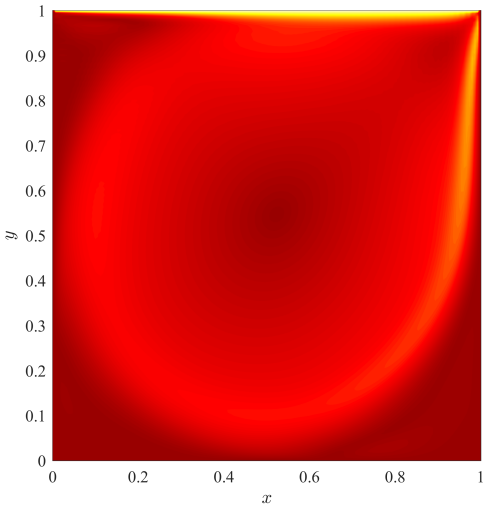

Figure 10. Velocity magnitude contour plot for Re $=$ 3200 case.

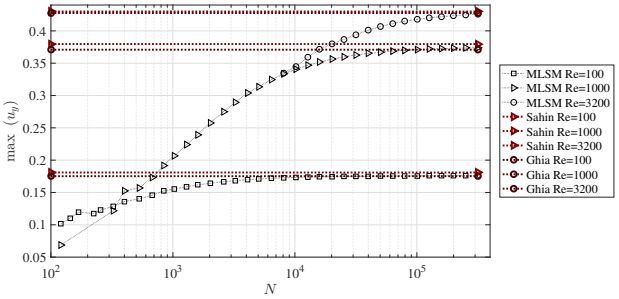

Figure 11. Comparison of present MLSM solution against reference data.

IV. Conclusions

In this paper we presented a concept of Coordinate Free software implementation of numerical solver based on the Meshless Local Strong Form Method. It is demonstrated that after the implementation of mathematical concepts, such as domains, scalar and vector fields, and differential operators, one can numerically solve a wide variety of PDEs with elegant and readable code. It is also demonstrated that coordinate free interfaces bring no observable overhead in execution time.

Acknowledgments

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National Supercomputing in Denmark

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Abstract - National supercomputing was for the first time introduced in Denmark in 2014. Three national supercomputers were jointly funded by the Danish Government, Ministry of Higher Education & Science, the larger universities in Denmark and the Royal Danish Library. National compute facilities were to fill the gap of computing resources between local university resources, Nordic, European and Internationally. However, more importantly the goal was to give all researchers in Denmark equal access to computing resources in order to meet and qualify within the foreseeable future of Big Data. Three years have passed and the amount of national HPC users is steadily increasing every day. Workflows across university borders have been established, national payment models are in place and eScience expert hubs and centers are forming and adjusting to local needs and resources available. All in all, eScience is forming its landscape in Denmark. This paper illustrates the journey Denmark has been through in establishing and integrating national supercomputing into its research culture. Previously, such significant compute resources were strong competitive research parameters. They are now national collaborative facilities opening up for newcomers to HPC, increasing interdisciplinary research, transferring of HPC expertise between scientific disciplines etc. Furthermore, this paper addresses the challenges and successes in reaching this cornerstone for Denmark and in addition identifies the impact of national supercomputing on science in Denmark.

Keywords - supercomputing; HPC; Denmark: eScience; research impact: Abacus 2.0; Computerome; Cultural Heritage Cluster: DeiC; national collaboration

I. INTRODUCTION

This paper reflects upon the journey Denmark has been through in the establishment and integration of national supercomputing into the Danish eScience landscape and university cultures.

A. The History of Danish e-Infrastructure Cooperation (DeiC)

DeiC (Danish e-infrastructure Cooperation) was established in 2012 as an organisation under the Danish Ministry of Education and Research. The organisation was the result of a merger of the supercomputing activities within the Danish Center for Scientific Computing (DCSC) and the national research and education network. The latter belonged to the Danish universities and UNI-C.

B. The Danish Research Network

The first computing systems of the Danish universities were based at regional computing centers. In 1985, these centers were merged into a joint organisation, named UNI-C. Around 1984, the Danish universities started connecting their local area networks nationally in order to communicate with each other. The connections were established via bridges: On one side of the bridge the local area network was connected via Ethernet, on the other side a telco line connected to the other university. Eventually, TCP/IP routers were added to the architecture, making UNI-C the first to manage a large network in Denmark based on Internet technology. The network, known as DENET, was also connected to the Internet. Later the network

was organised under the Danish name 'Forskningsnettet' (i.e. The Research Network). Since 2003, the Danish research network has been financed by the universities through the national Danish budget. Until 2012, a network secretariat ran the administration while operations were outsourced to UNI-C.

C. The National eScience Competence Center

In April, 2011, the Danish Ministry of Higher Education and Science published a roadmap for research infrastructure [1]. This roadmap was based on input from six panels covering different areas of science and research. The roadmap stipulated that DeiC should be established as a merger of the DCSC and the research network. Furthermore, DeiC should establish a national eScience competence center in order to catalyse the knowledge of eScience. It was also decided that DeiC should be involved in the area of research data management.

D. Supercomputing

When DeiC was formed back in 2012; 6,7 million EUR (i.e. 50 million DKK) were transferred from the part of the national budget earmarked for research infrastructure. The money was used for establishing the three national DeiC HPC (High Performance Computing) centers. The DeiC national HPC centers are based at two individual universities and at the Royal Danish Library, established in cooperation with them (Table I). But the centers are available for all researchers at Danish universities and research organisations. Hence, the model is a combination of a centralised and decentralised organisation.

E. ABACUS 2.0

The DeiC National HPC Centre at SDU, hosts the ABACUS 2.0 supercomputer, a state-of-the-art solution for academic HPC suitable for a wide range of research and technological applications. All researchers at Danish universities and all academic users can benefit from the available resources under the same conditions. Access to the facility is granted on a pay-per-use base and all academic users, independently of their host institution, pay the same price. This allows all researchers at Danish universities to take advantage equally of the partial public funding to the national facility at SDU. The ABACUS 2.0 supercomputer

TABLE I. DeiC National High Performance Supercomputing (HPC).

HPC	***DeiC National HPC Centre, SDU*** ***ABACUS 2.0***	***DeiC National Life-Science Supercomputer*** ***COMPUTEROME***	***DeiC National Cultural Heritage Cluster*** ***KAC***
Host/Location	Southern University of Denmark, Odense (SDU)	Technical University of Denmark, Lyngby (DTU)	Royal Danish Library, Aarhus (KB)
Cores Storage	14,000 CPU 1 PB	19,000 CPU 8 PB	<500 CPU 0.1 PB
Access model	Pay-per-use	Pay-per-use Subscription model	Subscription model
Special features for data handling	Non-restricted data	Non-restricted data Sensitive data Proprietary data	Non-restricted data Sensitive data Copyright data*

* Special access to a collection of webpages, newspapers, radio and TV broadcasts > 4 PB data.

is currently one of the most power-efficient HPC installations in the Nordic countries and offers one of the best pricing options for academic users in Europe, also thanks to the national funding from DeiC. Users are billed according to how many node hours they are allocated on the ABACUS 2.0 supercomputer. For small projects (less than 240k corehours) resources must be spent within the agreed time frame (currently 8 months) or they will be lost. Larger projects can request access via a regular call every four months and last for a length of one year. It is possible to move up to 20% of the allocated resources to the next allocation period. Access to the HPC facility, the allocated resources as well as the appropriate user support are provided within the scope and the limits of the HPC Centre policies and regulations.

The ABACUS 2.0 HPC facility provides a pay-per-use service open to all, where national academic users are given priority. In case the requests for access exceed the available capacity,the final decision on access to the HPC facility remains with the SDU eScience Steering Committee. The Committee allocates resources at the facility taking into consideration the requests received and according to the HPC center policies and regulations.

Requests for access to the HPC facility for private/commercial users are allocated depending on the available resources and within the limits of the service agreement with DeiC.

The price for academic access to HPC resources is calculated based on the full cost of ownership to operate the facility. This includes:

- the cost of the HPC hardware and the cost of the fast, parallel GPFS storage system;
- the cost of the infrastructure needed to host the HPC facility at SDU, including: the server rooms, the cooling system, the required electrical components to connect to the power grid (e.g. transformers), etc.;
- the cost of the electricity for the whole HPC facility (HPC hardware, storage system, cooling system, etc).

Note that the pricing model at the national HPC facility at SDU includes the costs for the storage in the cost of node-hours, i.e. users are not required to pay separately for the use of the fast storage system. Furthermore, the final price is based on this full cost calculation, that is very low for Danish researchers (i.e. 1.1 Euro Cents per physical corehour; slim nodes).

F. Computerome

The DeiC National Life Sciences Supercomputing facility "Computerome" is built as a collaborative and a dedicated state-of-the-art computing platform for health care and life sciences. The system represents the Danish infrastructure in ELIXIR[1] and Nordforsk project; Tryggve[2].

Approximately 2% of Denmark's Gross Domestic Product (GDP) is related to life sciences. There is a large foundation based on pharma with a tradition of Public-Private Partnership. The demand for High performance infrastructure to support the growth has lead to a national strategy for HPC infrastructure dedicated to life sciences.

The architecture of Computerome is very unique and it is the largest system of its type in the world. Computerome has more than 1300+ users and completed 197M jobs in 2017. The architecture is tailored specifically for the workloads in healthcare and the field of life sciences. The system is built using the Security by Design principle and optimised to put a higher priority on throughput on storage, memory, reliability and accessibility than raw number of floating point operations (FLOPS), The metric that traditional HPC systems are designed around.

One of the key features of Computerome is the ability to house multiple tenants working with sensitive data, compliant with strict national regulations. Currently, Computerome consists of about 19,000 CPU cores and 8PB of storage.

Computerome hosts computing for both non-sensitive and sensitive research projects. The offering for non-sensitive data is Computerome's HPC system, with configuration aimed at data-driven research typical in biosciences. The system also offers a secure cloud computing platform both as Platform-as-a-Service (PaaS) and Software-as-a-Service (SaaS) variants, with several security profiles including extremely high-security setups use cases. Within the private cloud platform researchers are free to create their own "supercomputers on demand", comprising of hundreds of nodes (thousand of CPU cores) and petabyte-scale storage. At the same time maintaining complete freedom to define any environment they require, such as commercial analytical platforms, Next Generation Sequencing (NGS) analysis pipelines, user management schemes, queuing systems etc. The environment is built with certified, high performance and high security components designed for processing of large volumes of data.

Two-factor authentication is mandatory for all projects. Integration with Citrix Access Gateway allows locking environments down, with no internet access or possibility to "copy-paste" data out of the system.

The National Life Science Supercomputing Center has started the process of establishing a new system, which is planned to arrive in 2018. This new system will still be called *Computerome* and offer five times the capacity of the current installation. Built to handle production-grade services at a national level, using state of the art data management system to enforce the FAIR principles. The system will automatically offer full data lifecycle service.

G. Cultural Heritage Cluster

The Cultural Heritage Cluster is by far the smallest cluster in Denmark's national e-infrastructure. It would not be fair to call it an HPC given the size of the installation. Nevertheless, this specialised installation plays an important role as it fills a gap for specific type of research and specific types of researchers.

With the additional funding for HPC, at the establishment of DeiC, also came a requirement from the funders for DeiC to work on broadening

[1] https://www.elixir-europe.org
[2] https://neic.no/tryggve/

the use of the HPC technology among new user groups, especially researchers from the humanities and social sciences. The Royal Danish Library holds very large collections of digital cultural heritage (e.g. a web archive with 900 Tbytes of data, radio/TV collections with more than 3 Pbytes of data). Legal complications are an issue when moving such large collections, where some data also holds personal sensitive data, alongside the practical implications by moving Pbytes of data over a network. Hence, this led to the establishment of what today became the Cultural Heritage Cluster inside the Royal Danish Library.

The Cultural Heritage Cluster is a small infrastructure consisting of 10 nodes and a capacity of 360 CPU cores. The core technologies on the cluster are Hadoop and Spark, on top of which are access interfaces, currently in the form of RStudio and Jupyter Notebook.

The Cultural Heritage Cluster had an unfortunate start with the selection of a commercial platform provider, which were to deliver the platform and the end user interfaces. After 18 months of struggle with both the basic platform and serious problems with the e.g. handling of access rights in use cases working with personal sensitive data, DeiC stopped the cooperation. Since the spring of 2017, the Royal Danish Library has been working on a new platform, all built on open source tools with Hortonworks Data Platform as the central component. Now, the platform is fully functional and the first pilot project is running at full speed. The very first results are promising and the cluster is already improving the analysis processes for the users. The Cultural Heritage Cluster is fx. capable of statistical computing a 2 billion rows dataset within seconds, a task that would have taken hours or even days on a single laptop or server.

Apart from working with the very large digital collections of the Royal Danish Library, users are very welcome to bring other data to the platform. This could be any kind of data, but the platform and the knowledge of the library concentrates its focus on data in the form of text, images, audio and video.

Due to the delay of the establishment of the Cultural Heritage Cluster the payment model is still to be deployed. During 2018, a number of pilot projects with researchers from the humanities and the social sciences are planned to be carried out. Based on the experiences of these projects, a suitable payment model will be developed. Currently, the initial thoughts around payment models are that it is most likely to be based on a combination of a fixed time based payment (e.g. per week of access alias a subscription model) and a variable element based on usage (e.g. based on CPU-seconds and storage).

II. PAYMENT MODELS

There is a financial risk for a university to host a national supercomputer. The installation is partly subsidised through national funding alongside partner universities' co-funding, however, there is still a significant running cost on a fairly short-term lifespan hardware facility (i.e. four years), which must be able to recover both its existing costs and the costs for the next generation of hardware installation. This risk can potentially create local financial pressure. Each host of a national HPC system was to establish their own payment model in order to reach local sustainability. However, with every new installation follows a start-up period where test-runs, workflows, support set-up, service descriptions etc. need to be developed and integrated. Hence, three national HPC centers have given rise to three different payment models.

The payment model of ABACUS 2.0 benefits its users in terms of dedication to the amount of compute resources specified and applied for. However, this model challenges new HPC users, due to their inexperience within estimating the needed compute time for a given compute job. To meet this challenge of primarily new HPC users; overestimated and unused compute hours are re-allocated on-to the following allocation period, as described in the 'Supercomputing' subsection for ABACUS 2.0. Another challenge of the administration of ABACUS 2.0, is to collect the payment from the researchers up-front, before the compute job is initiated on the HPC. Hence, a research grant is paid to the granting institution through midterm or at the end of the given project period when deliverables are met. However, in order for ABACUS 2.0 to meet its local financial criteria, payment of allocated compute hours must be in place before the compute job is initiated.

The payment model of Computerome is very flexible and is based on a "pay as you go" principle. The users are charged for the "CPU hours" the system uses for working on their jobs and the "TB" storage they use. There is no pre-reservation needed

as the workload in life sciences is highly unpredictable and comes in spikes.

However, it has been a challenge for many groups, independent researchers and individual clinical departments to take full advantage of the infrastructure due to this payment model. Most of the users consider this type of infrastructure a basic requirement for their work. Therefore, a different payment model is brought up for discussion by the users at the national level.

The payment model of the Cultural Heritage Cluster needs to match the most diverse landscape of users, hence a sharply defined payment model is a challenging task to establish. Users will be running a very diverse number of jobs on a very diverse type and amount of data. It is difficult to foresee individual users usage pattern. On one hand, the platform needs to be shared between a number of users simultaneously given the size of the cluster. On the other hand, the payment model needs to take into account that some users will run very big jobs using many cluster resources whereas others will work very explorative with maybe smaller jobs on smaller data sets, thus only utilising the cluster resources within normal working hours. On top of that, researchers from social sciences and humanities are (overall) not very used to working with large technical infrastructures. Therefore, they are not used to having internal budgets for buying access to technical infrastructure nor are they used to having that kind of budget in their external funding applications. Hence, both cultural and behavioral changes are needed in order to reach a focus where technical infrastructure is a natural part of the individual research budgets.

III. TURNING COMPETITION INTO COLLABORATION

Denmark holds eight universities and even with its fairly small size of a country (5.7 million inhabitants) the competitive strength between universities lives well. Up until 2012, where national funding was distributed between local compute facilities, the hardware was seen as a competitive asset for a university. Hence, when the idea of national compute resources was introduced in Denmark, it was also the beginning of a new era and a shift in the competitive mindset of the universities. They were to change a culture from, the more hardware the stronger competitive asset, to now letting go of that value proposition, and instead integrating external and national compute resources when the maximum of local capacity is being reached. Instead of strengthening local compute capacity through national funding, the time was now right to pool the money, join efforts and strive for larger and shareable compute resources, in order to prepare Denmark for the future of Big Data.

An unforeseen competitive barrier did arise through the researcher's preferred choice of compute resources. However, not due to a deselection of less HPC capacity, but instead a protests against the (external) compute resources now had to be visible in research budgets. Local compute resources have for historic reasons always been financially covered through the university's overhead-percentage, hence this financial post was invisible to the researcher. In situations where compute resources are bought through external platforms (eg. at a national HPC Center), the cost suddenly becomes visible. From a researcher's viewpoint, this means an extra cost of his/her research budget, since he/she is still paying the same overhead percentage to the university. However, from the university budget's point of view, this means a reduction of costs, since this is no longer covered through the university's overhead-percentage. Thus, accidentally the new national HPC price models became unattractive to the researcher's HPC operation conditions. However, alongside the university and researcher commitment slowly became more and more established and engaged, with the fact of national supercomputing facilities, a more supplementary compute landscape started to find its way, in a symbiosis of local, national, Nordic, European and even commercial compute resources. A landscape navigating amongst available compute resources matching the variety of HPC users at various levels, and at the same time meeting the needs arising from the Danish research landscape [2].

IV. THE ESCIENCE LANDSCAPE OF DENMARK

Alongside national supercomputers were launched in Denmark around 2014-15, the majority of the universities started to organise themselves with a focus on building stronger eScience expertises both across faculties and departments. Different concepts of eScience organisations developed

around the eight universities in Denmark. Some of the larger universities established their own eScience Centers; i.e. Technical University of Denmark (DTU) and Southern University of Denmark (SDU). University of Copenhagen (KU) was the first to establish their own eScience Center within the Faculty of Science even before national supercomputing was introduced in Denmark. Aarhus university (AU) established an eScience committee with representation across scientific disciplines, Roskilde University Center (RUC) established their own HPC hub with a dedicated focus on the natural sciences. Aalborg University (AAU) established an HPC committee focussing on allocating their HPC users on to national HPC. The IT University of Copenhagen (ITU) did already have an overall eScience profile by being a dedicated university of IT. Copenhagen Business School (CBS) has continued with their existing organisation.

The Danish eScience landscape mirrors self-developing communities of principles and practice deploying ICT tooling, software and e-infrastructures, which indeed challenges the speed of new discoveries. The eScience landscape of Denmark builds on each university's organisation and mission. Denmark keeps a high priority within protecting the variation of the existing research landscape, benefitting from the diversity of each university and their individual strategies.

DeiC eScience Competence Center was established by the end of 2014 (two years later than the foundation of DeiC), as a national platform for all various eScience parties to share expertise, best practices and challenges. Thereby, creating cross fertilisation over disciplines, i.e. a crucial eScience collaboration platform bridging the various and differentiated eScience Communities across universities throughout the country. The staff of the DeiC eScience Competence Center support and collaborate with the Danish eScience communities in order to enhance their integration of tools and competences benefitting from both national and international resource opportunities.

The eScience diversity within such a small country as Denmark naturally challenges national decision making between different interests and university strategies. The strength of building national HPC facilities alongside a national collaboration platform (i.e. DeiC) is that it creates equal access for both beginners and experienced HPC users across all disciplines, within the national landscape of computing access.

The local compute units and environments around the Danish universities play a very important role in the whole life cycle of eScience and HPC competences. Hence, if local HPC reaches its level of capacity for an individual researcher, new and larger HPC requirements are to be made accessible for both the individual researcher alongside his/her local HPC support.

V. DEIC NATIONAL SUPERCOMPUTING IN DANISH RESEARCH

An analysis was made in order to track HPC publications generated from DeiC National HPC facilities in the period 2015-2017. The purpose was to illustrate the impact of HPC in Danish research. This bibliometric analysis is based on input from the HPC users (500+). The users were asked to identify the papers that have been enabled by DeiC National HPC. This resulted in collection of 290 publications across a broad range of scientific disciplines distributed in 160 different scientific peer-reviewed journals. The total of 290 scientific publications corresponds to approximately 1.3 % of the yearly amount of scientific publications in Denmark [3]. It should be noted that in the remaining 98.7% there is additional HPC related papers from local HPC clusters that are not accounted for in this analysis.

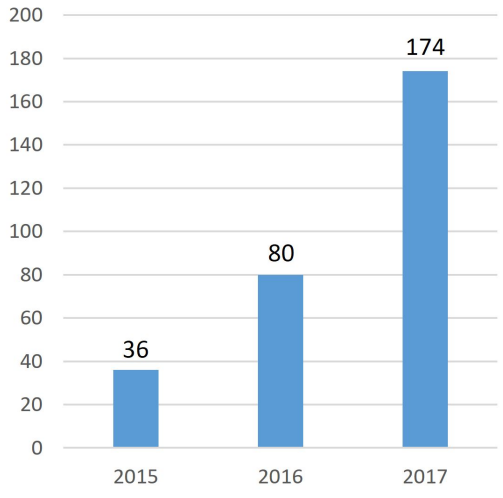

Figure 1. Number of scientific publications (n=290) using DeiC National HPC in the period from 2015 to 2017.

TABLE II. JIF ranking of scientific publications that used DeiC National HPC in the period 2015 to 2017.

JIF Interval	*n Pub*	*% Pub*	*Average JIF in the interval*
0 - 2.49	43	15	2
2.5 - 4.99	117	40	4
>5	130	45	13

Abbreviations: n Pub, Number of publications; % Pub, Percentage of publications; JIF, Journal Impact Factor.

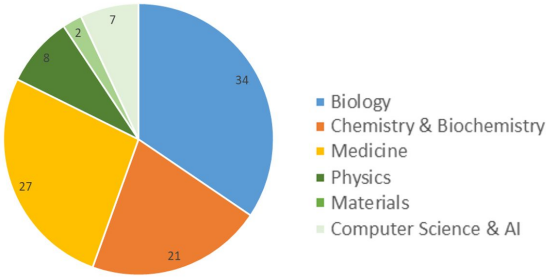

Figure 2. Distribution (%) of 290 scientific publications into research areas that used DeiC National HPC from 2015 to 2017.

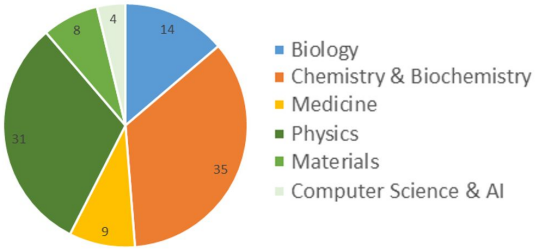

Figure 3. Distribution (%) of 80 scientific publications that used Abacus 2.0 HPC from 2015 to 2017.

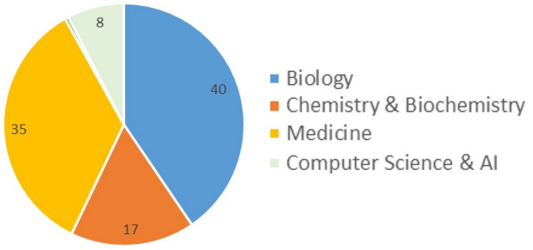

Figure 4. Distribution (%) of 210 scientific publications that used Computerome HPC from 2015 to 2017.

A. Research Areas that used national HPC

A 5-fold increase in the number of HPC publications was detected since the establishment of National HPC in 2014/2015 (Fig. 1; 2017, n=174; 2015, n=35). The majority of the HPC publications was detected in research areas such as Biology (34%), Chemistry & Biochemistry (21%) and Medicine (27%), respectively (Fig. 2). The distribution of scientific HPC publications among the National HPC facilities match the strategic intentions behind diverse HPC architecture for different scientific areas. ABACUS 2.0 was designed to aim for a broad range of scientific disciplines (Fig. 3), whereas Computerome addresses Life Science (Fig. 4). The National Cultural Heritage Cluster is intended to be used within Humanities and Social Sciences in the near future.

B. Scientific output measured by JIF

The Thomson Reuters Journal Impact Factor (JIF), is a common bibliometric index used to describe the impact of scientific publications [4]. The JIF is a proxy for the relative importance of a journal within its field. A total of 85% of the DeiC National HPC publications from 2015 to 2017 was JIF indexed above 2.5 (n=247), and 45% of the publications scored a JIF average of 13 (n=130) (Table II). As an example, the HPC publications from 2017 accounted for 17 publications (10% of total 174 publications) in journals related to the "Nature"-series [5-21], that is ranked with a JIF higher than 12 (e.g. Nature Communications (JIF 12.124) and Nature Structural and Molecular Biology (JIF 12.595)). Publications that included the use of DeiC National HPC were also published in Nature Cell Biology (JIF 20.060), Nature Methods (JIF 25.062), Nature Genetics (JIF 27.959), Nature (JIF 40.137), Nature Review Genetics (JIF 40.282), Nature Biotechnology (JIF 41.667) and Nature Reviews Drug Discovery (JIF 57), respectively, for the period 2015 to 2017 [5-35]. In addition, one paper was published in the journal Science (JIF 37.205) [36] and two papers in Nature Microbiology (No JIF, journal less than two years old) [28,29]. Denmark was recently rated as number 13 compared to other OECD-countries regarding the number of publications in Nature from 2012-2016 [37]. If the number of inhabitants was taken into consideration then Denmark was placed as number 3 on the list. This indicates that Danish research is of a high international standard. A full list of the 290 publications using national HPC in the present study is available on the DeiC National eScience Portal (Appendix 1).

In addition to counting scientific HPC publications and using a citation-based bibliographic metrics (JIF) in the analysis, one could in the future use a Field-Weighted Citation Impact (FWCI) index.

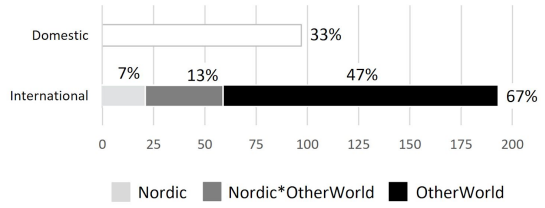

Figure 5. Distribution of 290 scientific publications that included international collaboration using DeiC National HPC from 2015-2017.

C. International Collaboration

An indicator for high scientific impact in the international community is publications made together with international research groups. Furthermore, it may be expected that international collaboration within different research areas leads to development of new competences of mutual benefit for the universities. Therefore, it is interesting to look at the rate of publications that actually involve international collaboration. A total of 58% of Denmark's scientific publications was recently rated to involve international collaboration [38]. This places Denmark as number 7 compared to other OECD-countries, which is the same level as Sweden and Norway. However, in the present study, international collaboration with other universities was detected for the majority of the scientific publications that included DeiC National HPC (Fig. 5). A total of 67% (n=193) of the publications involved International collaboration of which 20% was in collaboration with the Nordic countries (Fig. 5; Nordic and Nordic*OtherWorld).

VI. SUMMARY & CONCLUSIONS

Denmark mirrors a diverse and dynamic eScience landscape building upon a variety of organisational concepts among its eight universities. Each eScience organisation (and those without) develop and integrate their eScience competences at own pace and in line with the individual university strategies and resources. Through the national eScience Competence Center at DeiC, it is possible to share expertise and inspire across this diverse eScience landscape. At the same time, establish new partnerships, hence, slowly joining forces around a national eScience vision.

The first science in Denmark using national HPC matches the strategic intentions behind the three national HPC architectures.We have not seen the scientific outcome yet from the Cultural Heritage Cluster, however, we foresee a clear dedication from the humanities and social sciences.

These first results of the scientific output from Denmark's national HPC facilities have shown a strong scientific impact. A total of 45% of the peer reviewed scientific publications that have used national HPC in Denmark, within these last three years, lies within a Journal Impact Factor range of 5 and up to 57, holding an average of 13. Furthermore, 67% of these publications involved international collaboration - an indicator for high scientific standing in the international community for Danish research.

It is important to state that the conclusions drawn from the initial peer-reviewed scientific publications that have used national HPC, is based solely on what was possible to identify through the bibliometric analysis described. Hence, there is a potential for an even higher amount of scientific publications present, than those identified through the analysis.

ACKNOWLEDGMENT

We acknowledge the comprehensive collection and verification of the scientific publications that have used the national HPC, carried out by Executive Officer Wendy Engelberts, SDU eScience Center; Senior Executive Officer Myhanh Nguyen and Administrative Officer Spela Zajec, National Life Science Supercomputing Center, DTU; Senior Information Officer Jeannette Ekstrøm, DTU Library. We thank Director of SDU eScience Center, Professor Claudio Pica for his excellent comments and reflections and special advisor Per Møldrup-Dalum for good discussions and his engagement in the overall national collaboration, Cultural Heritage Cluster, The Royal Library, Aarhus. Last but not least, we thank Communications Officer Sanne Holm at DeiC, for her editorial work on this paper.

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[38] Danish Ministry of Higher Education and Science (2017) [Forskningsbarometeret 2017.Årlig statistik og analyse om forskning og innovation]. Page 57-59. ISBN: 978-87-93468-80-1. https://ufm.dk/publikationer/2018/filer/forskningsbarometer-2017.pdf

Appendix 1. List of www-material sources

DeiC National eScience Portal [Vidensportalen]:
https://vidensportal.deic.dk/en/publications

DeiC National HPC Centre, SDU (ABACUS 2.0):
http://www.abacus.deic.dk

DeiC National Life-Science Supercomputer (Computerome):
http://www.computerome.dk

DeiC National Cultural Heritage Cluster (KAC):
https://vidensportal.deic.dk/en/KAC

Visualization of computable scalar 3D field using cubic interpolation or kernel density estimation function

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***Abstract* - Visualization of data, both computed or empirical, is an important part of knowledge acquirement process. Although computed data, e.g. molecular fields, are usually well structured for advanced visualization including volume rendering, often an enormous computation power is required for efficient data presentation including but not limited to visualization by means of isosurface. In order to reduce required computation power various algorithms have been developed. In the paper three of them, namely tri-linear interpolation, tri-cubic interpolation and approximation employing kernel density estimation function, have been tested and compared against direct isosurface solution in respect to computation time, accuracy and visual appearance. All examples were computed using hybrid data visualization styles using advanced texturing as part of data presentation. For fast prototyping of visual styles and computation of visual examples POVRay completed with newest version of ScPovPlot3D toolkit has been used.**

Keywords - volume rendering; isosurface; KDE function; POV-Ray; ScPovPlot3D; electric field visualization, Catmull-Rom splines.

I. INTRODUCTION

Numerous phenomena are defined in 3D space including physical, technical and medical problems (e.g. [15]). One may list 3D distributions of scalar values like temperature, pressure, density, concentration, electron density, molecular electric potential field, humidity as well as vector fields of e.g. fluid flow or electric field strength. Some of them may be measured directly on designated measurement grid, some can be sampled only and, in selected cases, the field may be computed based on "first principles". Visualization of these fields is known as "volume rendering", which despite many years of intense development it is still a subject of research and hopefully may be improved in relation to computation time, information capacity, accuracy and visual appearance. In the paper four visualization techniques based on volume rendering by isosurface are discussed. Two of them, direct implementation of isosurface algorithm and trilinear interpolation were presented and discussed in [1] and are used here for comparison. The other two, uniform Catmull-Rom cubic splines interpolation and based on Gaussian Kernel Density Estimation (KDE) function approximation have been implemented in ScPovPlot3D, POV-Ray driven toolkit [8], specifically for this work. To ensure comparability of the results, model of hypothetical water cluster, $(H_2O)_6$ [2] (Fig. 1), was used for computation of electric field potential and strength. Selected structure is scientifically interesting [9], complex enough to investigate weaknesses of visualization models while remains reasonably simple not to excessively expand computation time. Due to focusing of current analysis on visualization aspects, not molecular field itself, simple classical, Coulombean approximation was used based on assumption, that electric charge is pinpointed to the oxygen and hydrogen atoms.

Two variants of hybrid visualization were tested, i.e. isosurface of electric potential textured by strength of the electric field and isosurface of electric field strength textured after electric potential. Computation times, accuracy and visual appearance of all four designs are compared and discussed.

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II. METHODS

A. Virtual laboratory

In numerical experiments performed several components were used both software and hardware. All visualizations were computed on HP ProBook 430 G2 laptop equipped with i5 Intel processor and 8GB RAM, running Windows 8.1/64bit OS and POV-Ray™ 3.7.0, (msvc10.win64 build) as a raytracer. ScPovPlot3D toolkit [8] described in [1, 2, 3] is a set of procedures organized in several task oriented modules, written in domain specific language SDL of POV-Ray [10]. Graphics were rendered mainly using 16bit/channel resolution (total 48 bits/pixel plus alpha channel) using EXR (OpenEXR High Dynamic) format, then, for required tone mapping on usual 8bit per channel palette GNU GPL program "Luminance HDR" was used [17]. Approximate total computation time was determined from debugging output returned by POV-Ray rendering engine because there is no usable function of SDL which might be used for measuring of execution time and profiling. Accuracy of interpolated surfaces was evaluated by close observation only as there is no method for numerical comparison yet.

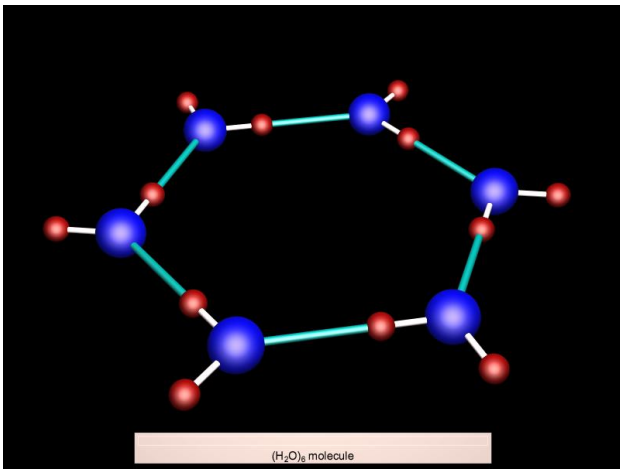

Figure 1. Visualization of flat, six molecule water cluster $(H_2O)_6$. Atoms are marked as spheres scaled according to respective ionic radius: hydrogen as smaller red while oxygen larger blue. Bonds are rendered using thin cylinders. Hydrogen bonding is shown in cyan tint. Source: own, based on [2]

B. *Visualization*

One of the most important volume rendering methods is isosurface representation, i.e. surface of constant value of selected variable. It may be surface of the same X-Ray density, temperature, flow speed, humidity or, as selected in that paper, electric potential i.e. equipotential surface. As described in [1], this surface may be computed using root finding algorithm as it is implemented in POV-Ray. Usually surfaces generated in this manner are of very good quality, but, due to repetitive calculation of real value of the field in a given point required by root finding algorithm, they are extremely inefficient for more complicated systems. Moreover, this method cannot be directly applied to data recorded in experiments or measurements, especially if it has been collected on irregular grid. In order to overcome this difficulty several methods have been worked out [4, 13]. However in case of computable fields examined region may get sampled on regular, preferably cuboid grid and then some sort of interpolation may be used for every cell [14, 16]. In this paper four methods have been compared:

- direct visualization using single isosurface built-in POV-Ray visual primitive over all volume of interest. For complicated fields this method is very slow (Fig. 2, Fig. 6) [10],
- trilinear interpolation [1, 11] all volume of interest is split into elementary cells and then piece of isosurface is computed in every cell for which sought isosurface may exist. This method is very fast, however, while continuity of interpolated function is guaranteed on algorithm level, continuity of the first derivative is not. Thus, traces of the computation mesh may be observed (Fig. 3, Fig. 7),
- cubic interpolation using uniform Catmull-Rom splines, i.e. third order polynomials [11, 18, 19, 21]. All volume of interest is split into elementary cells and isosurface is computed in suspected for containing solution only, however, due to nonlinearity of interpolation function, selection algorithm tends to be unreliable leaving holes in the surface. Although continuity of interpolated function as well its first derivative is guaranteed on algorithm level, few artifacts may be spotted, which is a known problem with polynomial interpolation (Fig. 4, Fig. 8),
- approximation using kernel density estimation function KDE. In the paper Gaussian kernel has been tested (Fig. 5, Fig. 9), other kernels will be evaluated, including inverse distance method (*Nearest neighbor weighted interpolation* [13]). While the general shape of exact isosurface is properly reproduced, numerous artifacts and gaps related probably to granularity of calculation mesh as well as to limited number of nodes included in computation of current cell are clearly visible.

In the following section the two last algorithms will be presented in more details - all implementation details are

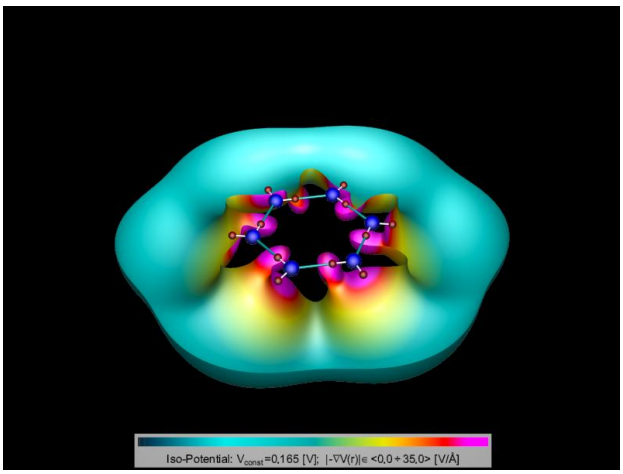

Figure 2. Visualization of electric potential around water cluster, U_{const}=0.165 V using direct isosurface estimation. Surface is textured according to electric field strength. Total computation time: 0h 28m 48s. Source: own.

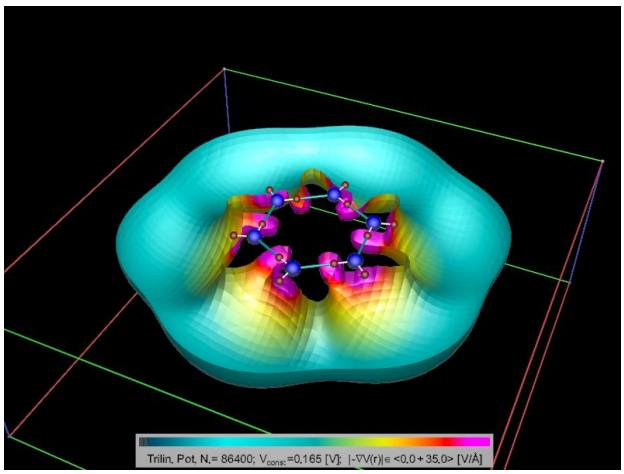

Figure 3. Visualization of electric potential around water cluster, U_{const}=0.165 V, using trilinear interpolation. Surface is textured according to electric field strength. General shape is properly reproduced, however artifacts of calculation mesh (86400 cells) are clearly visible.Total time: 0m 52s. Source: own.

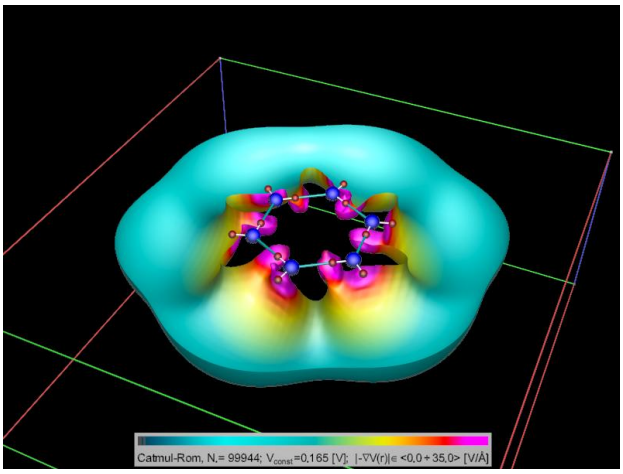

Figure 4. Visualization of electric potential around water cluster, U_{const}=0.165 V, using uniform Catmull-Rom interpolation. Surface is textured according to electric field strength. Calculation mesh (99944 cells) is almost invisible, however some artifacts may be spotted. Total time: 2m 48s. Source: own.

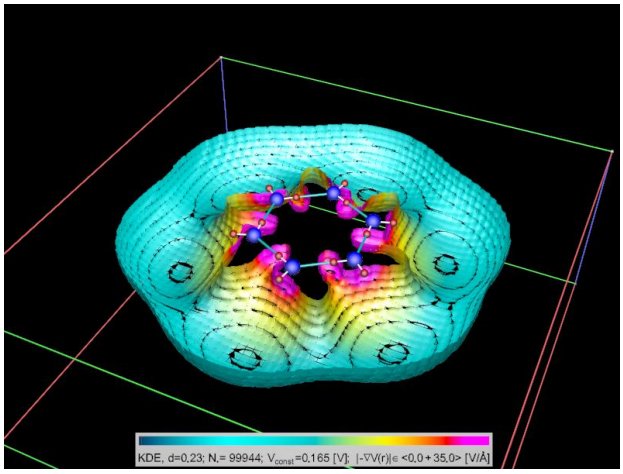

Figure 5. Visualization of electric potential around water cluster, using KDE interpolation with gaussian kernel. Surface is textured according to electric field strength. While general shape is properly reproduced, numerous artifacts and gaps related to granularity of calculation mesh (99944 cells) are clearly visible. Total time: 9m 27s. Source: own.

available in the source code [22].

III. CATMULL-ROM INTERPOLATION

Catmull-Rom interpolation is a kind of third order (cubic) piecewise polynomial interpolation [11, 18, 19, 21]. Basic formulation leads to uniform Catmull-Rom splines which are in certain circumstances prone to creating loops or cusps. This may be avoided using *centripetal* or *chordal* Catmull-Rom splines formulation, unfortunately, this cannot be easily implemented, due to SDL limitations, (Scene Description Language, POV-Ray's domain specific, scripting language).

For one dimensional case it is assumed that nodes are distributed uniformly at the distance '1' from each other. Subset of nodes for the given range from node i to node $i+1$, may be indexed as $Q_{i-1}(x_{i-1})$, $Q_i(x_i)$, $Q_{i+1}(x_{i+1})$, $Q_{i+2}(x_{i+2})$. Let us denote for simplicity: $Q_{i-1} = Q_m$, $Q_i = Q_0$, $Q_{i+1} = Q_1$, $Q_{i+2} = Q_2$ (Fig. 10) where x_{i-1}= -1, x_i=0, x_{i+1}=1 and x_{i+2}=2. Coefficient τ defines values of tangents at u=0 and u=1 (denoted t_0 and t_1 respectively), and most often takes value 0.5 (1), however, it may be varied a little around.

$$t_0 := \tau(Q_1 - Q_m), \qquad t_1 := \tau(Q_2 - Q_0) \tag{1}$$

Then for u ∈ <0; 1>, interpolated value $\tilde{Q}(u)$ may be expressed in the form of linear combination of nodal values Q_m, Q_0, Q_1 and Q_2 using *blending functions* (2) [18]:

$$\tilde{Q}(u) = \begin{bmatrix} -\tau u^3 + 2\tau u^2 - \tau u \\ (2-\tau)u^3 + (\tau-3)u^2 + 1 \\ (\tau-2)u^3 + (3-2\tau)u^2 + \tau u \\ \tau u^3 - \tau u^2 \end{bmatrix}^T \begin{bmatrix} Q_m \\ Q_0 \\ Q_1 \\ Q_2 \end{bmatrix} \tag{2}$$

The same procedure may be repeated for y and z axis with parametric variables 'v' and 't' respectively. However, in order to obtain final, interpolated value

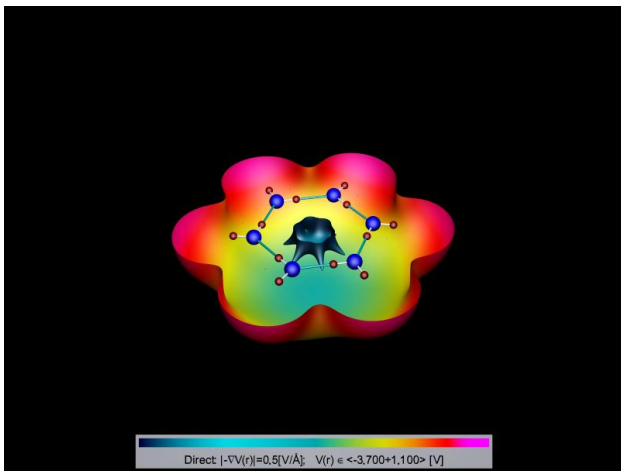

Figure 6. Visualization of electric field strength around water cluster, |-grad(V)|=0.5 [V/Å], using direct rendering. Surface is textured according to electric field potential. Total time: 2h 44m 16s. Source: own.

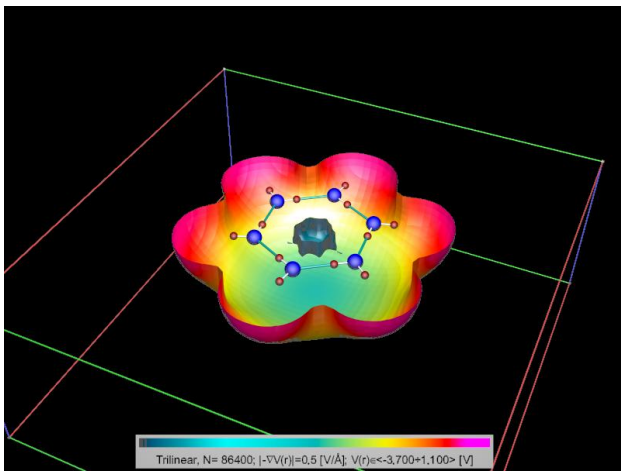

Figure 7. Visualization of electric field strength around water cluster, |-grad(V)|=0.5 [V/Å], using tri-linear interpolation. Surface is textured according to electric field potential. General shape is properly reproduced, however artifacts of calculation mesh (86400 cells) are clearly visible. Total time: 0h 0m 49s. Source: own.

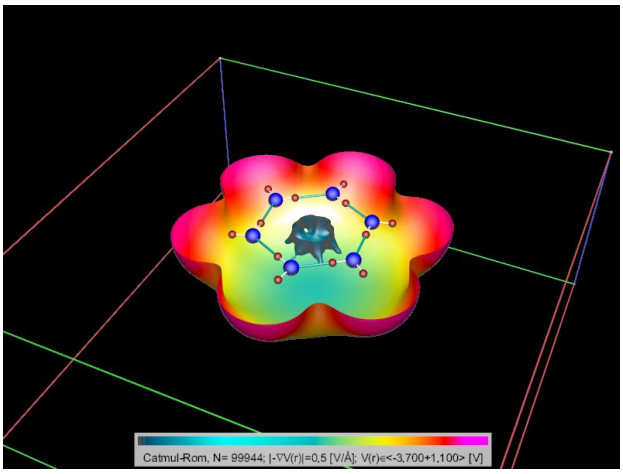

Figure 8. Visualization of electric field strength around water cluster, |-grad(V)|=0.5 [V/Å], using Catmull-Rom interpolation. Surface is textured according to electric field potential. General shape is properly reproduced, discordancy related probably to granularity of calculation mesh (99944 cells) is clearly visible in the center of the molecule. Total time: 0h 4m 29s. Source: own.

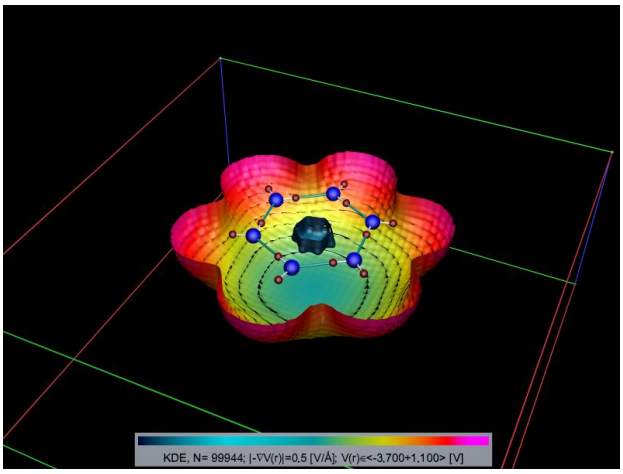

Figure 9. Visualization of electric field strength around water cluster, |-grad(V)|=0.5 [V/Å], using KDE interpolation with gaussian kernel. Surface is textured according to electric field potential. While general shape is properly reproduced, numerous artifacts and gaps related to granularity of calculation mesh (99944 cells) are clearly visible. Total time: 0h 31m 48s. Source: own.

$\tilde{Q}$(u,v,t), multi-stage procedure is required involving 64 nodes as shown in the Fig. 10. This reduction may be completed in any order as shown in [24], what results mainly from linearity of transformation (2). Let the order be $x \mapsto y \mapsto z$ (Fig. 11). First, based on 16 splines along X axis (red arrows) 16 intermediate values $\{\tilde{S}(u)\}$ are computed (green circles), which in turn, made basis for computing 4 intermediate values $\{\tilde{R}(u,v)\}$ (magenta circles) using 4 splines along Y axis (green arrows). Finally, $\tilde{Q}(u,v,t)$ (blue circle) is computed using only one spline along Z axis based on four values $\{\tilde{R}(u,v)\}$ calculated in previous step (magenta arrows). Subtle change of τ coefficient may positively influence the look of interpolated surface, however it should remain constant, at least for selected axis. Of course, it is possible to recompute τ for every cell but different values in adjacent cells may lead to visible discontinuity of the first derivative on boundaries between cells. Other implementations are possible as well [24].

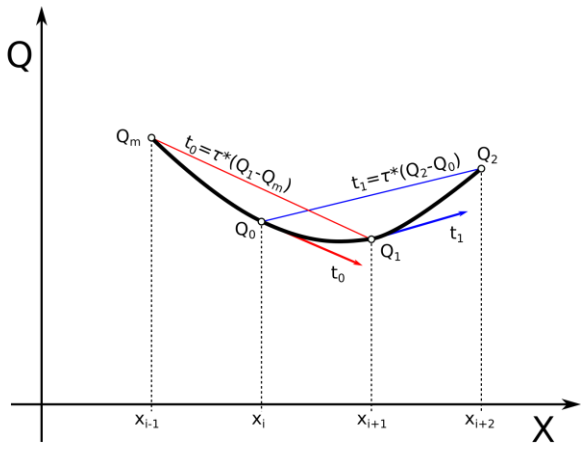

Figure 10. Catmull-Rom spline definition. Interpolated values are computed over interval <x_i; x_{i+1}>, points Q_m and Q_2 are used to compute tangents t_0 (red arrow) and t_1 (blue arrow) [18]. Usually points $\{x_j\}$ are distributed uniformly and separated by one unit from each other. Source: own.

Accuracy of this algorithm depends on size of elementary cell, local gradient of the scalar field because it influences values of tangents t_0 and t_1 and floating-point precision - for high gradient fields at least double precision is required and extended precision (80 bits) is recommended.

IV. GAUSSIAN KDE APPROXIMATION

In general, kernel density estimation function algorithm is based on weighted arithmetic average concept. Known values, measured or computed in number of nodes, are summed up using weights depending on

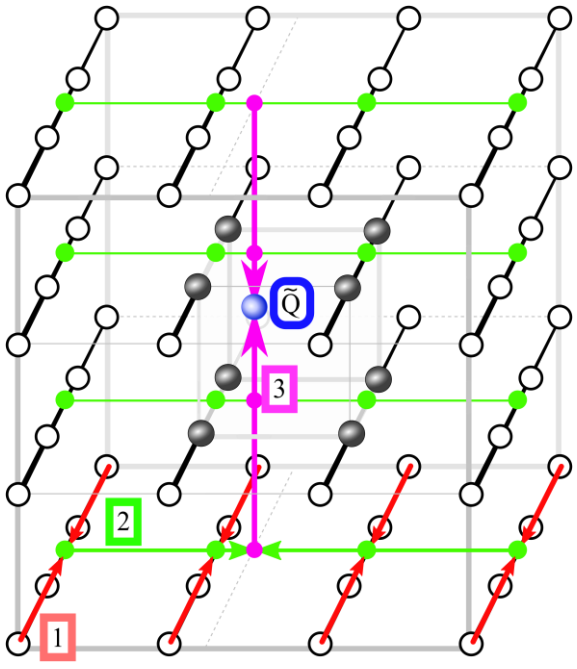

Figure 11. Grid reduction using Catmull-Rom uniform splines. Arrows and numbers shows order of additions: red first (along X axis), then green (along Y axis) and eventually magenta (Z axis). Firstly green circles are computed (16 values), then .magenta circles (4 values) and finally blue dot in the inside of the elementary computing cell denoted by $\tilde{Q}$. Source: own.

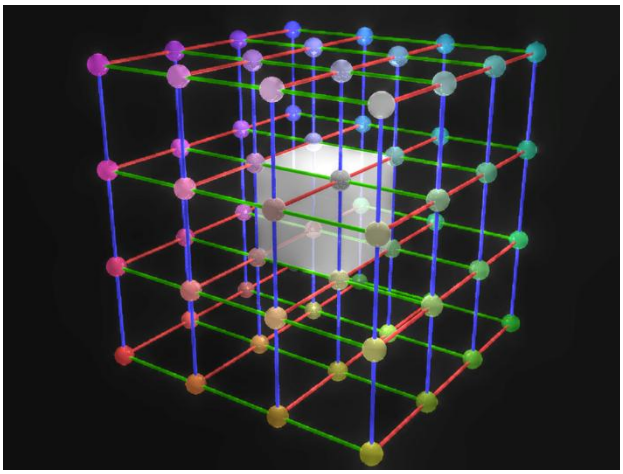

Figure 12. Grid used to compute estimate inside central cell (bright cube in the center). Grid nodes are represented by spheres, edges connects nodes visually only. Source: own.

distance from given node to observation point. A range of functions and procedures may be used to compute weights, including simple kernel density formulations and advanced kriging [5, 6]. In particular weights may be computed using Gauss function, inverse distance function, Cauchy or Hann kernels, several are implemented in well known plotting program gnuplot [7, 25]. Originally these algorithms were developed for estimation of value in observation point while known values are distributed irregularly over measurement field. Such a procedure is particularly important in geology, but not only, where measurements cannot be done in freely selected spots, due to terrain constraints (mountains, marshes, lakes, roads). Results may be very important, e.g. for mining industry (search for deposits) or just for evaluation of risk of seismic or tectonic instability, by estimation of stress distribution in rock bed. The latter may be of key importance for the safety of important industrial facilities like LNG hubs (e.g. in Omišalj) or simply for tourism, as even minor earthquake may cause not only damage to the infrastructure but also panic [23].

Despite the fact that this algorithm has not been designed for interpolation it is important to test its capabilities, discover strengths and weakness. In the paper Gaussian kernel has been tested (3):

$$\tilde{Q} = \frac{\sum_{i=1}^{i=N} Q_i \, e^{-\left(\frac{r_i}{d}\right)^2}}{\sum_{i=1}^{i=N} e^{-\left(\frac{r_i}{d}\right)^2}}, \qquad (3)$$

where N is the number of nodes in the grid, $\tilde{Q}$ is an estimate at observation point, Q_i is a load at data point '*i*', r_i is the distance from data point '*i*' to the observation point and *d* is scaling factor (being used as range factor because it controls influence of remote nodes).

Estimate generated by the full formula inherits analytical properties of the kernel, in case of Gaussian kernel this means that estimate is infinitely differentiable, i.e. colloquially speaking - perfectly smooth. However, this requires using all data points (tens of thousands on minor grids, millions on larger) in the formula, which is unacceptable due to efficiency reasons.

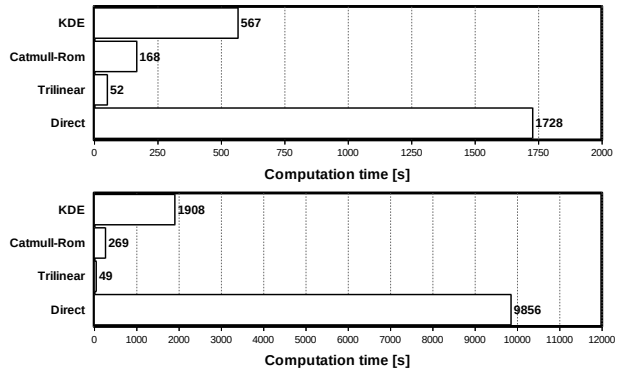

Figure 13. Approximate total computation times for different interpolation methods. Upper chart: field potential, field strength in the lower. Direct method is the slowest, while trilinear is the fastest. Source: own.

Thus instead, a limited set of nearest nodes should be used (4), unfortunately, this leads to imminent discontinuities at boundaries between adjacent cells, especially for larger values of suppression coefficient *d*:

$$\widetilde{Q_i} = \frac{\sum_{k=1}^{k=64} Q_{ik} \, e^{-\left(\frac{r_{ik}}{d}\right)^2}}{\sum_{k=1}^{k=64} e^{-\left(\frac{r_{ik}}{d}\right)^2}}, \qquad (4)$$

where $\widetilde{Q_i}$ is estimate inside cell '*i*', Q_{ik} is load on one of 64 nearest nodes and r_{ik} is a distance from node 'k' to the observation point. All 64 data nodes involved and computation cell (bright cuboid in the centre) are shown in the Fig. 12.

V. Results and Discussion

Computation times differed significantly depending on interpolation method used. In approaches involving computational mesh, total computation time consisted of three components: computation of values in every node of the mesh (or importing them from datafile, computed externally e.g. on supercomputer), computation of isosurface in selected cells and then visual rendering of the surface. There is no first step in direct approach, however isosurface must be computed over all volume of area of interest which extents significantly computation time.

A. Potential distribution - field strength as a texture

In this specific case, calculation of potential in a single point is relatively simple thus fast - just requires summation over all - few and discrete - sources. However, in case of continuous distribution of field source (e.g. electron density function) or very extended structures

TABLE I. Comparison of Computation Times

Method	***Computation time [s]***	
	Potential	***Field strength***
KDE	567	1908
Catmull-Rom	168	269
Trilinear	52	49
Direct isosurface	1728	9856

Source: own

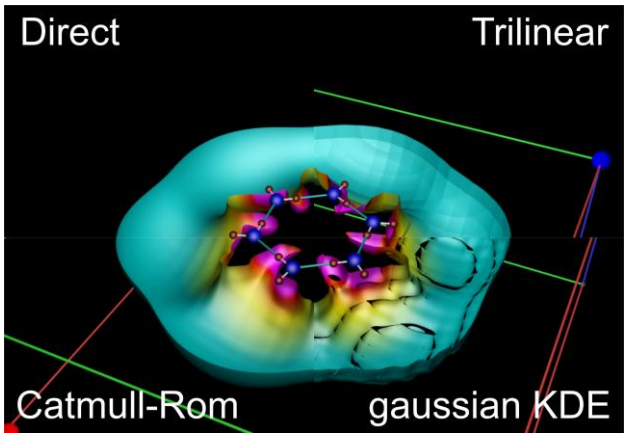

Figure 14. Comparison of accuracy of rendering methods tested. At selected computational cell size, Catmull-Rom interpolation is almost as precise as direct method while at trilinear and KDE approaches numerous artfacts are visible.. Source: own.

computation burden may be enormous. As expected computation time in all gridded algorithms was shorter than of direct isosurface algorithm (Fig. 13, Tab. I). There are at least two reasons for that:

1. only selected cells are computed,
2. calculations based on known values in surrounding nodes are just faster.

Accuracy of computed isosurface depends on the size of computation cells thus on total number of cells. However, trilinear algorithm requires more than 2.2 times smaller cells, thus on average 10 times more cells in order to achieve comparable visual appearance (Fig. 14).

B. Field strength distribution - potential as a texture

Computation of the strength of the field imply computation of the gradient (indirect method) or direct computation of vector of the field and then its length (explicit method). Computational complexity of both methods is very high. The indirect method requires computation of 6 values of potential for 3 vector components and then square root of sum of its squares while explicit method requires summation of all additives to vector components followed by calculation of the square root of its squares. It is particularly evident at direct computation of isosurface which takes (Fig. 13, Tab. I) approximately 5.7 times more time then in case of isosurface of the potential. However, approaches involving mesh are almost as fast as in case of potential. This is because complicated function of field strength is computed only once in every node of the mesh and then, this stored value is used directly in computations.

VI. CONCLUSIONS

All presented methods have internal and characteristic advantages and disadvantages. The choice of one should be based on the goal of particular visualization.

Suggested exploration scenario is to firstly get general view of the field using trilinear interpolation as the fastest method or Catmull-Rom as a bit more accurate at coarser mesh and finally select small area of interest for direct method, as it returns the best visual at lowest speed. Other visualization including cross sections may be used as well. Some improvement of all presented methods is possible and should be carefully inspected.

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Visualization of irregular datasets using kernel density estimation function

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Abstract - **Visualization of empirical data is an important part of knowledge acquirement process. Numerous visualization techniques are thus employed including surface and volume rendering. Usually algorithms of visualization require data to be organized in a regular manner. Unfortunately data accumulated empirically often does not exhibit any internal regularity e.g. due to varying spatial density of samples resulting from natural constraints. In order to cope with this problem several preprocess procedures have been developed including distance-like methods. In the paper are discussed problems connected with data preprocessing for visual data analysis, hybrid data visualization styles using advanced texturing as part of data presentation. For fast prototyping of 3D visual styles and computation of visual examples POVRay with newest version of ScPovPlot3D toolkit has been used.**

Keywords - irregularly distributed data, kriging, volume rendering, POV-Ray, ScPovPlot3D

I. INTRODUCTION

Visualization is over times recognized as an important part of data analysis and efficient tool for sharing results. Most often, the amount and properties of collected data allows for application of standard visualization techniques, e.g. classic histogram chart for point data or surface chart for spatial data. Input data for both techniques must, however, fulfil specific conditions. For example, in the case of the histogram chart, the number of items assigned to a given class interval has to be greater than some minimal value, usually this limit is set on 5 items. This means that for 9 class intervals at least 45 data-points must be available. In the case of spatial, or volume data, this condition relies on the availability of a single or multiple measurements of a value at nodes of a regular grid, preferably with square (cuboid) cells; multiple measurements leads to statistical distribution [1, 2, 3].

However, there is quite a lot of cases where the number of available data is insufficient because they come from a population with large dispersion of feature values or from measurement at points that are irregularly distributed in a domain of interest (plane or volume) [11, 12]. This may be due to high cost of data acquisition or the natural data unavailability. For example, it is not possible nor viable to perform measurement in drillings in inaccessible or conversely populated, urbanized areas (e.g., swamps, rivers, protected areas, cities) [8, 14, 15, 16]. To cope with the problem of insufficient or unevenly distributed data some dedicated techniques must be used, e.g., kriging 0.

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Another problem is that the measurements are often subject to intrinsic uncertainty which often results just from instability or fluctuations present in the phenomena itself. This includes measurements of atmospheric pressure, temperature distribution, ocean water level or tension distribution in bed rock. This means, that there is no such thing as exact value at observation node thus there is no good reason to demand that approximated surface run exactly through given data point. This uncertainty can be modelled efficiently by e.g. interval arithmetic [2, 4, 5, 6, 17] however visualization of uncertainty in data is separate task [4, 5, 6].

The paper aims to present suggestions of how to overcome difficulties caused by both insufficient number of and measurement uncertainty in data. There are three main parts. The first one is devoted to analysis of 1-dimensional data using proposed inverted histogram method which is compared to well known kernel density estimation function KDE approach. In the next section two dimensional case is discussed focused on topography modelling using approximated geospatial data. In the last section three dimensional kernel smoothing function approach with Gaussian kernel is presented on the example of electric field distribution in the vicinity of six molecule water cluster. The paper ends with concluding remarks. All calculation were performed using HP ProBook 430 G2 laptop equipped with i5 Intel processor and 8GB RAM, running Windows 8.1/64bit OS and POV-Ray 3.7.0, (msvc10.win64 build) as a raytracer. ScPovplot3D toolkit [21] described in [1, 2, 3] is a set of procedures organized in several modules devoted to specific task, written in domain specific language SDL of POV-Ray [27]. Source code of presented examples and supplementary gallery of images are available at [28] for reference and detailed analysis.

II. INVERTED HISTOGRAM APPROACH

For the needs of the study, simulated data from mixed distribution based on two Gaussian distributions were prepared, marked in (1) with the symbols $g_1(x: \mu_1, \sigma_1)$ and $g_1(x: \mu_2, \sigma_2)$, mixed in ratio 1:2 (see: Tab. I). The theoretical shape of the probability density function resulting from (1) is shown in Fig. 1. Two maxima of the distribution are clearly visible. Such a situation can occur in many fields of science and technology. In biological sciences, it may mean that in the studied population there is, for example, sexual dimorphism (body mass, size), there are two (or more) varieties of a given species, or the examined trait may be differentiated, for example due to environmental pollution. The latter may take place in the case of environmental pollution (heavy metals, pesticides,

BPA bisphenols) that accumulate in the body in such a way that living organisms in subsequent calendar years or in subsequent emission cycles (fertilization, heating cycles, plant protection), absorb similar doses, depending only on the individual nutritional characteristics of the subject due to, for example, sex or age. In this way, maxima, correlating with age should be visible in the population under research [1].

In the field of technical sciences, the way of constructing experiments as well as the nature of the designed production lines indicate the unimodality of the statistical distributions. The appearance of a multimodal distribution usually means a failure or an unusual situation. In some cases, however, this may suggest a manifestation of an unknown phenomenon. Economic sciences are an even more sensitive area of research as distributions with elevated values of standard deviation are common. In this case, improper assessment of statistical material has not only a negative impact on the understanding of phenomena, but can also translate into wrong decisions resulting in the weakening of the position of companies or social groups.

A. Classic histogram

A random sample of 31 numbers was drawn from the mixture distribution (1), where $f(x;\ \mu_1, \mu_2, \sigma_1, \sigma_2)$ denotes mixture probability density function and $g_1(x;\ \mu_1, \sigma_1)$, $g_2(x;\ \mu_2, \sigma_2)$ are mixture components, here Gaussian probability density functions. Mixture weights w_i along with means μ_i and standard deviations σ_i and are listed in Tab. I. The size of the sample was chosen so as to be able to test the effectiveness of different visualization methods for a small number of measurements with outliers.

$$f(x;\ \mu_1, \mu_2, \sigma_1, \sigma_2) = w_1 \cdot g_1(x;\ \mu_1, \sigma_1) + w_2 \cdot g_2(x;\ \mu_2, \sigma_2) \quad (1)$$

As one can see, the histogram from Fig. 2 does not reveal the bimodality of the data. Probably the reason for this are measurements distant from the average value, usually considered outliers as well as a small number of counts per class interval or improperly selected number of histogram bins.

Computing and drawing many histograms with different numbers, or different widths of class intervals, due to the lack of sufficient theoretical background, as well due to practical reasons is not a rational solution.

The problem of the optimal number of class intervals or the optimal width of the class interval was tried in many ways. The general rules for determining the number or width of class intervals can be found in the literature. However, all of them are sensitive to outliers and ill conditioned data. In research practice, the final adoption of

TABLE I. PARAMETERS OF DISTRIBUTIONS USED TO GENERATE DATA FOR ANALYSIS

i	σ_i	μ_i	w_i
1	15	80	$1/3$
2	20	130	$2/3$

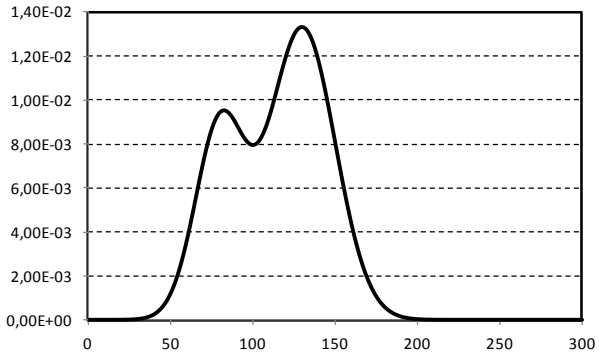

Figure 1. The probability density function calculated using data from Tab. I. Source: own, based on [3].

one of the considered histograms most often results from experience, expert knowledge and knowledge of the specifics of the subject under study, consequently being subjective. Meanwhile, the method of data visualization should have the value of objectivity.

B. KDE, Kernel density estimation

One of the ways to overcome the above-mentioned difficulties is the method known in the literature as the kernel density estimation [3, 13, 14, 19, 21, 22, 25]. This method allows to generate a smooth probability density distribution function (as opposed to a histogram which is stair function) based on the general formula (2):

$$\hat{f}_h(x) = \frac{1}{N\,h}\sum_1^N K\left(\frac{x - x_i}{h}\right) \quad (2)$$

where the positive h parameter determines smoothing and is referred to as "bandwidth" whereas the function $K(x)$ is referred to as the kernel. Unfortunately, the function estimated in this way strongly depends on the assumed value of bandwidth parameter h. Also in this case there is a general rule that suggests the best value for the bandwidth parameter. For the analyzed sample, the suggested value of the bandwidth h is approximately 29.9, which does not give satisfactory results. In order to assess

TABLE II. TEST DATA USED IN THE ARTICLE. SOURCE: [3], REWORKED.

N	**x**	**N**	**x**	**N**	**x**	**N**	**x**
1	5.0	9	85.2	17	124.2	25	138.6
2	15.0	10	85.9	18	126.9	26	139.8
3	37.0	11	102.9	19	127.3	27	145.4
4	41.5	12	105.7	20	128.9	28	148.2
5	59.5	13	106.8	21	130.4	29	201.0
6	64.8	14	115.3	22	132.2	30	230.0
7	66.4	15	115.7	23	135.9	31	277.0
8	74.3	16	124.0	24	137.0		

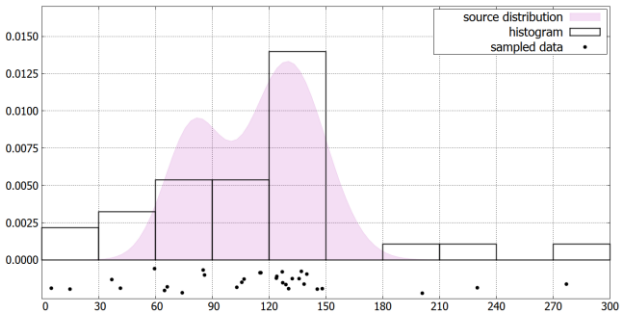

Figure 2. Histogram generated in gnuplot [22], superimposed are source distribution and sampled data. Source: own, [3].

influence of the value of parameter h on the shape of the resulting distribution estimate, it is enough to create several graphs for different values (Fig. 3).

In order to resolve this ambiguity, the novel method, named provisionally "inverted histogram method" is proposed.

C. *Inverted histogram method*

For the above mentioned reasons, the search for a method of visualization of distribution of sampled data which would be insensitive for improperly selected parameters and at the same time simple enough to be implemented in a spreadsheet of general application was started.

The basic premise in this case is the observation that in the sample drawn from the population the values of the examined feature (body weight, bone length, etc.) are centered around the maxima of probability density function, which in particular favors the fact that, on average, the distances between the individual observations are in surroundings of the maxima smaller. So, if one puts them in the nominative, one gets the maxima more or less where there are actual maxima of the probability density function.

The proposed method of the inverted histogram is thus expressed in a few steps:

1) The sample obtained from observation or experiment is sorted in ascending order to obtain series x_i, where: $i = 1, \ldots, N$ (X variable),

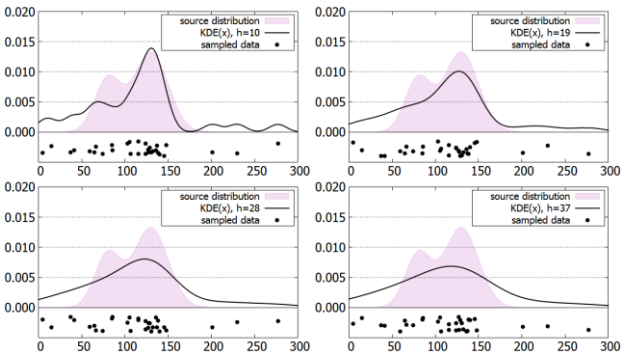

Figure 3. Comparison of the shape of the estimated probability density function obtained at four different values of parameter $h \in \{10, 19, 28, 37\}$. The result closest to the original distribution was obtained for $h \cong 10$. The result obtained at the recommended $h = 29.9$ bandwith value does not indicate a bimodal distribution, with higher values a skewed mono-modal distribution is generated. Source: own, [3].

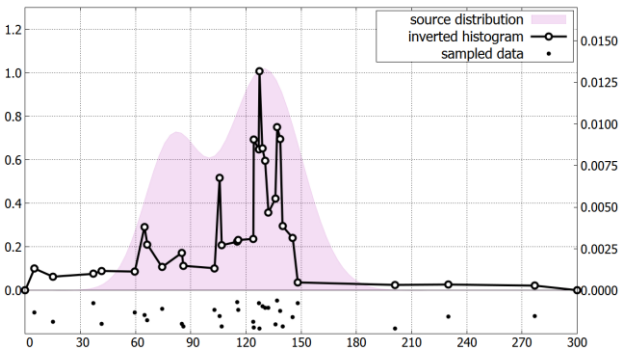

Figure 4. Example of inverted histogram. Straight line cut-offs connects points visually only. Rank *k*=1. The chart suggest multimodality of experimental data. Source: own, [3].

2) Y_i values are computed using the formula (3) (Y variable), where parameter *k* is a rank of the method.

$$y_i = \begin{cases} \frac{1}{y_2 - y_1} & , i = 1 \\ \frac{2k-1}{y_{i+k} - y_{i-k}} & , i = k+1, \ldots N-k,\ k \geq 1 \\ \frac{1}{y_N - y_{N-1}} & , i = N \end{cases} \quad (3)$$

3) The X and Y variables form the input data for the Y(X) dot plot. The result of this procedure for the data from Tab. II for rank k=1, is shown in Fig. 4.

It must be stressed that Y variable is not related directly to the probability density function. In particular, PDF is dimensionless while Y is expressed in [m^{-1}] units.

It can be said that the method fulfilled the task set, because it allowed to hypothesize the multimodality of the studied population. The validity of such a hypothesis must be confirmed by statistical methods designed for this purpose, such as, for example, cluster analysis. At the same time, it should be noted that isolated distant observations do not have any negative impact on the conducted analysis as well as the appearance of the obtained graphs, which results directly from the mathematical structure of the presented method.

III. ESTIMATION OF SURFACE DATA (KRIGING)

In many research areas spatial data are in the form of the function $z = f(x, y)$. Usually, the best way to visualize this type of data is to present them using 3D surfaces.

However, visualization of data from field studies, though not only, is often difficult due to the inability to collect data on a regularly distributed, rectangular measurement grid. For example, accurate altitude data for geospatial visualizations are obtained from planned measurements using LIDAR. Sometimes, however, there is no precise data for the given area, there is no time to acquire them or they are paid, so one needs to use approximate data over irregular grid. However, the majority of popular programs for data analysis, even professional ones, for the preparation of graphs of data in the form of a surface graph of functions $z = f(x, y)$ require data in form of rectangular grid measured over a rectangular area. Few programs have a built-in system for regularization of irregularly distributed data. One example is Origin™ [24], which also allows you

Figure 5. Path used to collect geospatial data. Approximated area is 110 km2. Source: own.

Figure 6. Geospatial visualization of Karlobag - Kubus Ura area using ScPovPlot3D library. Smoothing constant h=4. Vertical scale exaggerated. Total computation time: 97s. Source: own.

to choose one of several available approximation methods, e.g. Renka-Cline, Shepard, Thin Plate Spline, Kriging correlation or Weighted Average. The other is free application "gnuplot", which has built-in algorithm colloquially named "3d gridding" data, based amongst others on Kernel Density Estimation function (kernels: Gaussian, Cauchy, Han, cubic splines, etc.). However, neither gnuplot nor Origin can overlay the required texture on the obtained surface shape function, which is useful, inter alia, in geophysical or geospatial visualizations.

For testing purposes, an attempt was made to make own implementation of algorithm based on equation (4) with texturizing, using generally available free tools for required gridding and rendering. In general, on the computation level, kriging may be considered a weighted sum of N scalar values V_i measured in sampled points $\vec{r}_i$ (4) over sampling area (or volume) with data driven weights w_i (Gaussian in this paper),

$$\hat{f}_h(\vec{r}) = \frac{\sum_1^N w_i\left(\frac{|\vec{r}-\vec{r}_i|}{h}\right) V_i(\vec{r}_i)}{\sum_1^N w_i\left(\frac{|\vec{r}-\vec{r}_i|}{h}\right)} \qquad (4)$$

where constant h scales influence of distant points. In fact more formal definitions are used [29].

In the numerical experiments, data obtained using the GoogleEarthPro program (free software [23]) and a specially written template in SDL language for POV-Ray program were used. The area from Karlobag to the Kubus Ura pass (Croatia) was chosen as the test area. Geospatial data [28] were acquired in the GoogleEarthPro program in the form of a "*.kml" file as a data of the measurement path (Fig. 5). Files in KML format requires conversion into the ASCII format [25] in which each point corresponds to one line according to pattern [*latitude*, *longitude*, *altitude*]. The terrain texture was also obtained using the GoogleEarthPro program. Approximated values at nodes of the computational grid were computed in the POV-Ray program using the *RawDataSurface*() function of the *BPatchSurf.inc* module of *ScPovPlot3D* templates using the Gaussian KDE kernel for weights (4). Based on meshed data, final surface was evaluated using Bezier patches. Relevant source code is available [28]. The results obtained are shown in Fig. 6 - they are very similar to the rendering presented on GoogleEarthPro maps, despite the relatively small (2348) number of measurement points per area of approximately 110km^2. This is due to the fact that geospatial data does not show fast variability, so sampling can be relatively low in terms of Nyquist frequency [18]. Moreover, for the given area and established network of measurements points, fitting parameters once estimated may be reused, thus allowing for precise comparison and resulting monitoring of terrain for subtle changes.

Samples can be obtained using other methods, for example from a network of remote GPS sensors attached to the ground and connected on-line, which enables continuous monitoring of the profile of the selected area, what is particularly important around large structures (e.g. bridges, highways, harbors, LNG hubs) in seismically active areas e.g. near the faults. The knowledge about dynamics of the rock mass obtained in this way may help to assess the risk of a stronger or weaker earthquake in next few weeks. Other scenario is assessment of terrain changes following natural disasters (landslides, floods) using drones equipped with precise GPS based elevation sensors.

IV. 3D Field approximation

Simple 2D algorithm (4) may be easily extended for 3D fields, however visualization step is not so simple as previously, because requires volume rendering, which in turn may be implemented in many ways, e.g. using cloud of points, marching cubes or isosurfaces, with or without additional information layers overlaid. As a test example, an interesting case of the electric field potential around the cluster composed of 6 water molecules 0 was selected. The area around the cluster contains both slow-changing areas (small gradients) and very high variability (very high gradients). This allows the evaluation of dependence of the approximation accuracy in the context of the relation between the sampling density and the accuracy of surface mapping as well as computational complexity.

A. Algorithm and accuracy

Proposed computational algorithm consists of three stages. Firstly a number, here $N_S = 15000$, sample points are drawn using flattened spherical triangle distribution (5), where $Tri(0.0, 1.0, 0.6)$ means asymmetric triangular distribution on interval $[0;\ 1]$ with modal value $c = 0.6$; in every point electric potential value is calculated and assigned. In the second step, by means of KDE approximation with the use of the Gaussian kernel, the values of electric potential in the nodes of the cuboid computational grid are calculated. In the final step, the

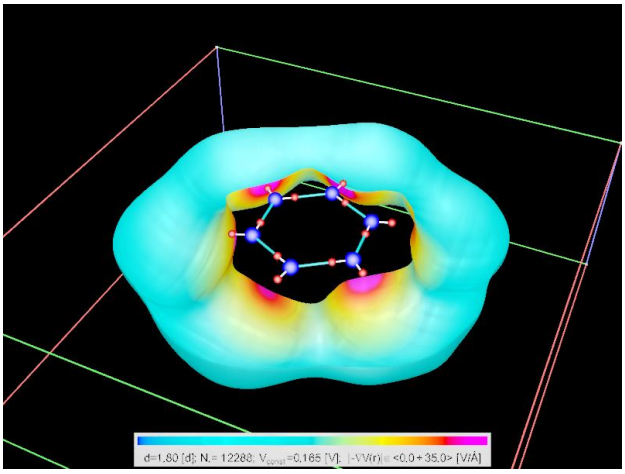

Figure 7. Equipotential surface computed using 3D KDE approximation and Catmull-Rom piecewise interpolation over 9000 cells. Network of 15000 sample points was used. Total computation time: 0h 46m 38s. Source: own.

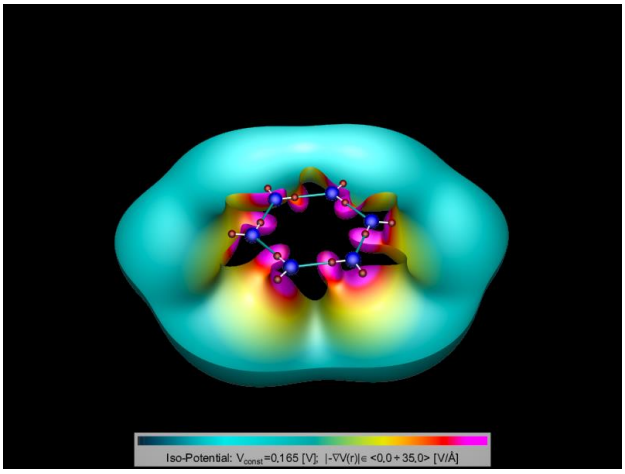

Figure 8. Equipotential surface computed using direct approach. Total computation time: 0h 28m 48s. Source: own.

shape of the equipotential surface is calculated using Catmull-Rom tricubic interpolation and then rendered.

$$P(\varphi,\theta,\rho) = \begin{cases} \varphi = rand(), & x = \rho\cos(\theta)\cos(\varphi) \\ \theta = rand(), & y = \rho\cos(\theta)\sin(\varphi) \\ \rho = Tri(0,1,0.6), & z = 0.3\,\rho\sin(\theta) \end{cases} \quad (5)$$

The obtained exemplary calculation result is shown in Fig. 7, while in the Fig. 8 the equipotential surface calculated by the direct method is shown for comparison. Visual comparison suggest that the approximate method gives comparable results in the low gradient area ($|-\vec{\nabla}V(\vec{r})| \in [0;17(V/\text{Å}]$), but it fails heavily in the areas of fast field variation $|-\vec{\nabla}V(\vec{r})| \in [0;17(V/\text{Å}]$. It can be assumed that this is directly related rather to the number of samples per unit of the field gradient, not elementary cell size. If so, in order to maintain the accuracy of calculations, a larger number of samples should be drawn, measured or computed in the area with a larger gradient, which means the need to develop a self-adaptive sampling algorithm.

B. *Computational complexity*

In discussed algorithm total computation time consists mainly from three components: data sampling or reading (t_S), computation of nodal values on the grid (t_G) and finally rendering (t_R).

The first one clearly depends only on the size of sample N_S, thus $t_S(N_S) = O(N_S)$. This is illustrated on the Fig.9. The computation time of the render stage depends heavily on rendering quality settings, and complexity of rendered scene. Thus, in tests, where quality settings were fixed at lowest possible level, it should be expected constant. In fact an asymptotic dependency, shown in Fig.11, was observed, which may be expressed by equation (6),

$$t_R(N_S) = A\left(1 - e^{-\frac{N_S}{B}}\right), \quad (6)$$

where N_S is a sample size and coefficients A (A=60.3±5) and B (B=9333±300) were fitted to experimental data using gnuplot. The reason for that is simple. For smaller sample size, surface generated by algorithm is rough which in turn shorten computation time. If sample size N_S is big enough, complexity of generated surface does not change any more, thus rendering time remains constant. Thus asymptotically $t_R(N_S) = O(C)$.

At the present, the second stage, gridding, is the most time consuming as it takes more than 95% of total computation time which in turn is twice as long as direct approach [7]. In gridding algorithm, approximated value $\hat{f}_h(\vec{r}_k)$ must be computed at every node of the grid N_G, using formula (4). Thus, function computing relevant additives is called $N_S \cdot N_G$ times. This suggest, that for the fixed grid size, computation time should scale linearly with sample size $-t_G = O(N_S \cdot N_G)$. As is shown in Fig.10, this is the case. However, k-times reduction of cell size, results in k^3 increase of N_G and then gridding time.

This defect can be removed using external program written in C, massive parallelization, some enhancements to the algorithm and/or caching of intermediate results.

V. CONCLUSIONS

Visualization of irregular data has many important applications, thus requires further in-depths analysis. A number of issues remain to be solved, such as improving the speed of operation, developing a method of assessing the accuracy of approximation, with particular emphasis on marking places with an excessive error.

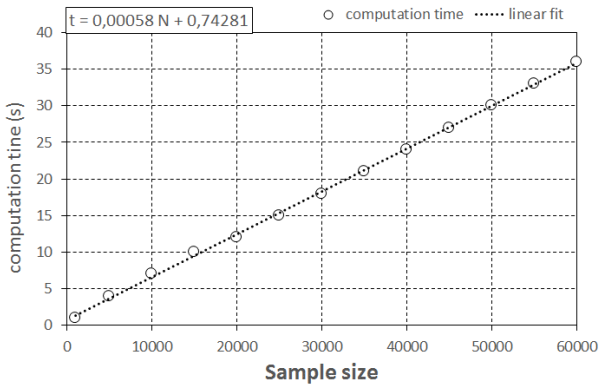

Figure 9. Sampling time t_S vs. sample size N_S. Source: own.

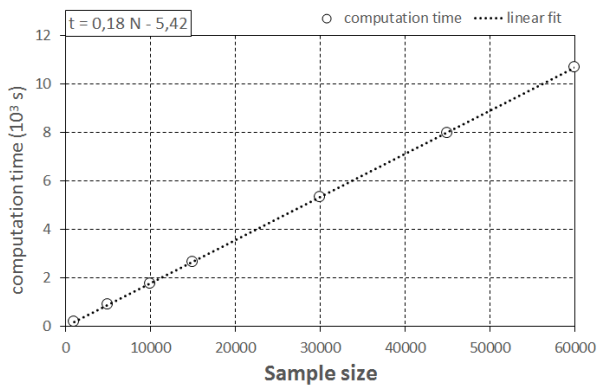

Figure 10. Gridding time t_G vs. sample size N_S. Source: own.

For one dimensional data the reverse histogram method seems to be promising, however, it requires further work. In particular, the influence of the order of the method *k* on the reliability of results should be considered.

Z(x,y) data approximation, in particular geospatial, with natural texture mapping may be successfully performed using KDE with Gaussian kernel but other kernels should be tested as well. Quality and efficiency of algorithm may still be improved as well as error assessment.

Kriging-like algorithms may be successfully used for visualization of general 3D data, not only for geospatial, however in the presence of enormously high gradients, common for molecular electric fields, very dense sampling is required what makes method impractical, because sample size badly influences overall computation time. Thus, this method is limited to low gradient cases.

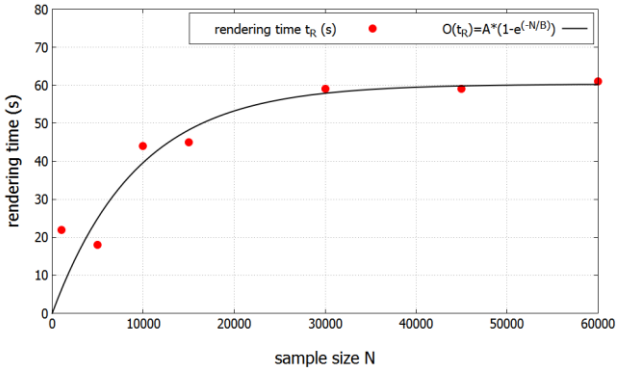

Figure 11. Render time t_R vs. sample size N_S. Fitted values of parameters A and B were 60.3(±5) and 9333(±300) respectively. Source: own.

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Automatic Focusing of Optical Microscope Using Off-the-Shelf Hardware Components and In House Software

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Abstract **Optical microscope is one of the most important instruments in medical diagnostic. It is also one which requires high mental concentration and eye strain for extended periods of time. To make a microscope into real high throughput instrument, as much as possible routine work has to be shifted to the computer. Some commercial systems exists, but for a premium price. The system developed here is proof of concept that the required performance can be achieved with the reduction in cost for two orders of magnitude.**

Two computer systems were used: Desktop PC for data collection and analysis and indirect hardware control through the communications with a Raspberry Pi computer which controlled the step motors.

Our first effort was directed toward focusing of the microscope (Z-axis control). In plane control (X & Y-axis) is conceptually much simpler. The focal point was found using Haar transform with inter and intra application of the least squares.

The real life examples were taken from medical imaging of stained human cells as they are used in medical pathology.

Key words: optical microscopy; image processing; focusing

I. INTRODUCTION

The importance of microscopy for medical diagnostics can not be overstated [1]. The multitudes of microscopy methods span the range from tissue studies to molecular level information [2].

The complexity of instrumentation and ever increasing pressure to collect more data, as well as requirement for highly qualified operator presents an interesting challenge for automation of microscopic procedures. Physical work at microscope is exhausting because of eye strain and high mental concentration. The instruments and additional equipment developed with idea to alleviate some of the problems are selling for premium price.

The main goal in our work presented here was to build automated data collection microscope using of the shelf hardware components and in house software. The primary focus of our work here is to automatically focus the microscope.

II. THEORY

To find the focal plane of a microscope we have to understand what distinguishes the focal plane image from the rest of the image stack. It is somehow obvious that focal plane image should be the most sharp and clear one from image stack collected at different values of vertical axis. However, the criteria of sharp and clear have to be quantized in order to be useful for automation. It is easy to conceptually extend requirements of sharp and clear to frequency space and consider the use of the Fourier transform in order to find the focal plane. However, the information we are looking for is in high frequencies and exponential distribution of power in the Fourier transform leads to comparison of small numbers to determine focus. This could be a problem because the edge effects can affect the high frequencies. In order to avoid some of the problems we used the simplest wavelet transform, the Haar transform. The one dimensional Haar basis functions can be understood as a first numerical derivative taken at various level of resolution. The numerical derivative for high sequencies should be higher value for in focus image then for smeared, out of focus one. It turns out that the idea works very well and it is extremely fast due to simplicity of the Haar transform as shown in equation (1) and (2).

Wavelet mother function $\psi(t)$

$$\psi(t)=\begin{cases} 1 & 0\le t<\frac{1}{2} \\ -1 & \frac{1}{2}\le t<1 \\ 0 & otherwise \end{cases} \qquad (1)$$

Scaling function $\varphi(t)$

$$\varphi(t)=\begin{cases} 1 & 0\le t<1 \\ 0 & otherwise \end{cases} \qquad (2)$$

Figure 1. Optical microscope with attached hardware

III. Results and Discussion

One of the goals in this proof of concept project was to see how much the cost of a system can be reduced from commercial one and still keep its basis functionality. Off the shelf hardware components were basic personal computer (PC) with four+ processor cores, 4+G of memory, Raspberry Pi 3 Model B, two step motors with controller board and simple USB camera. Total hardware cost without microscope was around US$250.

The microscope itself was not changed mechanically except by removing handles on focusing screws and connecting the screws with motors using some custom machining parts. Fig. 1. shows the setup.

The data set typically consist of stack of 50 to hundred images. The processing is done on PC and in all cases the computing the sum of absolute values in highest sequency was enough to determine image in focal plane.

In this version of the project we did not scan the samples in horizontal plane. Such a scan can be done systematically along the grid once the focal plane is determined and does not represent any challenge except the size of data set.

From the image stack collected along the vertical axis of the microscope, consisting of 105 images we are showing only three here: The image bellow the focal plane as Fig. 2, the image in focal plane as Fig. 3, and the image above the focal plane as Fig. 4. The difference in the sharpness of the image is obvious even by simple visual inspection, but it can also be computed and quantified.

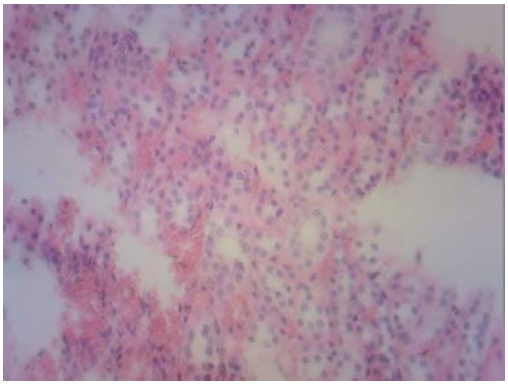

Figure 2. Image collected immediatelly bellow the focal plane

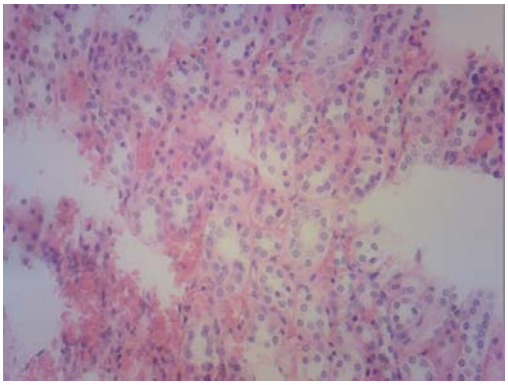

Figure 3. Image collected in the focal plane

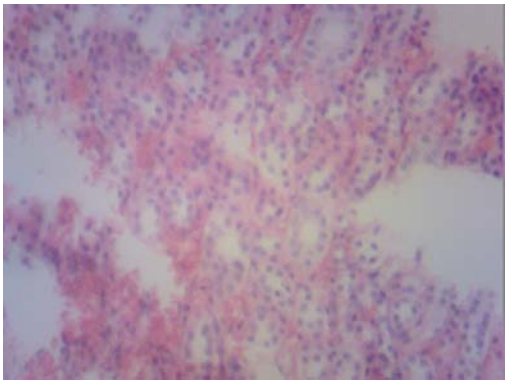

Figure 4. Image collected immediately above the focal plane

The summary data for the whole stack are shown in Fig. 5. The x-axis is index of the image from bottom up, the y-axis is computed from Haar transform of the image as described previously (called ”Haar sum“ here). The discrimination between out of focus and in focus images is very good. The peak in the graph is narrow and well defined. There are no multiple maxima in the graph.

The data set is coming from biomedical application which is of interest to local medical community while the

newer examples in literature are more oriented toward mechanical applications [3],[4].

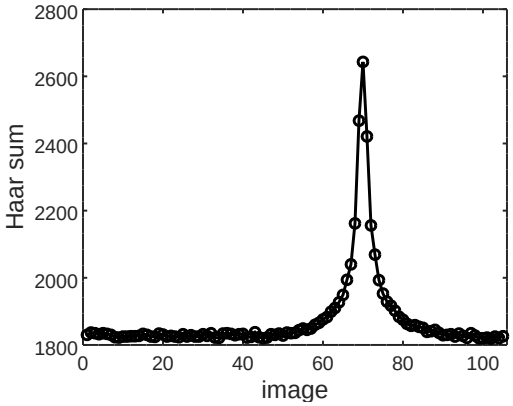

Figure 5. Sum of absolute values in highest Haar sequency for all images in the stack. Focal plane image is #70

IV. CONCLUSION

The goal of constructing simple and inexpensive system for automating the data collection from optical microscope using off the shelf components has been successfully demonstrated. The price tag for proof of the concept system was about US$250, not counting the PC and the software development. Our system solves the most complex task in data collection: the focusing of microscope which was achieved through innovative use of Haar transform.

LITERATURE

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Parallel Matrix Multiplication

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***Abstract*—Utilizing all CPU cores available for numerical computations is a topic of considerable interest in HPC. This paper analyzes and compares four different parallel algorithms for matrix multiplication without block partitioning using OpenMP. The comparison of the algorithms is based on the achieved speed, memory bandwidth and efficient use of the cache of the algorithms.**

***Index Terms*—algorithm, cache, memory bandwidth, speed, OpenMP, thread, loop order, matrix multiplication, transpose**

I. Introduction

The simplest and most common implementation of a serial matrix multiplication is an algorithm in which each row of the first matrix, one after another, is multiplied with each column of the second matrix. The complexity of matrix multiplication is $O(n^3)$, but what worries more is the inefficient cache usage which leads to low memory bandwidth and long execution time, especially when multiplying large matrices. In this case the execution time can last more than couple of hours. By enlarging the matrix dimensions, the execution time is becoming considerably longer, hence the bandwidth is becoming lower, as presented on Fig. 1.

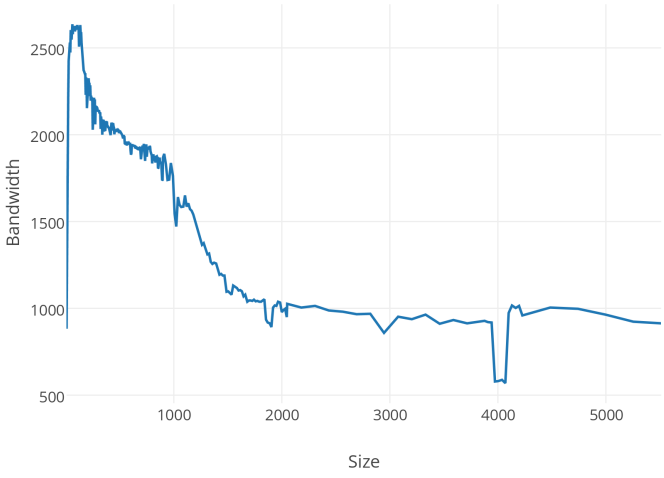

Fig. 1. Serial execution of the matrix multiplication algorithm

In this paper, we present four methods to parallelize the matrix multiplication:

- Row First (RF) parallelization,
- Column First (CF) parallelization,
- Row by Row (RR) multiplication, and
- Matrix Transposing first (MT) approach.

The RF parallelization method is a classical approach of the parallel matrix multiplication problem. It basically does the traditional matrix multiplication, but multiplying more rows from the first matrix at the same time, with every column from the second matrix.

CF parallelization is a similar concept, but instead works by multiplying more columns from the second matrix in parallel, with each row from the first matrix.

RR multiplication is a way of multiplication which does not use columns. It rather multiplies more rows from one matrix in parallel, with every row from the other matrix and updates the product matrix with the temporary results obtained from each multiplication.

The MT approach works by transposing the second matrix prior to multiplication, and then multiplies more rows from one matrix in parallel, with each row from the second matrix.

Our research task is to find the best OpenMP parallel technique for modern multicore processors with several CPU cores per chip using a shared memory architecture. The experiments include testing configurations with different sizes of threads, even hyper threading cases.

The paper follows the next structure organization. Related work is discussed in Section II. Section III describes the used parallelization approaches and their implementation issues. The testing methodology is specified in Section IV and results in Section V. Detailed explanation and evaluation are discussed in Section VI. Finally, Section VII concludes the paper and gives future work directions.

II. Related work

Golub and Van Loan [1] give a comprehensive overview of matrix algorithms and their parallelization. Optimal parallel matrix multiplication has been analyzed a lot, and optimized library LAPACK [2] and their successors have been developed. Shatz et al. [3] present a systematic overview of parallel matrix multiplication, analyzing the grid dimensions, process location, distribution, and process communication.

Lately, several authors have experimented with wide range of matrix multiplication techniques, including the ones presented in this paper. They came to similar conclusions and got similar results. Ristov et al. [4] experimented with different sizes of the matrices and were measuring the performances of the CPU. The results led to a conclusion that the CPU achieves best performance when the matrices can be fit in L1 cache (or using blocks that can be fit in the L1 cache, if blocking matrix

multiplication algorithm is used) which is also concluded in this paper as well.

Anchev et al. [5] gave an overview of a huge number of techniques for matrix multiplication. Some of the conclusions that are related to this paper are using parallel implementations increases the performance and the speedup. Also they were testing some optimizations according to memory resources and concluded that matrix transposing and optimizing the cache usage leads to great speedup and performance increase.

Anath et al. of [6] experimented with various optimizations of the matrix multiplication algorithm. They start with the naive matrix multiplication algorithm and optimize it with intention to get better performance. Among the various optimizations of the naive RF approach, CF and RR are used and tested. The results of the measurements are the same as in this paper. CF is performing better than RF, but RR is far superior approach among these 3 approaches, especially when the matrix dimensions exceed 1000, while RF and CF slow down remarkably. They state that this is the direct result of cache optimization. They emphasize the importance of the way data is stored and accessed in a matrix multiplication task, especially when large matrices are used.

Anchev et al. [7] compare AMD's and Intel's performance and speedup of matrix multiplication algorithms, the experiments executed with i7 processor gave the same results about the speedup as in this paper, that is, the speedup as a function of matrix size for each parallel execution complies with the Gustafson's Law for Intel i7. It is greater for greater matrix size and saturates towards linear speedup.

III. Parallel approaches

As the new CPU trends tend to increase the number of cores rather than the operating frequency of the processor, it is a good practice to parallelize our algorithms to reach the full potential of the CPU. In this section, we explain some parallel methods that solve the problem of matrix multiplication that will hopefully enhance the performances achieved with the serial algorithm.

A. Row First (RF) parallelization approach

The simplest way of parallelizing the matrix multiplication algorithm, thereby improving the memory bandwidth and operational speed is multiplying more rows from the first matrix in parallel with every column from the second matrix independently. This can be achieved in a way that the first matrix will be divided on as many parts as there are threads available, and each thread will work with those rows that are assigned to it.

This approach would be most efficient if each thread executes the same amount of operations as the other threads, or in this case each thread has the same number of rows to work with as the others. For that purpose, instead of mathematical division of the first matrix with the number of threads, and then distributing the remaining rows equally between the threads, aiming for each thread to be given the same number of rows, it is better to distribute the rows based on the thread's ID, that is, each thread will work with every row that satisfies the condition the remainder of the row's number divided with the number of threads to be equal to the number of the thread, the thread's ID. With this approach, depending on the number of threads that are used, which depends on the processor used, there are major improvements over the serial implementation.

Our research task will be test the impact of number of physical cores and number of specified threads on the performance of the applied approach.

B. Column First (CF) parallelization approach

The RF parallelization approach is not suitable for big matrices, or matrices with dimensions larger than 4000. However, there is a room for improvement even for small matrices, because the cache utilization is very bad in the first approach. Changing the algorithm in a way that more columns from the second matrix are being multiplied in parallel with every row in the first matrix rather than vice versa, proved to be improved and more efficient algorithm.

The CF parallelization is an implementation of a loop ordering approach for the matrix multiplication.

C. Row by Row (RR) matrix multiplication

In order to increase the cache efficiency we can conclude that multiplication with columns should be avoided, and in order to achieve that, the loops should be ordered again so that the rows from the first matrix will be multiplied with the rows from the second matrix and the result is still correct.

In the RR matrix multiplication approach, more rows from the first matrix, are being multiplied with every row from the second matrix. The product matrix fields are firstly initialized to 0. With each multiplication of two elements, the result obtained is added to the number on the proper product matrix field, and the product matrix gets updated. This may seem like a small change, but it has major performance improvements and significantly increases the operational bandwidth.

The RR parallelization approach is also an implementation of a loop ordering approach.

D. Matrix Transpose first (MT) approach

The RR algorithm would have been excellent if it didn't require memory access for each iteration of the *for* loops. The best way to address this problem, and therefore increase the memory bandwidth and operational speed, by applying the row by row multiply approach to perform fast for both the small and big matrices, is to transpose the second matrix first, and then multiply more rows in parallel from the first matrix with every row from the second matrix.

This can be implemented vice versa as well, because when rows are multiplied by rows the loop ordering is irrelevant. The transposing of the second matrix allows huge reusability of the rows stored into the cache. Each element stored is used and no element is ever going to be stored for no reason. The temporary results are written into a thread's local variable thus the memory accesses are minimized.

IV. Experimental setup

The experiments were performed with a computer using the Intel I7-6700HQ processor, with 4 cores with 2 hyper-threading threads, a total of 8 threads. Each core has L1 data and instruction cache memory of 32KB, which is 8-way set associative, 256KB of L2 cache memory, 4-way set associative, and all cores share a 12-way set associative 6MB L3 cache memory. The line size is 64 bytes for all levels, and the first and the second level are direct-mapped. The system used has 16GB of RAM. The compiler used is was GCC 6.2, and the programs were compiled using the -O0 flag.

The experiments were made with square matrices for simplicity. A lot of different dimensions were used. To be precise, the algorithms were tested for each dimension up to 1024. Then, the dimensions were incremented by 8 up to 2048. After that, the execution times became considerably longer, so the dimensions were incremented for 32 for each testing. In addition, these particular dimensions were chosen to expose the effect of the cache associativity problem for power of two dimensions.

This cache thrashing will occur only for matrices that can't fit into the first two levels of the cache memory, because those two levels are direct-mapped and bypass the problem. Enlarging or contracting a power of two dimensions will result in a a lot different cache use pattern. That's why few successors and predecessors of each 32nd value were tested also, for padding and more realistic graphical representation.

The system's RAM was large enough to store both matrices regardless of their sizes. So there were no disk accesses. Only the multiplication part was measured (and the transposing in the appropriate algorithm).

The algorithms will be tested in two ways, using less or all the physical threads of the processor, and using hyper-threads. We can expect that using physical threads will be faster than the serial execution proportionally to the number of threads used. Using a large number of logical threads, will probably have some small benefits for large matrices, but will still behave as using all the physical threads of the CPU. The processor used for the experiments specifically has hyper-threading technology, so using all hyper-threads will possibly lead to some performance gains as well, over only using the physical cores.

Since the test bed uses 8 hyper threads, the test cases include serial implementation, and implementations with 2, 4, and 8 threads.

For each test run we measure the execution time T of the matrix multiplication part, without initialization and termination parts. For dimensions smaller than 1024, each test was executed 1001 times, up to 2048 - 101 times, and for larger matrix sizes - 11 times, and the average value of the results T_{avg} was used.

The memory bandwidth B represents the amount of data read or written by the hardware in a second. It is calculated as the total amount of operations over the execution time, according to (1), where N is the matrix size and there are a total of $2 * N * N * N + N * N$ memory accesses in the matrix multiplications. S is the size of the data type. Integer matrices are used in our experiments. Finally, the result is divided by 1024^3 to convert it to GB/s.

$$B = \frac{2 * S * N^3 + S * N^2}{T_{avg} * 1024^3} \tag{1}$$

The operational speed is calculated as the number of performed operations in a second, and in our experiments, the speed can be calculated as a ratio of the number of operations and the average processing time, as presented by (2). The total number of matrix multiplications is $2 * N * N * N$.

$$Speed = 2 * N^3 / T_{avg} \tag{2}$$

The speedup represents how faster one execution time is from another and compares a given approach with the default one. (3) explains how it is calculated, where the B_{test} is the bandwidth obtained on the tested approach and B_{def} the default solution.

$$S_p = \frac{B_{test}}{B_{def}} \tag{3}$$

Note that the operational speed $Speed$ is directly determined by the memory bandwidth B analyzing the time required to perform a pipelined operation and time to access a memory element. In addition, in cases of big matrix sizes, where $N >> 1$, the operational speedup is actually equal to the bandwidth speedup (3).

Since we experiment with four different parallelizing approach, we will compute four different speedup values S_{RF}, S_{CF}, S_{RR} and S_{MT}, correspondingly to the RF, CF, RR and MT parallel approaches when compared to the sequential solution.

There are two types of graphical representations, the first one being size versus bandwidth, and the second one presenting size versus speedup. The first type presents the size on the x-axis and the bandwidth on the y-axis, while the second presents the obtained speedup on the y-axis.

The bandwidth is measured in GB/sec, while the speedup presents the number how many times the analyzed solution is better than the sequential solution.

V. Results

This section will graphically present the results achieved for analyzed approaches. The results will be presented in terms of size versus bandwidth. The explanations of these charts are in the next section.

A. Row First (RF) parallelization approach

Fig. 2 presents the results of experiments with the *RF parallelization approach*.

One can conclude that significant improvements are achieved with the usage of more threads. The pictures show that the best performance is achieved when the number of threads is equal to the number of cores. Using less threads proportionally decreases the performance of the algorithm. Also, specifically for this processor, it is good practice to use

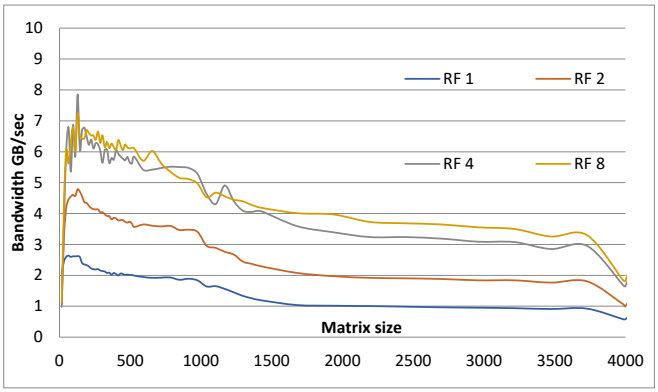

Fig. 2. Performance of the RF parallel matrix multiplication

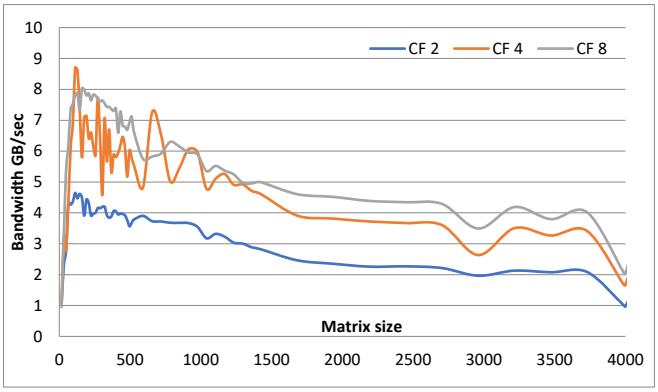

Fig. 3. Performance of the CF parallel matrix multiplication

all the hyper-threads, as they slightly improve performance even more.

B. Column First (CF) parallelization approach

The *CF parallelization* is a loop interchanging technique that improves the memory bandwidth and operational speed, as presented in Fig. 3. A comparison of the algorithms is given for executing with 2, 4 and 8 threads.

With the RF parallelization approach, when one row is being multiplied with every column, the row is initially stored in the cache. Since the C language implementation uses a row-major storage organization, a data transfer occurs with each multiplication of the row with the first column of the second matrix. This data transfer is from an upper cache level or the RAM memory to the first cache level. The data being transferred is the row from the second matrix which contains the element from the second matrix, that needs to be multiplied. If there is not enough space in the cache memory to store the whole second matrix in it, that means, the matrix cannot fit into the cache, the rows from the second matrix whose elements were already multiplied will be replaced with rows whose elements are yet to be multiplied.

When the second column has to be multiplied, the elements from the second matrix which are currently residing in the cache cannot be used because they are from the final and not from the first rows of the matrix. So again, for each multiplication there will be another data transfer. This will be the case with each row from the first matrix, so there is a data transfer for each operation of multiplication!

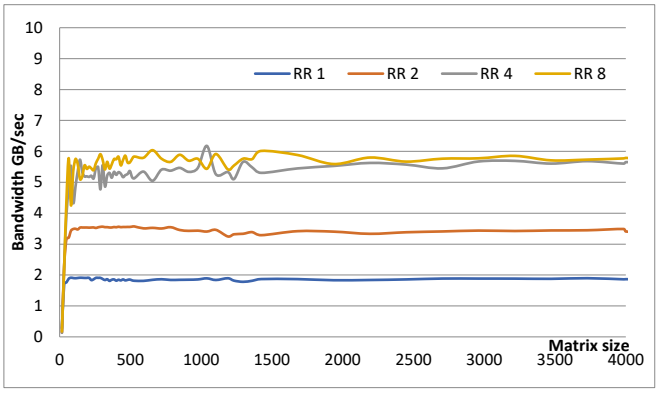

Fig. 4. Performances of the RR parallel matrix multiplication

In the CF parallelization approach, the row from the first matrix is stored in the cache once, and as many elements as the cache line can store can be used from it. However, for large matrices this will again be inefficient because the elements from the second matrix would have to rotate in the cache all the time, because it would be impossible to store the whole column into the cache. So, although this approach is an improvement from the first, it is still quite inefficient for big matrices, and the cache utilization is still not optimal, and because of the cache associativity there are still large drops in the performance for certain dimensions.

It can be concluded that even this is better approach than the first one, it still has inefficient cache utilization. It shows that high performance algorithms must avoid using of columns when multiplying matrices. Using columns causes cache thrashing, and its consequences can be seen on the pictures. This proves that only rows must be used, and gives the idea for the next approaches.

C. Row by Row (RR) multiplication approach

The results obtained with the *RR multiplication* approach as another loop interchanging technique are shown on Fig. 4.

The conducted experiments for this algorithm, lead to the conclusion that using only rows is a better approach. The graphs are completely different from the first two methods, mostly because the cache thrashing is eliminated. This means stable memory bandwidth regardless of the matrices size. Large matrices are not causing cache thrashing, because every element that is stored in the cache is used. This algorithm is more suitable for large matrices but gives poor performance for smaller ones, because the bandwidth does not vary too much.

D. Matrix Transpose (MT) first multiplication approach

Fig. 5 shows the superiority of the MT algorithm is superior in terms of speed and memory bandwidth.

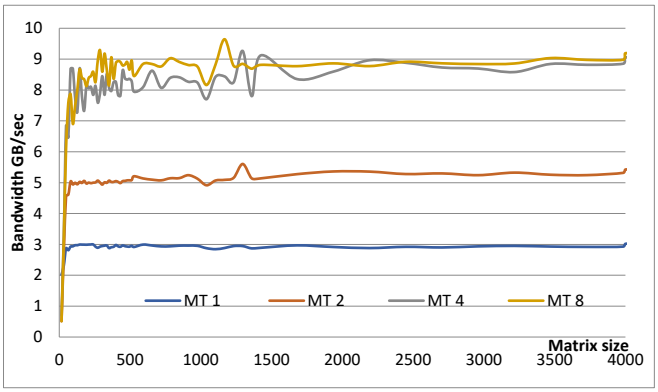

Fig. 5. Performance of the MT (Transpose then multiply) approach

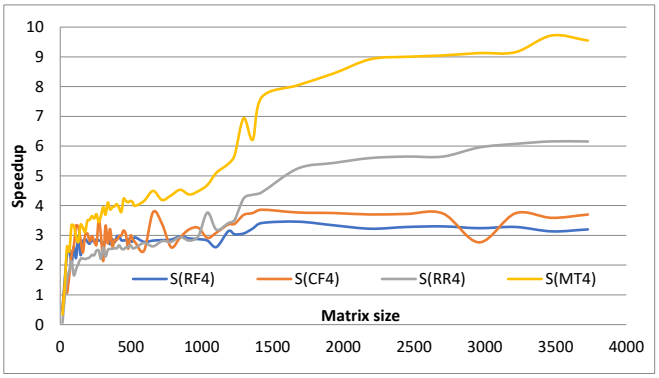

Fig. 6. Speedup comparison with 4 threads

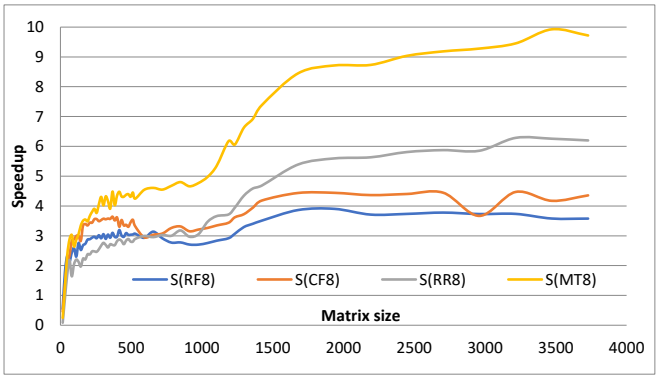

Fig. 7. Speedup comparison with 8 threads

It can be concluded that this is by far the best approach. This algorithm achieves stable performance for small and large matrices, and very high memory bandwidth. It eliminates the problem of cache thrashing from the RF and CF algorithms, and eliminates the writes in every loop iteration from the RR approach. Eliminating the first problem results in memory bandwidth that is not varying, and eliminating the second problem gives us higher memory bandwidth than the RR approach. So, the MT algorithm has both high and stable memory bandwidth.

VI. Discussion

In this section, we evaluate the results and give interpretations of performances and the explanation about behavior of a particular algorithm. Also, the algorithms are compared in terms of performance, especially with an analysis of the speedup charts on Fig. 6 and Fig. 7.

Observing the experimental results, one can conclude that the number of threads do impact the performance. This dependence is valid up to the number of physical cores and the use of hyper threading does not influence the performance a lot. The hyper threading approach shows only slight improvement for particular matrix sizes and there is no behavioral trend.

The processor used uses 4 cores with 2 hyper threads per core. The obtained speedup was linear to the number of threads up 4 threads, which is the number of physical cores, and the speedup for 8 threads achieved slight improvement compared to the usage of 4 threads. However, different behavior dependent on the matrix dimensions can be noticed. Using 4 threads is more suitable for multiplying small matrices, but for large matrices using 8 threads was advantageous. This happens due to the reuse of the cache. The whole content of the smaller matrices can fit in the L1 and L2 caches and is therefore setting advantage for using 4 threads, while in the case of large matrices, when blocks of matrices are transferred in the cache, it is more beneficial to use 8 threads due to re-use of the same blocks.

As demonstrated on Fig. 6 and Fig. 7, the best cache utilization, provided by the MT algorithm, led to the highest speedup in comparison to the simplest algorithm, the serial RF algorithm. The experiments suggest that the MT is the best algorithm, followed by RR, CF and RF. RR is only good for large matrices, but has lower speedup than RF and CF for smaller ones. RF and CF are behaving similarly and both provide low speedup, which is higher using the CF algorithm for a factor very close to 1 compared to RF. The graphs using 4 and 8 threads look similar, but the advantages of the hyper-threading technology can be seen on the later. The speedup gained with 8 threads may seem small, but for large matrices when the execution times are very long, low speedup of factor close to 1 can have big influence in reducing the execution time.

The experiments with using more threads than the CPU supports physically, suggest that using a lot of logical threads does not scale with the number of physical threads.

It can be seen on the pictures that the optimal number of threads is 8, although it depends if the CPU supports hyper-threading technology. Not using these hyper-threads, or using 4 threads does not decrease the performance a lot. So the optimal number of threads is equal to the number of cores the processor has, or the number of hyper-threads.

Various cache optimization approaches [8] can be used to mitigate the growing gap between CPU speed and memory bandwidth. The cache impacts the performance and needs to

be analyzed to ensure the algorithms work fast.

In this paper, we have neither analyzed algorithms based on block approaches nor compare to the LAPACK and BLAS algorithms [9], [10], since our goal was to present essential ideas and approaches that can be used by coders in developing efficient programs for problems that can not directly map existing subroutines. Although the experiments are provided on a small computer resources, still the conclusions derived can be efficiently used in HPC environment.

VII. Conclusion

In this paper, we analyzed four algorithms with their strengths and weaknesses.

Although the MT algorithm is the best and the most reasonable choice, the other algorithms can be considered depending on the programming language used, and the size of the matrix. The goal was to analyze and compare the performance of the algorithms in terms of memory bandwidth and the speedup they provide, with special consideration for the CPU architecture and the different number of threads used.

The first point of this paper was to prove that utilizing the CPU to its full potential has huge benefits in HPC applications, such as matrix multiplication. We explained how the performance of the algorithms varies when using different number of threads, and how using more physical cores leads to nearly linear speedup. However, it is also important to note that the performance of the algorithms using different number of threads also depends on the matrix size.

The second point was that utilizing the cache memory is a fundamental requirement in HPC computing. Improving the memory bandwidth leads to huge speedups, and in order to exploit this, high-performing matrix multiplication algorithms are obliged to minimize the usage of matrix columns when performing the multiplication. Eliminating the cache thrashing is a crucial approach in improving the cache efficiency, and the performance of the algorithms in general.

The last point was to emphasize the importance of the architecture of the used CPU, and its impact on the performance of the algorithms, especially the advantages that hyper-threading provides in terms of performance. As demonstrated, the hyper-threading technology leads to significant performance improvements when large matrices are multiplied. Good understanding of the system's CPUs architecture is a requirement for efficient cache usage and determining the optimal number of threads to be used, and thus creating high-performing algorithms.

A careful programmer may choose which algorithm to use depending on the situation, how many threads should be used, what are the benefits of the threads and the negative consequences that arise by creating more than enough threads.

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Explainable Artificial Intelligence: A Survey

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***Abstract* - In the last decade, with availability of large datasets and more computing power, machine learning systems have achieved (super)human performance in a wide variety of tasks. Examples of this rapid development can be seen in image recognition, speech analysis, strategic game planning and many more. The problem with many state-of-the-art models is a lack of transparency and interpretability. The lack of thereof is a major drawback in many applications, e.g. healthcare and finance, where rationale for model's decision is a requirement for trust. In the light of these issues, explainable artificial intelligence (XAI) has become an area of interest in research community. This paper summarizes recent developments in XAI in supervised learning, starts a discussion on its connection with artificial general intelligence, and gives proposals for further research directions.**

Keywords* - *explainable artificial intelligence; interpretability; explainability; comprehensibility

I. INTRODUCTION

In the last decade, especially since 2012, artificial intelligence (AI) and machine learning (ML) systems have achieved (super)human performance in many tasks that were previously thought to be computationally unattainable [1]. Advances in the field were achieved due to the rise of available information, and major hardware improvements combined with new optimization algorithms. We can also attribute these advancements to high-quality open-source libraries which allowed developers and researchers to quickly code and test models. Improvements in speech recognition, image classification, object detection, classical (board) games, Texas Hol'em, and many more have led to their proliferation and percolation to the real-world applications outside research labs, mostly in the area of supervised learning.

We also saw advances in application critical areas, e.g. medicine, finance, self-driving cars, government, bioinformatics, churn prediction and content recommendation but these applications also brought attention to the crucial trust-related problems. Future applications will, in addition to extensions in aforementioned areas, also include cognitive assistance, interpretable science and reliable ML [2], [3] The all-pervasive utilization of these systems will significantly transform the social landscape of the world. These changes include many ethical challenges to which society will have to adapt fast in order to steer the developments to the favorable directions and outcomes. Automation will significantly change the job market [2], which may lead to more unfair wealth distribution. Content recommendation [4] and generation of fake content [5] coupled with other technologies will deeply impact the social dynamics [6]. Many things will be prescribed by such algorithms and that will affect human lives in ways maybe now unimagined so people will need to trust them in order to accept those prescriptions. Systems must, like humans, satisfy many criteria (assurances) in order to boost trust [2]: unbiasedness (fairness), reliability, safety, explanatory justifiability, privacy, usability etc. Among humans such assurances are assumed due to bias towards human decision making, since people are social creatures accustomed to life in human communities. Artificial intelligence, due to its novel status in our lives, as well as being of the human making, causes much skepticism - rightfully so. Deep learning, as one of the most successful machine learning approaches in supervised learning has been criticized in [7] for working well as approximations where answers often not to be fully trusted, pointing out to model vulnerabilities in language and vision models. Spoofability and biasedness have been demonstrated for visual recognition in [8], [9] and natural language processing [10], [11]. No robust solution has been found to these problems so far. The potential ethical pitfalls should be addressed as soon as possible since inactivity could lead to unforeseeable splits and differences in the future society. European Union introduced a right to explanation in General Data Protection Regulation (GDPR) [12] as an attempt to remedy the potential problems with the rising importance of algorithms. Since the aforementioned trust criteria are hard to formalize and quantify, usually criteria of interpretability and explainability are used as intermediate goals. Afterwards in the following stage, system's explanations can be checked if they satisfy other desirable trust criteria.

More generally, abstracted explanations can be utilized for finding useful properties and generating hypotheses about data-generating processes, such as causal relationships – which is crucial application in science as well as in future Artificial General Intelligence (AGI). Generated hypotheses can be basis for further automated or manual experimentation, knowledge discovery, and optimization. This view is supported by [13] and encompasses: checking for satisfaction of trust-criteria, optimization of ethical outcomes due to technology, assisted(automated) scientific discovery, transferring skills, etc. mentioned in[3], [14]–[16]. Previous overviews and surveys of interpretability in machine learning are given in [2], [3], [14], [15], [17]–[19].

In this paper we survey the advances in the interpretability and explainability of machine learning models under the supervised learning paradigm. Much of the recent work is in the area of deep learning, due to remarkable performance gains of these models on the one hand and intrinsic opaqueness on other hand. The paper is organized as follows: in section 2 we deal with the preliminaries and definitions. In section 3 we categorize the work in methods for interpretability. Section 4 offers discussion into the current state of the research field and lists future research ideas. Section 5 concludes the paper

II. PRELIMINARIES AND DEFINITIONS

In this section we offer definitions of: trust, interpretability, comprehensibility, and explainability.

Trust is defined in [2] as a psychological state in which an agent willingly and securely becomes vulnerable, or depends on, a trustee, having taken into consideration the characteristics of the trustee.

Authors in [15] claim that unlike normal ML objective functions, it is hard to formalize the definitions of criteria that are crucial for trust and acceptance, view backed by [2], [3]. In those cases of incomplete problem formalization, interpretability is used as a fallback or proxy for other criteria.

However, there is no unique definition of interpretability [3], [15]. In [3] interpretability is found not to be a monolithic concept, but in fact it reflects several distinct ideas and that in many papers interpretability is proclaimed axiomatically. Authors in [15] define that to interpret means to explain or to present in understandable terms. Then, interpretability in the context of ML systems is the ability to explain or to present in understandable terms to humans.

Interpretability and explainability are often used interchangeably in literature, but some papers make distinction. In [17] interpretation is the mapping of abstract concept into a domain humans can make sense of, while explanation is the collection of features of interpretable domain that have contributed for a given example to produce a decision. Edwards and Veale in [20] split explanations into model-centric and subject-centric, notions which correspond to definitions of interpretability and explainability from [17]. Similar roles in [15] take up global and local interpretability, respectively. In that view, we can see that GDPR covers only explainability. Comprehensibility [14] is used in a literature as a synonym for interpretability. Transparency [3] is used as a synonym for model interpretability, that is some sense of understanding the working logic of the model.

None of the aforementioned definitions is specific or restrictive enough to enable formalization. They implicitly depend on user's expertise, preferences and other contextual variables.

III. METHODS FOR INTERPRETABILITY AND EXPLAINABILITY

There are two categories of approaches to interpretability and explainability: integrated (transparency-based) and post-hoc.

Transparency [3] is one of the properties that can enable interpretability. Transparency was a traditional first step to protection of rights in human-based institutions and by analogy it is ported to algorithmic concerns such as unfairness and discrimination [20]. But, models in AI are becoming much more complex than human-based institutions and it becomes hard to find meaningful explanation that users might be able to understand. Also, human thinking, including our own, is not transparent to us and justifications in the form of explanations and interpretations may differ from the actual decision mechanism. In addition, predictive performance and transparency are conflicting objectives and they have to be traded-off in a model [21], [22]. In [7] it is stated that it is not clear how much transparency matters in the long run. If the systems are robust and self-contained it may not be necessary. But, if they are part of other systems, then transparency can be good for debuggability.

Post-hoc interpretability extracts informations from already learned model and it does not precisely depend on how the model works. The advantage of this approach is that it does not impact performance of the model which is treated as a black-box (BB). This is similar mode to how people make justifications for their own decisions, without fully knowing the real functioning of their decision-making mechanisms. However, special care must be taken in order to avoid systems that generate plausible but misleading explanations. Such explanations could satisfy laws like GDPR, but there is a problem of checking their veracity.

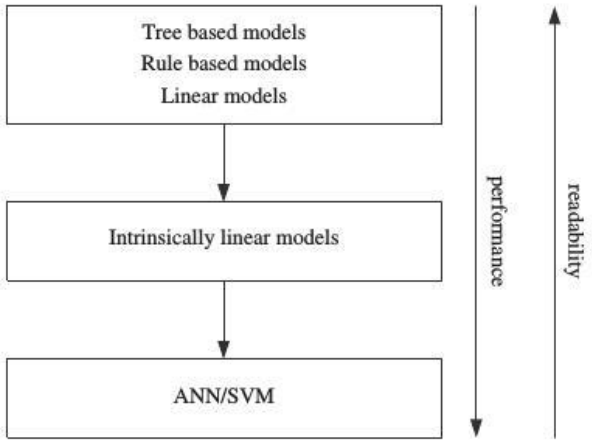

Figure 1 Performance-transparency trade-off [18]

A. *Integrated intepretability*

The best explanation of a simple model is the model itself; it perfectly represents itself and is easy to understand [23]. This approach is limited to the model families with lower complexity (flexibility), such as linear models, decision trees and rules. On the other hand, other

model families such as artificial neural networks (ANN) and support vector machines (SVM), boosted trees, and random forests are considered opaque and their complexity prevents users from tracing the logic behind predictions. The latter are most often considered as black-boxes and they are dealt with in a post-hoc manner. This trade-off between transparency and performance is conceptually depicted in Fig 1. The majority of work is done for classification tasks. Different constraints can be imposed on models in order to increase their interpretability. Model size, sparsity, and monotonicity ([14], [18]) are some of the constraints used in the literature. Even the choice of model family (representation) can be considered a constraint on models that affects the interpretability. Transparent models are both interpretable and explainable.

User-based studies on interpretability of decision-rules, tables, and tree algorithms in classification were conducted in [24] and [25]. In the latter paper, decision tables were found to be the easiest to use for inexperienced users and that the model size in general has negative impact on interpretability, answer time and confidence. Freitas in [14] gives an overview of work in comprehensible classification models where transparency plays the major role. Interpretability of decision trees, classification rules, decision tables, nearest neighbors, and Bayesian network classifiers is discussed and monotonicity constraints are advocated for improving the model transparency.

There are two sub-approaches: pure transparent and hybrid.

In pure transparent approaches we are restricted to use model families that are considered transparent. Evolutionary programming was used in [26] to search for sets of interpretable classification rules with small number of rules and conditions. Interpretable decision sets [27] are sets of independent if-then rules. Since each rule can be applied independently, interpretation is simple. The model is found by optimizing objective that takes into account both accuracy and interpretability. Oblique treed sparse additive models, region-specific predictive models, were proposed in [28]. They achieved competitive performance with kernel SVMs while providing interpretable model. Prototype selection [29] uses set covering optimization problem to achieve sparsity in samples for classification. Minimal set of prototypes is selected in order to get good nearest neighbor classifier. It was tested on recognizing handwritten digits and it showed reasonable performance.

Hybrid approaches combine transparent model families with black-box methods in order to get appropriate trade-off between the model interpretability and the predictive performance. Combination of logistic regression and SVMs was used for credit scoring in [30] in order to improve accuracy of the initial interpretable model. Multi-objective learning of hybrid classifiers was utilized in [31] to learn hybrid trees where certain leafs were substituted with black-box classifiers for boosting accuracy at the expense of interpretability.

B. Post-hoc methods

With hardware improvements and increased availability of data, predictive performance benefits of using complex, opaque models are increased. However, interpretability and explainability are issues that have to be properly addressed. In these approaches we start with trained black-box predictor and, sometimes, the used training data. Some methods deal with interpretability while others with explainability, according to the definitions in section 2. Methods are model-agnostic if they work only with the inputs and outputs of BB model, and model-specific if they use idiosyncrasies of some representation.

1) Interpretability

Transparent proxy model approach finds interpretable model that globally approximates the predictions of the black-box model. This approach offers both interpretability and explainability. In [32] a model-specific method was used to learn single decision tree from the ensemble of decision trees. The learned model was more accurate than the decision tree learned directly from the data. Rules were extracted from SVM in [33] to make more interpretable model for credit scoring. Interpretability was gained at only a small loss in performance compared to SVMs. Symbolic rules were extracted from neural network ensembles in [34]. Bayesian regression mixture with multiple elastic nets was proposed [35] and used on DNN, SVM, and random forests to explain individual decisions and look for model vulnerabilities in image recognition and text classification. Model vulnerabilities were tested with adversarial examples. Adversarial training scheme was used on DNNs in order to increase their interpretability [36]. Using adversarial examples, it was found that in normally trained DNNs neurons do not detect semantic parts but only discriminative part patches. Also, representations are not robust codes of visual concepts. After adversarial training scheme, representation is more interpretable, enabling to trace the outcomes to influential neurons. This is more transparent way of making predictions.

Indicative approaches give weaker notion of interpretability to BB model than the above methods. Some aspects of model functioning are elicited with conceptual representations. Visualization techniques for high-dimensional data like [37] can be used. In [38], visualization technique based on trained deconvolutional network was created for visualization of intermediate layers of convolutional neural networks. The insights through these visualizations enabled creation of improved architectures that outperformed existing approaches at the time. Similar was done for recurrent neural networks in [39], where character-level language models were used as an interpretable benchmark. Experiments revealed the existence of interpretable cells that keep track of long-range dependencies in text. Further work was done in [40] on interpreting neural models in natural language processing through visualization of unit's salience.

Model-agnostic visualization method based on sensitivity analysis was proposed in [41]. Input effects on model responses are inferred and visualizations of barplots for feature importance and Variable Effect Characteristic curves. The experiments were performed on neural

network ensemble and SVM models. Model-agnostic method for auditing indirect influences in BB models was presented in [42]. The procedure finds indirect influences of attributes to output through related features, even when attributes don't have the direct influence. Tamagnini et al. [43] created pedagogical visualization-based system Rivelo for interpretation of BB classifiers using instance-level explanations. User can interactively explore the set of instance-level explanations to create a mental model.

2) Explainability

These methods mostly output for each prediction also an explanation in the form of feature importances for making that decision. Layer-wise relevance propagation and sensitivity analysis were presented in [16] to explain predictions for deep learning models in the terms of input variables. In [44], deep Taylor decomposition propagates explanations from the outputs of DNN to the contributions of its inputs. Model-agnostic method for capturing the degree of influence of inputs on outputs of the system was presented in [45]. Local approximation method, SHapley Additive exPlanations (SHAP), was used in [23] to explain prediction f(x) for a single input x. SHAP is a unified framework for value estimation of additive feature attributions that generalizes several works from the literature [45]–[49]. Both model-agnostic and more efficient model-specific variant were proposed. DNN that identifies contents in the image and generates caption was described in [50]. For each word in caption, an explanation is generated in a form of highlighted relevant regions of the input image.

Other methods give explanations in other forms, such as visualization, text, examples, etc. DNNs were trained for visual question answering and explaining human activities in [51]. Justifications for decisions were given textually and evidence in images was emphasized using the attention mechanism. Textual explanations were generated together with visual classification using DNN [52]. Reinforcement learning based discriminative loss function was used for explanation model.

IV. Discussion

In the introduction we mentioned the utility of abstracted explanations for finding useful properties and generating hypotheses about data-generating processes which is important for science as well as for future Artificial General Intelligence (AGI) systems. Generated hypotheses can be further reasoned and experimented with, leading to the bootstrapped process of iterative improvement. However, as the authors in [19] point out, approaches listed in this paper only enable explanations of decisions, instead of actually generating them. It is up to the user to do the hypothesis generation, experimentation and reasoning. Research direction interesting for science and AGI is bridging neural-symbolic gap for seamless integration of learning and reasoning [53], [54]. Successful implementation would enable automatic generation of interpretations, explanations, and reasoning over them.

We have also seen that researchers use different names for similar or identical concepts. Definitions and vocabulary should be fixed in the community in order to enable easier transfer of results and information. Factors of trust-inducing criteria should be formalized, since these concepts are ambiguous and need to be split into smaller, more specific constituents. Model framework of human trust should be found, as an extension of work in [2]. This can be done in a similar data-driven approach as proposed in [15] for interpretability. There is a lack of empirical studies on user-based measures of interpretability. Also, richer loss functions need to be developed that take into account more criteria of performance in the real world. Most of the machine learning work has revolved around the scalar objectives, while the problems we are talking about are multicriteria with some criteria not even explicitly given in the form of optimization objective. Research into the extensions of interpretability research to reinforcement learning is another potential venue. Pedagogical interactive post-hoc approaches such as [43] are promising to enable people create their mental models of complex algorithms [20] which can boost trust by increasing the familiarity with models' decisions.

V. Conclusion

There are evident problems with the ethical- as well as quality-of-life implications of using AI in their current form in real-world scenarios. On several fronts, people are yet to see major impact applications such as in judicial, governmental, financial, and autonomous transport. But, for some time already, human lives have been influenced by algorithmic content recommendation which shapes opinions and tastes. With a greater spread of AI applications, trust-related problems are likely to become more pressing issues. Trust is boosted with specific criteria, but there are prominent problems with the incompleteness in problem formalization. This is a barrier to straightforward optimization approaches – some notions are so complex, multidimensional, and ambiguous that they are hard to put down in a formal way. Interpretability and explainability offer abstracted explanations for finding, checking, and reasoning over useful properties. This can be used not only for verifying trust criteria, but also for scientific discovery and in future AGI systems.

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Comparison between relational and NOSQL databases

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***Abstract* - The relational database is provided from the traditional DBMS, which ensures the integrity of data and consistency of transactions. For many software applications, these are the principles of a proper DBMS. But in the last few years, witnessing the velocity of data growth and the lack of support from traditional databases for this issue, as a solution to it, the NoSQL (Not Only SQL) databases have appeared. These two kinds while being used for the same purposes (create, retrieve, update and manage data) they both have their own advantages and disadvantages over each other. The purpose of this study is to try and compare the research question of what are the pros and cons for each of these database' features and characteristics? This paper is a qualitative research, based on detailed and intensive analysis of the two database types, through use and comparison of some published materials during last few years.**

Keywords - NoSQL, Relational Databases, Big Data, ACID properties, BASE properties

I. INTRODUCTION

A database management system is essential in managing data efficiently and enabling users to complete various tasks with ease. Performance of this system improves the effectiveness of business processes and decreases overall costs. These systems provide a highly effective approach for handling multiple types of data.

Nowadays, organizations and companies struggle with applications which are accumulating big data on regular basis and as a result, their amount increases rapidly. The existing relational databases (usually referred as SQL databases) are widely used for the applications, but their performance degrades when the data volume is increasing, and they cannot handle the big data issue properly. Furthermore, during the development and evolution of the application, the relational database cannot modify the schema over time and the changes cannot handle different types of data. So, principally those were some of the main concerns why the NoSQL databases were introduced as an impetus for future improvement.

The NoSQL was introduced as a paradigm not to oppose the relational databases but to provide another option for the concerns that relational databases could not satisfy. So, NoSQL databases are not a replacement for the relational database but furthermore these two technologies can coexist. Storing data in the tables and in pre-defining the database schemas are some of the relational databases principles which NoSQL databases do not use or use it in very loosely coupled fashion. There cannot be a perfect solution or definitive one, but there are advantages and disadvantages of both databases.

The aim of this paper is to show the features and characteristics of each database technology especially for NoSQL as a new solution over relational databases. This paper is organized as follows. Introduction where is given an elementary introduce of the traditional relational databases and NoSQL databases. After this section continues the part where mention some achieved results from different researchers. This section also mentions some related work on this topic. A deeper introduction for the types of NoSQL databases is given on the third section, while on the fourth section NoSQL and relational databases comparison is described. On the fifth section there are presented some analysis and suggestions how to choose the right database type to software applications. Finally, the conclusions are on the sixth section.

II. RELATED WORK

There are several research papers about the NoSQL databases characteristics, features and their usage in the world of technology. There are also papers that have evaluated the performance of both NoSQL and SQL databases. In the [1], the authors elaborate the types of NoSQL databases and the advantages and disadvantages of NoSQL databases over relational databases. They defend the prospects of the NoSQL databases with a few more advancements in architecture.

Experimenting the performance and comparison of NoSQL and SQL databases have been made by the authors in [2, 4, 6] research papers. In [2], the authors have chosen to compare the performance of MongoDB as a NoSQL database and Microsoft SQL Server as a relational database. By experimenting with MongoDB and SQL Server, they have noticed that MongoDB performs faster in insert, update and simple query, whereas SQL Server performs better in update, query with non-key attributes and for aggregate queries.

The experiment in the [4] research paper was between MongoDB and MySQL. The authors have noticed that MongoDB shows faster performance compared to MySQL in insertion to the database a large amount of data. They also highlighted the features that dynamic schema of the NoSQL database offers, which are valuable in developing a big data application.

The similar results are shown in [6] in terms of

performance speed, where RavenDB and Microsoft SQL Server are compared, and the results show that on average RavenDb is 50% faster.

In [3, 5], the authors have deeply explained the feature comparison of NoSQL and relational databases including the scalability, performance, flexibility, querying, security, etc. By listing, pros and cons for both data management types, they explain why one should choose NoSQL over relational databases when developing a software application.

In research paper [10], another NoSQL and SQL databases comparison is done. The author has focused on the overhead because of the online transaction processing. The conclusion is that the overhead is not related to SQL, but to other components such are logging, locking, latching and buffer management. The author examines those four components. And avoidance of the overhead, associated with one or more of these, can provide a speedup of two. The author assumes that one can improve SQL databases to compete with NoSQL databases.

According to performance compare of both database technologies done in research paper [11], not all NoSQL databases perform better than SQL or relational databases. The authors have compared different types of NoSQL databases including MongoDB, RavenDB, CouchDB, Cassandra, Hypertable and Couchbase and as a relational database was chosen Microsoft SQL Express. The operations which were tested are read, write, delete and instantiate. A similar comparison but in different way is done in research paper [14], where the authors have done comparisons of SQL, NoSQL and NewSQL databases for the use in Internet of Things. The different way was chosen because of the different nature of data, which are sensor data. The performance results show the ranking of the technologies as NewSQL, NoSQL and then SQL databases.

The data security of NoSQL databases is a very interesting issue that is elaborated in [12, 15]. The security issue in [12] is elaborated using five factors which are authentication, access controls, secure configuration, data encryption and auditing. The result of this analysis shows that there is a significant demand to improve the security of sharded NoSQL databases. Whereas, in [15] the authors have been focused only on the security of MongoDB and Cassandra and have found that both have lack of encryption support for data files, weak authentication, and very simple authorization.

Corbellini et al. in their work [16] did a broader revision of NoSQL, referring to the four NoSQL types of databases. They have described the important features to each NoSQL database type and cover those with implemented example by explanation of the concrete implemented database management system of that type. They conclude that NoSQL, particularly, in data storage, show higher performances because of sharding and persist data storage support and in general should be considered when selecting a storage solution. The use of relational databases can easily show a weakness on the storage requirements in those situations. Furthermore, they conclude that in some situations, it may be necessary to define a hybrid data layer dividing the application data in multiple databases with different data layouts. Therefore, application data requiring a relational schema and high consistency, can be stored in a relational database, whereas the data with no need consistency, but with necessary fast access, a NoSQL database can provide an adequate solution.

Zeng et al. have made a comparison of relational and NoSQL databases through a concrete implementation solution [17]. They have made a comparison, by implementation the patient cohort identification systems in MySQL as relational platform into MongoDB and Casandra as NoSQL platforms. They have recognized the heterogeneous data sources into patient cohort identification which may involve a complication in data loading, harmonization and querying. The stated concerns are attempted to solve by use of the NoSQL. Utilizing NoSQL databases, they overcame the limitation of maximum table column count in traditional relational databases. This study indicates that NoSQL-based systems offer a promising approach for developing patient cohort query systems across heterogeneous data sources.

Ribeiro et al. in their paper [18] presents a performance comparison between the two main approaches of data storage, relational and NoSQL databases in the task of obtaining the most frequent N-grams (in Text Mining projects). The comparison was performed using a database from an international competition. It is shown that the NoSQL approach overcomes, in a statistically significant way, the relational database and they suggest Text Mining solution developers the use of the NoSQL technology to obtain better results in this field.

Kumar et al. have analyzed the problem of different data format and effectiveness in store and processing those data by use of relational database technology [19]. The use of NoSQL databases proved to be one of the best solutions for handling these kinds of schema-less data. This work comprises about the various characteristics of NOSQL databases, the performance comparison of two widely used Document-oriented NOSQL databases viz MongoDB and CouchDB are analyzed. Through two databases, for experimental use, the qualitative as well as quantitative features are analyzed.

Wisal et al., have compared Oracle relational database and NoSQL graph database using optimized queries and physical database tuning techniques [21]. They have done various experiments by execution of the various queries and show that whenever data becomes more and more connected (large number of joins) and large in size, relational databases show worse performance than NoSQL graph database. According to them, this is due that relational databases use constraints, indexes and do not store any relationship information, while NoSQL graph database stores relationship information among various nodes.

A similar comparison of relational and NoSQL database is done by Raut [20].

III. TYPE OF NOSQL DATABASES

The rapid increase of the amount of data and the problem of changing the schema database over the evolution of the different platforms were the first concerns that motivated further development of NoSQL databases. Most of the NoSQL systems are distributed databases or distributed data storage focusing on high performance, high availability, data replication and scalability as opposed to an emphasis on immediate data consistency, powerful query languages and structured data storage [7].

There are four types of the NoSQL databases that can be categorized based on their model of storing and retrieving data. Those types are key – value, column-oriented, document-based and graph databases.

A. Key-value

Key-value model is a schema-less database which is implemented using a hash table where keys are stored as indexes and a pointer that holds the actual data. This structure creates the 'key-value' pair as the model itself is named. The hash tables are suitable for lookups for simple or complex values in extremely large datasets [1, 5]. The data in the key-value database are stored in the form of rows as structured data but also can be stored as JSON or some other self-describing data format as semi structured data [7]. In overall, these databases were created for fast and efficient data management in distributed systems.

One of the more important database management system of this type, key-value NoSQL database is DynamoDB, introduced by Amazon and Amazon use it for its shopping cart.

B. Column-oriented

Column-oriented model is a wider concept of key-value architecture, organized by columns. This model is a composite approach to relational databases and key-value model schema. The data are stored in column families and rows. Every row has a row-key and a row may contain many columns. A row can have a different number of columns and in case of nested columns inside another column, those columns are called super columns [13]. This database type works very well with complex datasets as a result of its scalability. Works perfectly with the enormous amount of data in distributed systems because of its time stamping functions [13]. The first technology that introduced this schema model is BigTable, developed by Google, to handle Google's applications amount of data storage such as Gmail, Google Maps, Web site indexing, etc.

C. Document-based

The most used of NoSQL database model is the document – based database model [6]. The document-based model perfectly handles all types of data including structured, semi-structured and unstructured data. This NoSQL model stores data as collections of documents. The document can contain multiple key – value pairs, key – array pairs or even can contain nested document. The documents in a collection should be similar, but a document can contain attributes that are not necessarily need to have other documents in that collection.

Document – based database model is appropriate for use on content management systems, blog software, etc. Otherwise, it should be avoided in case that the database needs to have a lot of relations and normalizations [1].

The most used Database Management Systems, based on document – based model, are MongoDB and CouchDB.

D. Graph databases

The data in a graph database model are stored and represented as graphs, which are a collection of nodes and edges. Nodes act as objects (entities) and edges represent relationships between data. It can be considered as a model of the network of relationships between specific key-value pairs. This model can support complex data queries for a relatively short period of time, also can support ACID properties [4] and the rollback feature which ensures the consistency of data. This type of database is used when the importance is given on the relationships between data than the data itself [13].

It is important to mention that even though the graph databases have relationships they have nothing to do with relational databases [5]. The most used Database Management Systems based on graph database model is Neo4j.

IV. COMPARING SQL AND NOSQL DATABASES FEATURES

This section compares SQL to NoSQL databases features such as scalability and performance, flexibility, query language, security, data management including storage and availability of data, and their advantages and disadvantages over each other.

A. Scalability and performance

The scalability of the DBMS is very important when we choose the database management system for our software application. Relational databases (SQL databases) use vertical scalability, which means that when the volume of data is being expanded, there could be expand just the storage capacity and computing power of existing node, for example, the capacity of CPU, the RAM and the SSD of the database server [5, 7]. This kind of scalability is expensive because of grater hardware failure risk, hardware costs in means of future upgradability (hardware became older and the support is less, vendors may have some requests, hardware and software limitations, etc.), so the overall implementation cost will increase with data growth. Whereas the NoSQL databases use horizontal scalability which means that when the volume of data is rapidly growing, and the volume of data is large the system expand by adding more nodes for data storage and processing power, for example, add servers to the NoSQL database infrastructure [5]. So, the horizontal scalability of the system is a cheaper solution than the vertical scalability. Inherently the NoSQL databases support the auto – sharding feature by distributing data on different servers, which increases the performance of the database [12].

The main priority of SQL databases is to meet the

ACID (Atomicity, Consistency, Isolation, Durability) properties which are like an impossible task for NoSQL databases. By use of the horizontal scalability is difficult to meet the ACID features. The ACID properties ensure more reliability and integrity of data from SQL databases in comparison to NoSQL databases. Nevertheless, NoSQL databases rely on BASE principles (Basically Available, Soft state, Eventually consistent). Both properties are obtained from CAP theorem which is Consistency – the data is always the same in every replication on every server, Availability – the data must always be accessible (permanently available) and Partition tolerance – the database works fine despite network and machine failures. This theorem says that it is impossible to satisfy and guarantee all three aspects at the same time for distributed systems. So, there will be needed to choose just two of them [6, 8]. So, ACID properties have consistency and reliability whereas BASE properties are more flexible.

B. Flexibility

The flexibility of changing the database schema during the development or the evolution of a software application is not a feature that every DBMS can provide. The SQL databases have a static database schema that should be pre-defined before data injection and should support structured data. If there is a need to change the schema, with pre-existing data, there is a huge problem and a modification of the database schema or tables should be considered precisely, because that modification can cause service failure, decrease performance, or may need maintenance and further investments to modify application modules. While on the other hand, NoSQL databases have a dynamic schema and not necessarily need to be pre-defined. NoSQL databases can easily accommodate changes in data type / structure due to its dynamic schema design [3]. The NoSQL databases because of their data modeling are used for agile and scalable environments which will be continuously developing and evolving.

Another issue for the flexibility of the database is the data structure. The SQL databases handle just well – structured data. This can reduce the performance of the database as data volume increases. While NoSQL databases handle every kind of data including their well – structured, semi – structured and unstructured data.

C. Query language

Relational databases use a standard query language known as Structured Query Language (SQL). This query language is a powerful one and can handle complex queries through a standardized interface.

On the other side, the NoSQL databases do not have a standardized language to query and manage data. However, every NoSQL database management system vendor has created their own query language but there is a lack of creating complex queries such as aggregation on NoSQL databases. Many NoSQL systems do not provide join operation as part of their query language, so the joins need to be implemented on the application side [7].

The fact that there is not a standard query language for NoSQL databases, creates difficulties when data scientists face the challenge to understand the query language for each database. Therefore, there is a need to create a standardized query language for NoSQL databases. Hence the SQL query language is an advantage of relational databases over NoSQL databases.

D. Security

The security is an important issue for a DBMS. The relational databases have very secure mechanisms which ensure the security of the services [8]. Since the feature of sharding is considered the key to success of NoSQL databases by distributing data over servers this probably has impact in data security as the most difficult challenge for NoSQL databases. There is a concern, how the confidentiality, privacy and the security of the data are guaranteed from these systems. Most of the NoSQL databases do not have secure client-server communication and do not provide these mechanisms that can ensure security [5]. There are some key factors that should be considered when dealing with the security of databases. Those factors are authentication, access control, secure configurations, data encryption, and auditing [12]. To ensure the authentication, authorization, and auditing there should be external methods to perform the operation and should be implemented based on the NoSQL database used. It is the same way in defining the access control of the users, some of the NoSQL databases provide access control from the system, but some of them do not ensure this kind of mechanism and need to implement it from the third party.

Because of structured data in the relational databases can be easy to manage the security issues. Therefore, in the NoSQL databases, a large amount of unstructured data and the lack of encryption can affect the security of the database. Based on these data we can see clearly that there is still room for improvement for the security of NoSQL databases in the future.

E. Data management - Storage and Access

In relational databases, data stored are highly normalized and very clean. The data redundancy is avoided in a remarkable way using normalization by slicing data in small logical tables and preventing duplication. In this way, happens the improvement and usage of storage in a reasonable manner.

On the other hand, the data in NoSQL database are stored in collections without relationships and normalization between each other so this could contain data redundancy.

Replication is useful when improving the data availability. NoSQL databases practice the data replication of the database between clustered servers, in order to prevent data loss and to guarantee the security of data. The replication process is done in two ways: master-slave and master-master [7]. Master-slave replication allows the slave to take a copy of the data just for read, while the master holds the permission to write and read the data, so this way guarantees the consistency of data. While master – master replication allows reads and writes to any of the copies and this may lose the consistency.

In the relational databases, a replication is when the whole database is replicated in every site of the distributed system. It is factual that the availability of data is improved but the performance of the database operations will be decreased obviously. There is another way called no replication which replicates a fragment in just one site, here are replicated just the primary keys to show the relationships. The third way is called partial replication where there are some fragments that are replicated, and some may not. In principle, this replication over distant sites consumes a lot of time and storage, especially when having big data sets.

V. CHOOSE THE BEST DBMS

When determining the technologies and the working environment for our software application, we initially should know exactly the system requirements, the constraints that application should satisfy and the issues which can encounter during development. Different software applications have different needs and requirements and along with them easily can be determined the appropriate technologies that we should select. When it comes to DBMS there are some key points that can be valuable in this process.

If the software application priorities are integrity and consistency of data, then the answer should be relational databases. Certain platforms usually have sensitive data and they need to ensure the security of the transactions and other sensitive actions. For example, for the sensitive data as bank transactions, financial, accounting records there is a need for security and consistency of data and is essential to perform several actions as a single atomic action, so the only reliable option is RDBMS. Working with data that need to connect multiple collections into a single result should be considered the relational database. There should be considered also security as an important factor besides the consistency and availability. Moreover, when the ACID properties are necessary for the platform then there is no space for doubt that the only choice is the relational database.

When we want to go beyond the possibilities that relational databases can offer us, for example, in cases where availability, performance, and scalability are essential then NoSQL databases can be the best choice. When software application does not require or does not have priority the data integrity then NoSQL databases can be a perfect choice. NoSQL can avoid the complexity of relational databases [5]. For example, social media sites, shopping sites, email providers, etc., can be the software applications which can consider NoSQL databases as perfect solutions because of the fact that they have a large amount of data, their data grows rapidly on daily basis and, they have different types of data which can be unstructured. Another issue that we must consider is the size of the platform and if there is a need to change the data model at any time without affecting the system or application performance then NoSQL database is the answer. These databases are built to develop an agile and scalable business environment while improving and expanding more the technology systems.

However, there can be cases where software applications can benefit even more from using different solutions within the application for particular tasks. Applications that need high – speed transactions and fast response, or that perform complex queries on data in real time it is good to consider combining different or multiple database technologies for some processing needs. The combination of the SQL based database technology and currently popular NoSQL databases technologies could create a better system with greater availability, scalability, and performance.

VI. CONCLUSION

Overall NoSQL databases just as relational databases have the advantages and disadvantages over each other. The process of switching from a relational database to a NoSQL database can be very challenging in many ways. Firstly, it is needed a detailed study of both solutions, their features, and their querying options. The emerge of NoSQL databases was not intended to ruin the relational databases market, but to bring a solution for the imperfections of them. The relational databases are very used because of their traditionalism and reliability and stability. Their existence over the years has proven to the users their indisputable quality.

Principally the NoSQL users are not so much, in number, comparing to relational database users, so this could be a weak challenge to the NoSQL databases in convincing the new users on applying of this new solution. Also, the lack of having a standard query language may be a additional fact on hesitate to use the NoSQL databases. Changing or pass from one NoSQL type to another requires the need of learning from the beginning of its query language technology, which can additional complicate the use.

There is no an absolute answer, which is the best database solution. To choose the appropriate database for certain software application we should consider some database key points such as scalability, flexibility, performance, query language, security, data replication, and availability.

When ACID properties are necessary, relational database are the appropriate choice. NoSQL databases have a more flexible model comparing to the relational databases, making it easier to organize large amounts of data with varied formats and with flexible increase over time. If there are large datasets, the need of constantly schema change and there is a need for performance and flexibility then NoSQL is the perfect solution.

In general, NoSQL databases are well experienced on big data evolution and they can perfectly face a huge growth of data, but there is a lack of security issues and they should use some of external method to perform and ensure the database security. Considering the development and improvement of NoSQL database technologies the prospects are excellent.

There is possible to make a combined system of both kind of technologies, where relational and NoSQL databases can be configured together and collaborate without obstacles furthermore, they can combine the

benefits of each technology solution to create a more effective system.

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Scalable Parallel Solver of Boolean Satisfiability Problems

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***Abstract* - One of the current trends in high-performance computing (HPC) is applying its possibilities to solve the Boolean satisfiability problem (SAT). SAT is the fundamental problem of mathematical logic and the computational theory. Many of the most important Data and Life Sciences problems can be formulated as SAT, in particular, the Regulation in Animals and Plants problem in Bioinformatics. Traditionally two approaches to the parallel solution of SAT are used, competitive and cooperative. We propose a new massive parallel SAT solver Hpcsat implemented using MPI technology based on the second approach. We describe the architecture and functionality of the solver and the toolkit for automation of the computational experiments process. The approving Hpcsat scalability results of computational experiments are represented. The results of the offered solver confirmed the advantage of Hpcsat in comparing with the existing analogous massive parallel HordeSat solver.**

Keywords – high-performance computing; scalability; parallel SAT solver; Boolean satisfiability problem; cooperative approach.

I. INTRODUCTION

The problem of Boolean satisfiability (SAT) is the problem of determining if such values of Boolean variables that satisfy given Boolean formula exist. Currently, the interest of the developers to design effective SAT solvers increases. These solvers are of practical significance due to the possibility to describe mathematical models of many important scientific and applied problems in different fields, for example, the Industrial problems of Electronic Design Automation, Software Verification, Bioinformatics, Statistical Physics, etc. by the systems of Boolean equations.

In [1] the problem of Gene Regulation in Animals and Plants is highlighted as a significant one. The model of gene regulatory networks is widely used in the form of binary dynamic systems (BDS) [2]. The BDS applications usage in scientific [3, 4] as well as in applied researches is extensive and the number of objects and problems, involving them, broadens year by year. Thereby currentness of creating the new and improving the existing methods of BDS qualitative analysis considerably increases. As it is known, the goal of a qualitative analysis of a dynamic system is to obtain a positive or negative answer to the question, whether the behavior of the trajectories of a dynamic system satisfies some set of constraints characterizing the property. Such constraints are Boolean for the BDS and have a form of the Boolean equations (SAT problem) or the Boolean formula with quantifiers (TQBF problem). For the first time, the theoretical possibility to use the Boolean constraints (Boolean equations to be exact) for the BDS qualitative analysis was described in [6]. The high computational complexity of SAT problems actualizes the creation of the software tools for their solving. The tools are supposed to involve the parallel and distributed calculations technology to provide the end user transparent access to the resources of high-performance computing domains. Different approaches to the parallel solution of the SAT problem, among which two main ones were singled out - cooperative and competitive, are considered in review papers [7, 8]. During implementing a parallel solver based on the first, cooperative approach (Search Space based), the search space is divided into parts, then the search is organized in parallel in each part of the space by a separate solver. In this paper, we discuss the architecture and functionality of the parallel solver Hpcsat based on the first approach. We study the applicability of this approach in case of the large-scale parallel solution of SAT problems. The report also discusses service-oriented tools for automating the solution of SAT problems in a high-performance distributed environment. These tools were used to conduct the computational experiments aimed to evaluate the characteristics of Hpcsat solver and compare it with a similar SAT solver HordeSat [9].

The paradigm of service-oriented computing is actively used at present to standardize access, integration, and coordination of loosely coupled software systems by creating an additional level of web services based on existing scientific applications [10]. This trend actualizes the development of tools for automating the creation and support of the functioning of service-oriented parallel user applications running in a distributed heterogeneous computing environment. The development of such software tools is aimed both at increasing the speed of solving the user problem and its dimensionality. The scalability provision is one of the main requirements for the development of the parallel and distributed software. In this paper, the scalability is understood as the property of a parallel program that characterizes the dependence of the change of the dynamic characteristics of its functioning (speedup, efficiency, overhead, etc.) from the values change of startup parameters of this application [11]. We investigate the scalability of a developed parallel SAT solver intended for using in fundamental and applied research dealing with functions whose domains of definition lie in vector spaces with binary components B_2^n

($B_2 = \{0,1\}$). For most solvers, the Boolean formula must be represented in CNF (conjunctive normal form).

The approach offered in [11] considers the scalability as a multidimensional function from a large number of startup parameters values and uses metrics for its evaluation. We use this approach for the study of the distributed solver scalability for various classes of Boolean satisfiability problems. In addition to investigating the dependence of the number of processes and the dimensionality of the problem for the random 3CNF class, the influence of the third parameter (loads on the slave processes of the MPI application) is analyzed.

II. Related work

In [7-9] an overview of parallel solvers developed in the last two decades is given. In [7] DPLL- and CDCL-based parallelization, pure portfolio approach is considered, the achievements and disadvantages of the modern parallel SAT solvers are given. As noted in [7], the question of designing SAT-solvers to achieve acceptable efficiency and high scalability on modern multi-core architectures remains open. In [8] an overview of the main algorithms of SAT solvers of recent years, including GPU- and FPGA-based algorithms is represented. There are two approaches to the development of parallel solvers: "parallel SAT solvers based on Search Space and parallel SAT solvers based on competitive parallelism" [8]. The development of scalable SAT solvers and the dynamic distribution of computing resources are indicated as the directions for the development of research in this field [8]. Despite recent years active research in the development of parallel software for SAT problems solving, publications about creating massive parallel SAT solvers intended for execution on modern computing clusters with a large number of processor cores are few. The analysis of earlier SAT solvers based on the Search Space, for example, GridSAT, GradSat, Pmsat, C-sat, etc. is given in [9]. They were designed primarily for execution on small computing clusters (up to 64 processors). The GridSat solver can work in a heterogeneous network that contains hundreds of nodes. However (as noted in [9]), the results of soled SAT problems are relevant at the time of writing. Now, these problems can be solved in a few minutes using modern sequential SAT solvers, for example, Minisat [12] and Lingeling [13]. However, modern SAT solvers, in turn, do not solve the new SAT problems, the dimension of which has now significantly increased. A new massive parallel HordeSat solver based on Portfolio approach is offered in [9]. The authors investigate the possibility of applying this approach for a large-scale solution of SAT problems. HordeSat scalability is evaluated experimentally on examples, including random satisfiable and unsatisfiable 3CNFs [14]. In this paper, we offer the new massive parallel solver Hpcsat based on the Search Space approach (cooperative approach), investigate its scalability and compare it with the HordeSat.

To support the horizontal scalability, the solution of SAT problems using Hpcsat in a distributed computing environment (DCE) is implemented using a service-oriented approach. Creation of the service based on Hpcsat and management of its functioning in the DCE is performed using the HPCSOMAS Framework [3, 4].

III. Architecture of the parallel solver

The massive parallel solver Hpcsat is an MPI application, created with C++ language and intended for parallel solving of resource-intensive high-dimensional Boolean problems on computing clusters with SMP nodes. The Hpcsat solver is implemented based on the full search method and uses data parallelism. Data parallelism realized by the splitting the original Boolean model (Boolean formula in CNF). The master process organizes a dynamic queue of subtasks and sends requests on its execution to slave processes. Subtasks can be assigned to simplify the sub-formula, to determine the sub-formula satisfiability, and to perform the next splitting. A slave process can run both a multithreaded and a single-threaded (sequential) application [Fig. 1]. The SAT solvers running in the slave process are called basic solvers.

The Boolean sub-formulas after preprocessing can be significantly different in computational complexity. Therefore, the master process regulates a load of the slave processes, alternating the sending of tasks to simplify sub-formula and to determine its satisfiability in response to the request of the slave process, depending on the state of the queue and the splitting tree. The user is given the opportunity to install optional application startup parameters – the number of processors, size of the subtask block for the slave process (the load of the slave process), splitting heuristic, splitting depth, and the basic solver that is run in the slave process. Computational experiments were carried out to evaluate the Hpcsat characteristics. During these experiments, the application startup parameters values were changed to define the scalability dependence on these values. In comparison with the Hpcsat, the HordeSat [9] massive parallel solver was used with freely provided code.

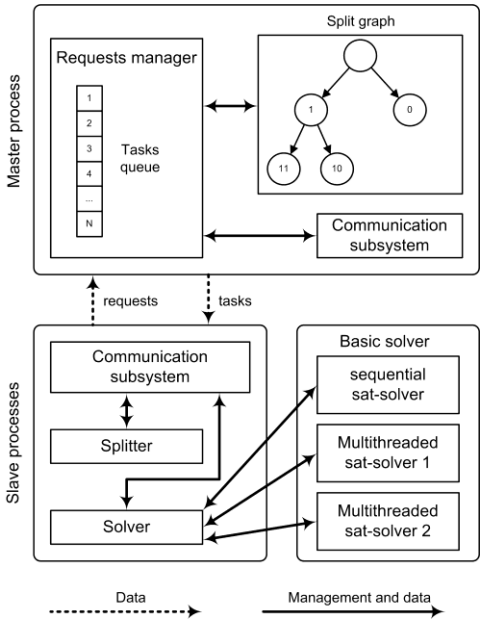

Figure 1. The architecture of the Hpcsat

IV. COMPUTATIONAL EXPERIMENTS

For the experiments, the classical problem of artificial intelligence on the pigeonhole [14] and a block of random 3CNFs were chosen, which included 200 satisfiable and 200 unsatisfiable SAT problems [15]. The time for solving one problem was limited to forty-eight and thirty-six thousand seconds, respectively. The pigeonhole problem determines the possibility to put n+1 pigeons into n holes so that each pigeon was set in a single hole. The dimension of the pigeonhole problem is denoted by the value n, the number of Boolean variables is $n\times(n+1)$. In test examples n = 11, …, 15. The problems are solved on a computing cluster of Irkutsk supercomputer center [16]. The first experiment is carried out to obtain the solution time on a different number of cores for the pigeonhole problems of different dimensions and to calculate the speedup and efficiency of compared SAT solvers. The second experiment is carried out to evaluate abovementioned characteristics and the dependence of its change from the additional startup value – slave processes load (the number of query subtasks) for random 3CNF problems.

A. *Efficiency evaluation*

Speedup (S) and efficiency (E) is calculated using the formulas:

$$S=\frac{T_u\cdot u}{T_n}, E=\frac{S}{n_p}, \quad (1)$$

where u – the conventional unit of processor cores, minimal required core number for the possibility to solve the test problem, T_u and T_n – execution time on respectively u and n_p processor cores, n_p – changing processor number, $n_p=\overline{u,N}$. Such conditional unit is used because some test problems cannot be solved with fewer cores. This approach is often used in the evaluation of the speedup and relative efficiency (for example, [19]).

The scalability metrics are calculated based on the approach proposed in [11]. This approach evaluates the effect of the parameters of launching a parallel application on its efficiency. These are the following metrics for M startup parameters (denotation is changed with comparison in [11] to be short):

- minimum and maximum domain values of all parameters (min (p_i), max (p_i), $i=\overline{1,M}$);
- minimum and maximum efficiency ($E_{\min}$ and $E_{\max}$) of parameters space values;
- the contribution C_i to the scalability change with the increase of the i-th parameter value;
- the integrated contribution of increasing of all parameters values (C).

The parameters space is divided into K multidimensional segments respectively steps h_i of increasing the parameters values. The SAT solver is run in each segments vertex. Startup solver parameters are equal to the values of corresponding vertices. The efficiency value is calculated in each vertex using experimental results correspondently (1). Then the changing of efficiency $\Delta e_{l,i}$ is calculated for increasing i-th parameter value in segment l:

$$\Delta e_{l,i}=\frac{1}{2^{M-1}}\sum_{i=1}^{n_i-1}\sum_{\substack{j_1,\dots,j_M,\\ j_k\neq i}}(E_{lj_1,\dots Ji^+,\dots lj_M}-E_{lj_1,\dots Ji,\dots lj_M}),$$

where $E_{j_1,\dots,j_M}$ – the value of the efficiency in the l-th segment vertex with coordinates (j_1, …, j_M) in the space of M parameters; the denotation i^+ indexes the value increasing of p_i in segment l; $j_1=\overline{1,n_1},\dots,j_M=\overline{1,n_M}$. The variable n_i is a number of parameter values in its domain and is found as follows:

$$n_i=(\max(p_i)-\min(p_i))/h_i+1.$$

The integrated changing of efficiency Δa_l in the segment l is calculated using the formula:

$$\Delta a_l=\frac{1}{M}\sum_{i=1}^{M}\Delta e_{li}.$$

Metrics of the contribution in the efficiency calculated as follows:

$$C_i=\frac{1}{K}\sum_{l=1}^{K}\frac{\Delta e_{li}h_i}{\max(p_i)-\min(p_i)},$$

$$C=\frac{1}{K}\sum_{l=1}^{K}\frac{\Delta a_l\prod_{i=1}^{M}h_i}{\prod_{i=1}^{M}(\max(p_i)-\min(p_i))};\ K=\prod_{i=1}^{M}n_i.$$

B. *Analysis of experimental results for the pigeonhole problem*

Computational experiments are carried out with the pigeonhole problem for two startup parameters: the processor number (p_1) and the problem dimension (p_2) (Fig. 2). Based on above approach for the next metrics of the scalability:

$$\min(p_1)=64;\max(p_1)=1024;$$
$$\min(p_2)=11;\max(p_2)=15$$

the following values of other metrics are obtained:

$$E_{\min}=0.09812;E_{\max}=1.06656;$$

$$C_{p_1}=-0.0001617;C_{p_2}=0{,}002299;C=0.00001188.$$

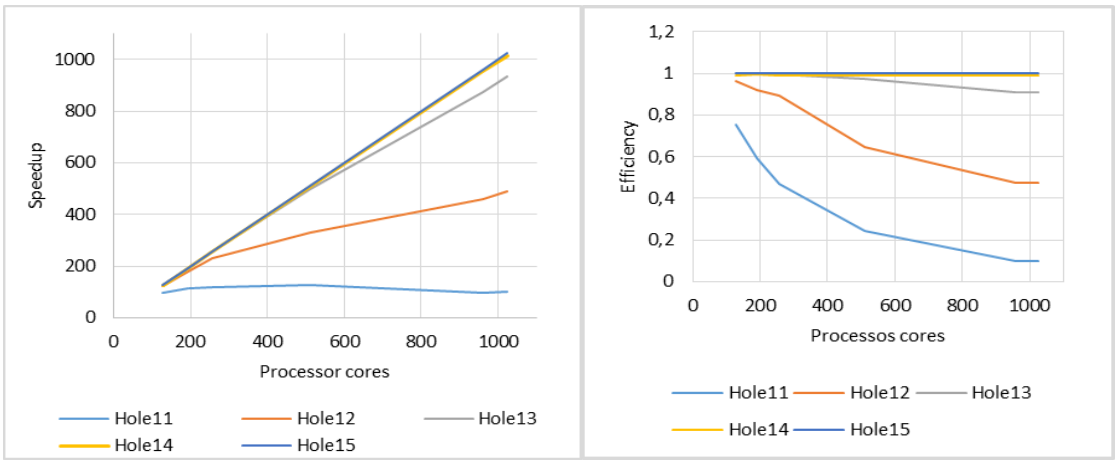

Figure 2. The speedup and efficiency of the Hpcsat solver

For the pigeonhole problem, the efficiency gradually decreases with increasing number of cores with the constant problem dimension. The increase in dimension with a fixed number of processor cores leads to an increase in the efficiency. The change in the efficiency with simultaneous increase in both start parameters remains positive, and its value approaches unity. In this experiment, the efficiency E is a function of the number of processor cores and the dimension of the problem ($E = f_e(p_1, p_2)$). As a result of approximating the experimental data, with the value of reliability of the approximation $R^2 = 0{,}928296$ we have the following form of the function:

$$f_e(p_1, p_2) = (-0.0254 p_2^2 + 0.7422 p_2 - 5.4205)\ln(p_1) + \\ + 0{,}091 p_2^2 - 2{,}6973 p_2 + 20.97 .$$

We introduce the denotation $d = p_2$. Putting the value of the function $E = f_e(p_1, p_2)$ equal to the required level of efficiency and carrying out the transformations, we obtain an expression showing the dependence of the dimension of the problem on the processor cores number:

$$d_{1,2} = \left\lfloor \frac{-g_2(p_1) \pm \sqrt{[g_2(p_1)]^2 - 4 g_1(p_1) g_3(p_1)}}{2 g_1(p_1)} \right\rfloor ,$$

where

$$g_1(p_1) = -0.0262 \ln p_1 + 0.0974 ,$$

$$g_2(p_1) = 0.7589 \ln p_1 - 2.8433 ,$$

$$g_3(p_1) = -5{,}4988 \ln p_1 + 21.796 - k_e ;$$

$0 < k_e < 1$ – the constant specifying the required level of the efficiency; $p_1 = u, u+1, \ldots, N$. Substituting the value k_e and p_1 into the formula, we obtain the lower and upper values of the dimension of the problem, at which (approximately) the required level of efficiency is saved. Conformity of efficiency surfaces constructed from the experimental data (on the left) and calculated using the given function $f_e(p_1, p_2)$ (on the right) for same parameters p_1 and p_2 is shown in Fig.3.

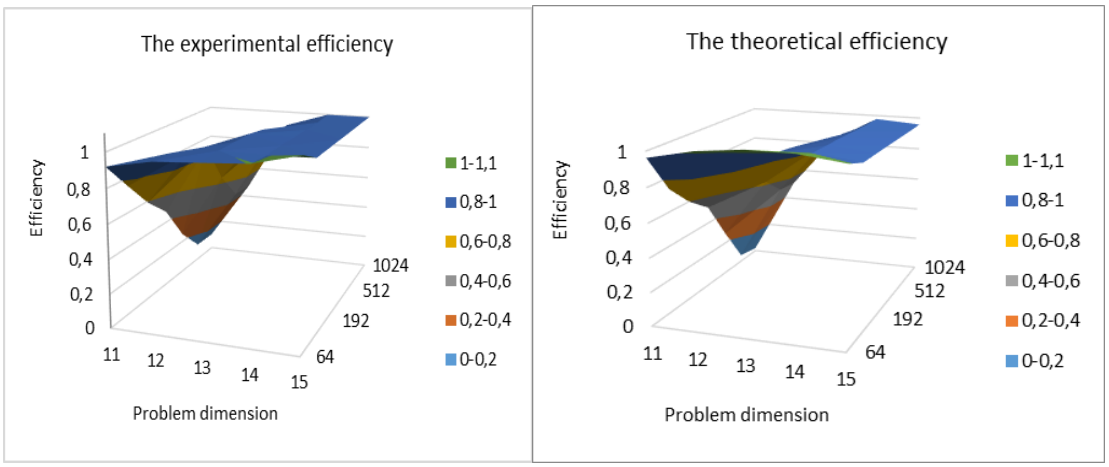

Figure 3. The dependence of the effeciency of the Hpcsat on two startup parameters, the dimension of the pigeonhole problem (x-axis) and the number of processor cores (y-axis)

C. *Scalability evaluation for random 3CNFs*

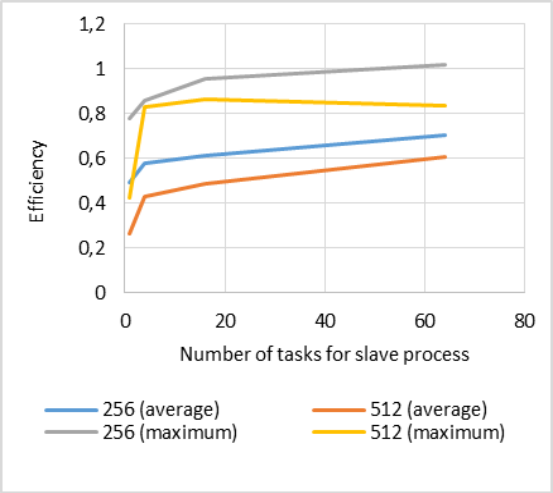

Figure 4. Hpcsat efficiency dependence on slave process load for unsatisfiable 3CNF

The generalized results of the solution of test 3CNF problems are given in Table. 1. The number of satisfiable and unsatisfiable (denoted "SAT" and "UNSAT" in the second column) 3CNF problems and execution time in seconds are given in the third column. The HordeSat solver did not solve some unsatisfiable SAT problems. Let us consider factors affecting the efficiency of solving such problems for Hpcsat. As the dynamic characteristics in evaluating the scalability of Hpcsat, the number of processor cores (p_1), the dimension of the problem (p_2) and slave process load (p_3) were used. The values of the metrics characterizing the parameter space on which the evaluation was made are as follows:

$$\min(p_1)=64;\max(p_1)=512;$$
$$\min(p_2)=400;\max(p_2)=440;$$
$$\min(p_3)=1;\max(p_3)=64;E_{\min}=0.25;E_{\max}=1{,}19.$$

The following contribution of p_1, p_2, p_3 (C_1, C_2, and C_3 correspondently) and integrated contribution C in the efficiency changing are obtained:

TABLE 1. EXPERIMENTAL RESULTS STATISTICS

Processor cores	*Characteristics*	*Hpcsat*	*HordeSat*
64	Summary time	138430,6	680934,9
	Average time	692,15	3404,67
	Number of solved SAT	200	200
	Number of solved UNSAT	200	196
256	Summary time	76320,24	776154,2
	Average time	381,6	3880,77
	Number of solved SAT	200	200
	Number of solved UNSAT	200	186
512	Summary time	69310,05	2484340
	Average time	346,55	12422
	Number of solved SAT	200	200
	Number of solved UNSAT	200	132

$$C_1=-0.030132;C_2=-0.00482;C_3=0{,}0099931;$$
$$C=-0.0000827.$$

These results and Fig.4 allow concluding, that the increasing the load of slave processes (the size of the subtask block transmitted in one query) helps maintain an acceptable level of the efficiency for unsatisfiable 3CNF.

Distinctive features of satisfiable SAT tasks is, first, that the subtasks obtained during data decomposition can differ significantly in structure and in execution time, depending on those variables that split the initial function. Secondly, when the solution is found for one of the subtasks, the other tasks are removed from the executing. Therefore, the runtime of the large dimensional problem may be less than small problem runtime. The experiments were carried out to evaluate the efficiency of satisfiable 3CNF for which sequential Minisat solver runtime was more 1400 seconds. In this case, the conventional unit u equals unity because such problems were smaller difficult in comparison the previous ones. The efficiency was calculated using (1) for the Hpcsat and HordeSat solvers. The results are represented in Fig. 5. The Hpcsat efficiency exceeds the HordeSat efficiency. The following metrics were using in evaluation:

$$\min(p_1)=1;\max(p_1)=512;$$
$$\min(p_2)=370;\max(p_2)=420;$$
$$\min(p_3)=1;\max(p_3)=64;E_{\min}=0.04;E_{\max}=11{,}1.$$

$$C_1=-0.03192;C_2=-0.00359;C_3=0{,}00824556;$$
$$C=-0.0000753.$$

During the comparing the scalability metrics for satisfiable and unsatisfiable problems, it can be noted that with increasing both the number of processor cores and the dimension of the problem, efficiency decreases. In both cases, an acceptable level can be maintained by increasing the size of the subproblem block sent by the service flows. In this case, the integrated contribution of the startup parameters to the change in efficiency (C) still has a negative sign, but the absolute value of this metric is rather small. Efficiency jumps in solving satisfiable test 3CNF are explained by the probability of finding the solution at the very beginning of the search for a successful choice of the variable for splitting. With such a quick solution, super-efficiency is observed. It is difficult to predict the time of solving such problems, unlike the pigeonholes problems. There are no solution of

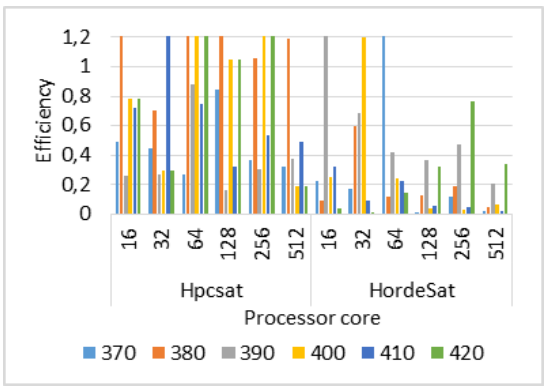

Figure 5. Hpcsat and HordeSat efficiency for the satisfiable 3CNF

unsatisfiable 3CNFs, so this situation does not arise, and the efficiency changes smoothly (see Fig. 4).

During the solving of random satisfiable 3CNFs, the efficiency decreases quite fast in case of increasing of both the number of processes and the problem dimension. The HordeSat overheads that decrease the efficiency, are connected with the learning of conflict clauses. The Hpcsat solver do not use this kind of exchange. So the overheard decreases. On the Fig.6 is shown execution time for the solving the pigeonhole problem. It is the evidence advantage of the Hpcsat. However, for 3CNF the time of processing depends on the subtask (contacting the solution) to be launched from the queue. Nevertheless, the Hpcsat solver is more effective for this kind of problems.

In general, based on the presented evaluations, we can conclude that the Hpcsat is sufficiently scalable, especially in case of solving SAT problems having a regular structure when the Boolean model is given analytically.

Based on the Hpcsat solver a service for solving Boolean satisfiability problems [17, 18] is developed. Thus, the property of horizontal scalability in DCE is provided. Integration with additional computing nodes included in this environment to use its resources is accomplished by installing a configurable HPCSOMAS agent on this node [3, 4]. The estimation of efficiency for the SAT problems using the service is given in [17].

V. CONLUSION

We created the new massive parallel SAT solver. The solver scalability is estimated. We also singled out the startup parameters of the solver that affect the efficiency of the SAT problems solving. These problems are of three classes – unsatisfiable problems with regular structure, random satisfiable and unsatisfiable 3CNFs. We compared the solver with the existing one; the results confirmed the advantage of Hpcsat efficiency.

ACKNOWLEDGMENT

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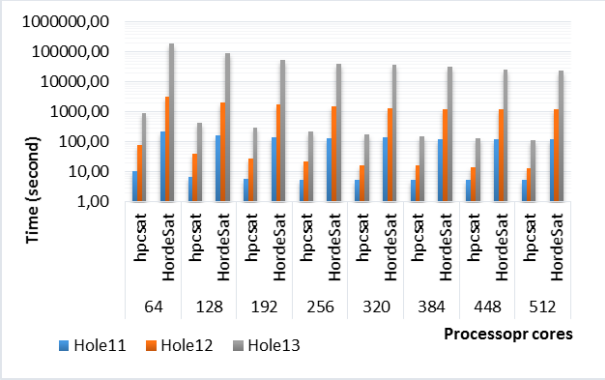

Figure 6. The execution time of the Hpcsat and Hordesat solvers

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Towards Precision Brain Disorder Rehabilitation

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***Abstract*—Brain disorders include any conditions or disabilities that affect the brain. Some frequently occurring brain disorders (caused by e.g., injury or stroke) are associated with balance disorders that can be to some extent compensated by highly personalized and long term rehabilitation. This paper presents basic principles and reports the first results of our project focused on design and development of new generation data-centric approach to treatment of balance disorders through exergames offering many levels of difficulties that can be adjusted through choice of their parameters. The suggested approach paves the way to future precision rehabilitation models, in which the significant part of the training can be ensured through game like exercise supervised by an intelligent adaptive system called Intelligend Therapy Assistant (ITA) providing the patient with biofeedback. Further, the supervising ITA iteratively modifies parameters of the next run of the game (adapts them) according to the current needs of the individual patient in order to keep the patient motivated – this is ensured by introduction of a feedback loop between the ITA system and thorough evaluation of results achieved by the patient during the therapy process.**

***Keywords*-brain damage, biofeedback, time series data, adaptive balance training**

I. Introduction

A. Motivation

In the modern neurology and medical rehabilitation disciplines, brain disorders are among key research areas addressed. They occur when our brain is damaged or negatively affected by injury, surgery, disease, or health conditions. They can influence function of most parts of human body. Necessary medical care and rehabilitation are often impossible without considering the state-of-the-art neuroscience research achievements and close cooperation of several diverse medical, care providing, IT and other specialists who must work jointly to choose methods that can improve and support healing processes as well as to suggest new treatment approaches based on better understanding of underlying principles. The key to their treatment decisions are data resulting from careful observation or examination of the patient during his/her exercise ensured as a part of the long-term therapy (that can last months and years) and information/knowledge extracted from these data. Because of the impressive advances in scientific domains, like the neuroscience, as well as in technology, the volume and complexity of the captured data have been continuously increasing and reaching the challenges of the Big data technology; we believe that the achievements of this technology in combination with high-performance multi-core processor architectures, novel IT infrastructures, like Cloud Computing could introduce the development of a new generation of non-invasive brain disorder rehabilitation processes. In this paper, we envision a novel data-centric approach, and in this way, we pave the way to future precision rehabilitation models.

B. Approach

Our approach targets balance disorders using two home-grown systems, namely *Homebalance* [1] and *Scope* [2]. *Homebalance* consists of a portable force platform connected to a computer as an alternative cursor actuator (instead of the standard mouse) complemented by a special software that leads the patient through a series of specific balance tests producing valuable data from four transducers, located in each corner of the force platform. The resulting data are both immediately visualized and stored in the involved data repository for a post-training analysis. These data provide unique and precise information related to immediate force and weight distribution of the patient, who (standing on the force platform) is instructed to move the item displayed on a computer screen by shifting his/her center of gravity. Visual and auditory feedback enabling game-like form of training makes the therapy more effective and provides higher compliance and motivation to exercise. The application of the system during therapy processes requires careful choice of appropriate settings for a large number

of system parameters. Combination of available choices leads to a large search space that has to be considered. The challenge and an ambitious research goal is to find an optimal therapy process for each individual patient. To do so we apply automatic scaling and an adaptive optimization of involved therapeutic processes including precise monitoring, assessment, automatic therapy intensity scaling, learning, and response cycles and based on patient-specific modeling. This step is based on the second home-grown system called *Scope* intended to support research in biology, psychology, human research, etc. It finds use whenever there is an appropriate need during in-vivo experiments, continuous and accurate sensing of biological and technical signals. Correlations between data from different sensors are examined (for example comparison of the heart rate and a relative change of skin resistance).

C. Paper Organization

The rest of the paper is organized as follows. Section II provides relevant background information and discusses the related work. The balance training process and data capturing strategy are introduced in Section III. Section IV introduces the idea of the Intelligent Therapy Assistant, a kernel component of our Precision Rehabilitation approach. Illustration of selected functionality patterns is presented in Section V. Future research ideas are outlined in Section VI. Finally, we briefly summarize the achieved results in Section VII.

II. Background and Related Work

The use of modern technologies for the rehabilitation of patients with brain damage has made a remarkable progress in the past decade. The needed therapy (some form of training) is primarily provided in rehabilitation centers; the aim is to extend it to patients homes, because home therapy, without direct participation of a therapist, can save the patient traveling to centers, makes the rehabilitation more attractive, provides motivation to exercise, and so, it can be more effective. Data can be locally collected and then transmitted to the rehabilitation center and processed there

Balance training is one of the main focuses of brain disorder rehabilitation. Most modern balance training environments are interactive and built up on measuring instruments called force platforms (or force plates) that measure the ground reaction forces (their summary vector is often called as center of pressure) generated by a body standing on or moving across them, to quantify balance, gait and other parameters of biomechanics [3]. Methods based on virtual reality technology and biological feedback are appropriately supplementing conventional rehabilitation procedures. In this context, in our lab, we have developed a stabilometric system [4], [5], based on the WiiFit balance force platform [6], with a set of 2D or 3D training scenes so that patients can experience situations appearing in these scenes without any risk. Commonly used 2D gaming systems are not suitable for this purpose. The therapy includes active repetitive game-like trainings.

The patient standing on the force platform is set the task to control his/her center of pressure (COP)[1] movements to achieve goals of the games. The COP movement is depicted in the virtual environment to provide the sensory biofeedback, which can be established by means of the visualization of the projection of position of COP, by acoustic signal, or even by electro tactile stimulation of tongue [7]. The efficiency of patients COP movement is measured and presented as a score value. The training difficulty and sensitivity of sensors can be adjusted to the current patient‘s state and his/her score achievements. The patient‘s state is objectively evaluated in the beginning and during the entire rehabilitation process. Data is analyzed in both time and frequency domain. Graphs and raw values can be exported. Similar objectives have been followed by other researchers [8]–[13]. Papers [11], [12] analyze the state of the art in balance rehabilitation systems supported by the virtual reality and biofeedback technologies, respectively. The WiiFit force platform [6] based rehabilitation systems and experience gained from the real application environments are discussed in [8]–[10], [13]. A game engine that involves advance characteristics needed to support rehabilitation at home is described in [14]; here, a rule-based component partially steers the therapeutic process.

III. Novel Rehabilitation Model

A. Balance Training

Investigations in the above discussed research showed that the personalized application of the available systems during therapeutic processes requires careful choice of appropriate settings for large number of system parameters, values of which cannot be estimated purely from few simple measurements (e.g. weight and height of the patient). The system parameters must be modified w.r.t. to current patients state as well as to the set of multiple diseases the patient is suffering from. This is the first reason why a large search space should be considered when planning the type of therapeutic processes to be recommended for system parameter settings. The second issue is related to the fact that individual combination of therapeutic processes is recommended for each patient and this combination influences the parameter values for individual processes. All this leads to combinatorial explosion that has to be faced. Our objective is to contribute to the solution of these challenges by an approach that includes biofeedback- and physiological parameters-based methods. Figure 1 illustrates basic elements of biofeed-back realization. The system parameter setting currently relies mainly on subjective observation of the status and behavior

[1]Each COP value is associated with the position of the centre of gravity; therefore, these terms are used interchangeably in the literature.

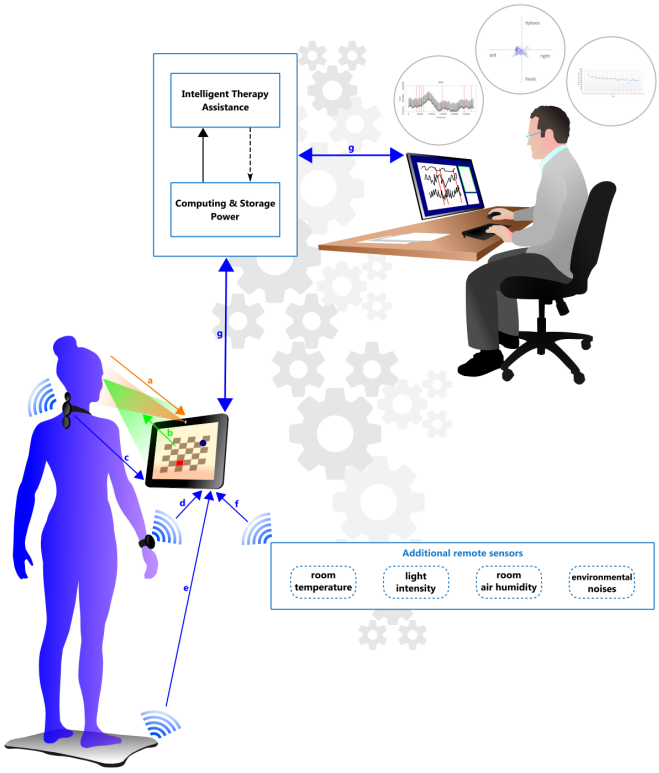

Figure 1. Balance training supported by biofeedback data and intelligent therapy assistance: a) patient face is observed by a camera (a post-analysis can identify e.g., specific emotions, concentration, etc.); b) patient gets audio-visual feedback; c) sensing neck muscle tension; d) measuring pulse frequency; e) data streams from balance force platform sensors; f) data streams from other observations, like room temperature, light intensity, room air humidity, environmental noises, etc.; g) data transfer and processing between patient and therapist areas.

of the patient by the persons steering the therapy; this type of human expert supervision is time consuming, sub-optimal, and unproductive. The challenge and an ambitious research goal is to provide technical support for design of an optimal therapeutic process for each individual patient. A prerequisite for this approach is to collect enough training data that fully characterize the detailed advance of the patient during the rehabilitation processes and his/her therapies.

As sketched in Figure 1, the therapist is overloaded with the avalanche of data streaming from the sensors and at the same time he/she must be aware of the patient medical record data relevant for the therapy session. Moreover, he/she should promptly adapt the therapy parameters to dynamically react to the therapy process status he/she intuitively assumes from the observed data streams. To meet these challenges, we support him/her by the Intelligent Therapy Assistant that is discussed in Section IV.

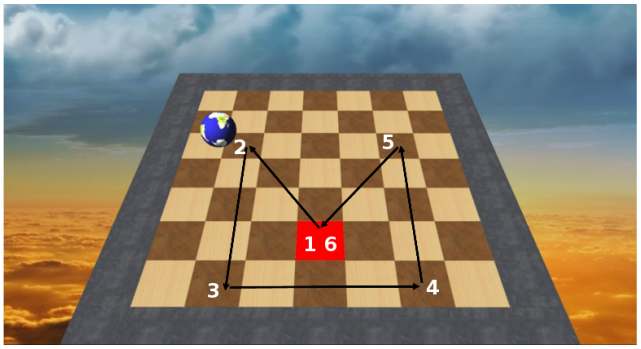

Figure 2. Chessboard scene: Trajectory of the required globe movement. The numbers, 1-6, denote board positions, the sequence of required movements, of the globe that correspond to the projections of shifting the center of gravity.

B. Data Capturing

The typical training (rehabilitation) session using the Homebalance system and the Scope device used for capturing biofeedback and physiological data consists of three consecutive tasks that the probands are to perform: a simple chessboard scene described below, and two scenes (city street virtual scene, and water maze virtual scene) in 3D virtual environments discussed in the chapter we provided for [15]. Each of the considered training sessions has several levels of complexity given by the used parameters of the used task, e.g. maximal time allowed for accomplishing the task, expected scope of movement, type of cognitive task to be ensured together with the movement. Complexity of the task assigned to the patient is changed during the exercise in accordance to the feedback data informing how demanding is the actual setting for him/her. If the patient manages the task well, the current setting level can be slightly increased by a session supervisor (clinician, home therapist, intelligent software agent, etc.). In the opposite case, it can be decreased. Scaling of the task complexity is described separately for each of the included training sessions bellow.

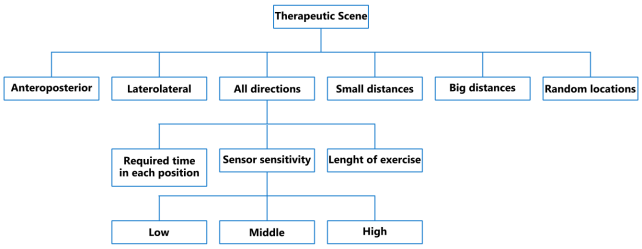

Figure 3. Taxonomy of the training input parameter space: *Required time in each position* ∈ <0.1s, 0.5s, 1s, 2s, 3s, 4s, 5s>; *Length of exercise* (predefined time scope) ∈ <1, 2, 3, 4, 5, 10, no restriction>. Other therapy scenes, e.g., *Anteroposterior*, have the same parameter structure as shown by *All directions*.

In the chessboard scene depicted in Figure 2, the proband

is shown a chessboard with a sphere and a target location on the chessboard is highlighted. Standing on the balance force platform, the proband is instructed to move the sphere by shifting his/her center of gravity (COG). A body's COG is the point around which the resultant torque due to gravity forces vanishes. If the projection of COG to the platform is shifting in correct direction, the sphere moves to the highlighted location. The process is then repeated several times, with different target locations. The difficulty of training session can be adjusted to the current patient's state. Tasks used for the first phase of rehabilitation process are designed with target locations near the middle of the chessboard, with short time of quiet stance on each required position. If the patient completes the basic task correctly, the therapist chooses training scene with target locations in outlying positions and longer time of quiet stance on each position. Figure 3 depicts the taxonomy of the parameter space available for trainings.

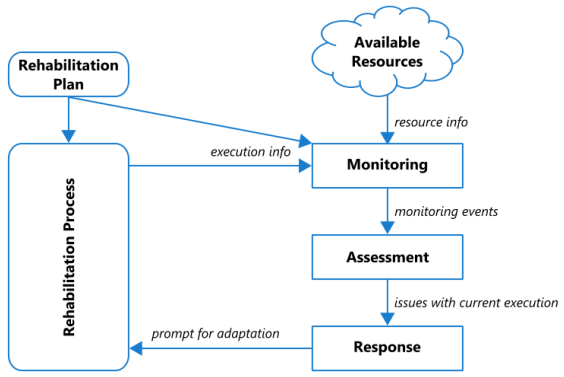

Figure 4. Intelligent Therapy Assistance (based on [16])

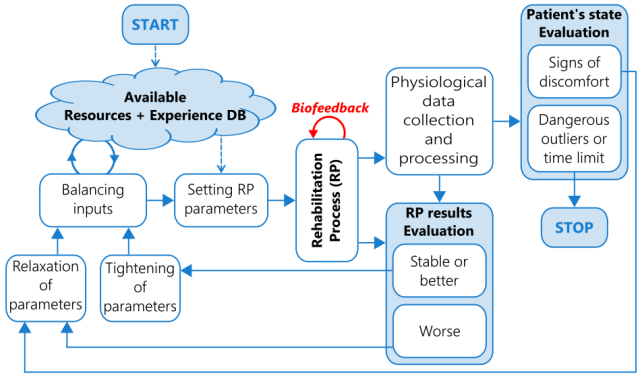

Figure 5. Rehabilitation process steering diagram

IV. Intelligent Therapy Assistant (ITA)

Motivation sources for our design of the architecture and functionality of the ITA mainly are: a) intelligent agent theory [17]; b) expert system technology [18]; and c) adaptive database query optimization approaches for dynamic distributive environments [16].

Figure 4 shows a diagram of what we envisage as a generic framework for adaptive rehabilitation steering. The above model is simple, yet powerful and comprehensive, as it can describe and combine different approaches. It practically models thinking and acting of a very skilled therapeutist in the context of Figure 1.

```
setting_therapy_parameters{};
therapy_start();
t = elapsed_time();
while (t < planned_therapy_length) {
 do face_camera()==negative_emotions
     --> verbal communication with the patient!
  []neck_muscle_tension()==higher_level
     --> adjustment of training difficulty!;
         verbal instructions to relax the muscles!
  []pulse_frequency()== low
     --> increase task difficulty!
  []pulse_frequency()==high
     --> decrease task difficulty!
  []pulse_frequency()==exttremely_abnormal
     --> stop training!;
         consult cardiologist!
  []skin_resistance()==low
     --> increase task difficulty!
  []skin_resistance()==high
     --> decrease task difficulty!
  []skin_resistance()==very_high
     --> stop training!;
         consult psychiatrist!
  []platform_sensors()==good_performance_observed
      --> gradually increase difficulty!
  []platform_sensors()==bad_performance_observed
      --> temporalily decrease difficulty!
  []platform_sensors()==abnormal_movements_observed
      --> stop training!;
          consult neurologist!
   . . .
  od
  t = elapsed_time();
}
```

Figure 6. Physiological data evaluation scenario

The sensors generate information about the state, quality and progress of the evaluation of a rehabilitation plan. Also, the resource repository provides up-to-date information about the registered resources, e.g. the space of available therapy parameters accompanied with an appropriate taxonomy. Based on such monitoring information, events are generated. The assessment phase evaluates these events in order to verify whether they denote changes in the values of interesting properties and whether such changes are an issue for the current execution, in the sense of something that may compromise its optimality. The event analysis may involve the evaluation of event-condition-action rules. Once an issue has been identified, the system tries to identify potential ways to respond. If such ways are found, the therapy steering parameters are adapted accordingly and its behaviour changes as a result.

The working (activity) logic of the ITA is depicted at the finer granularity level in Figure 5. Block *Balancing inputs* has to decide how to proceed if it obtains simulatneously two contradictory commands for parameter adjustment, e.g. when the block *RP results evaluation* observes that the patient's performance is improving while the block *Patient't state Evaluation* observing patient's comfort notifies that the patient has reached a stress threshold; taking an appropriate decision is a challenging task. Considering data from previous trainings of this patient or patients with the similar diagnosis would increase the training precision aiming at the optimal solution. As seen in Figure 1, during therapy, several forms of *feedback* (e.g., visual biofeedback responding changing COP positions) are continuously provided to the patient.

Block *Physiological data collection and processing* manages data streams produced by the therapy process sensors (see Figure 1) that come under time-series data category. Their raw data contents underlies specific processing including cleaning, transformation, analysis, visualization, etc.. Relevant time-series sections and descriptions of events discovered by the analysis are stored in the time-series database, together with appropriate metadata.

The sketch of the working scenario applied by block *Patient's state Evaluation* is expressed in Figure 6 in a pseudo-notation based on the iterative command of the form [19]:

do $B_1 \rightarrow S_1$
$[]\ B_2 \rightarrow S_2$
$\ldots$
$[]\ B_n \rightarrow S_n$
od

The command contains n entities of the form $B_i \rightarrow S_i$ (separated by the symbol $[]$), where B_i is a Boolean expression and S_i a command. $B_i \rightarrow S_i$ is called a guarded command, for B_i acts as a guard at the gate $\rightarrow$, making sure S_i is executed only under the right condition. How the command can be executed? Repeat (or iterate) the following until no longer possible: choose a guard B_i that is true and execute the corresponding command S_i. Upon termination all the guards are false.

V. Functionality Illustration

Properly visualized data offer very good insight into the problems the patient has to face when coping with a situation he/she considers to be difficult. It can help to distinguish between the situation when the patient is not able to ensure some specific movement and the situation when the problem is caused by his/her psychological block.

Figure 7 visualizes several features derived from the raw data streaming from corresponding sensors: the pulse rate (computed from the raw ECG data), GSR and EIMP data measured during a chessboard scene (Figure 2). The vertical red lines indicate occurrence of unexpected events from outside the training scenario (derived from sensors' data or directly signalized by the therapeutist) that may affect the probands performance, the vertical blue lines indicate important time points in the testing scenario. In our case, the blue line indicates the time when the proband successfully completes a sub-goal of the game scenario (in the chessboard scene, the moment where the sphere is moved to the target position)–this can be automatically recognized by the system or directly signalized by the therapeutist. The bottom two graphs show the ideal XY position of the sphere as if the proband chose the straightest path to the next target position without any deviation. The subjective observation of the therapist (insertion of red lines) may differ from the internal status of the patient. The therapist assumes entering a stress event, but the sensors do not and vice versa. The sensor data could be correlated with other data to explain the stress situation and the reason for it. For example, the patient doesn't trust himself/herself to perform an exercise involving standing on heels (only thinking about it would cause stress); but he/she is able to do it (sensors can help to discover it).

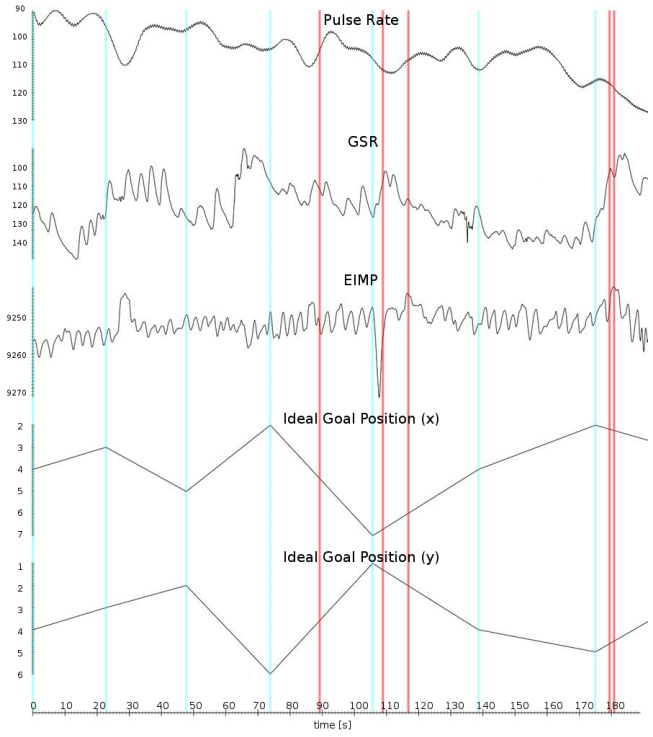

Figure 7. Visualization of selected features after data preprocessing. GSR–galvanic skin reponse measured by sensors attached to the fingers of the proband (Low levels are considered to be a clear sign of stress.); EIMP–electrical impedance of the chest (breathing frequency estimation).

VI. Future Work

The traditional model assuming rehabilitation conducted in highly-specified rehabilitation centers (clinics) puts limits

on therapy intensity and sustainability due to the high costs involved, among others. Therefore, there are already efforts to provide therapy at homes equipped with appropriate technical resources, too. Our long-term goal is to support reliable home therapy by the Cloud-Dew paradigm [20]; it means to create a network of cooperating nodes, where a node denotes a Cloud server associated with a rehabilitation center steering a set of home infrastructures. Each home system works autonomously, even if the Internet connection is not available at the moment, and in specific intervals exchanges collaborative information (analysis results, data mining models, etc.) with the center involved in the Cloud.

VII. Conclusions

Modern technologies used for the rehabilitation of patiensts with balance disorders have been a significant addition to convential procedures, whose experience and best practices have steered the development of these technologies. Application of these technologies is accompanied by production of massive data volumes that overhelm the therapists involved in the rehabilitation, so the full potential of these data is not used. A potential solution is the development data-centric therapy approaches that we call as precision brain disorder rehabilitation, which use biofeedback data and physiological data collected by a sensor network and attempt to dynamically adapt the rehabilitation process to optimally meet intended goals.

Acknowledgments

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Development of Distributed Subject-Oriented Applications for Cloud Computing through the Integration of Conceptual and Modular Programming

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Abstract - **The paper addresses the relevant problem related to the development of distributed object-oriented applications to solve large-scale scientific and applied problems in a public access computer center. The center includes dedicated resource for cloud computing (private cloud) and non-dedicated resources for traditional distributed computing. Applications generate flows of computational jobs. We propose a new approach to the development of applications. It based on the integration of conceptual and modular programming. We also create two toolkits to support proposed approach and develop applications. Applications software is based on the use of knowledge embedded in the conceptual model of the environment. It describes the parameters of subject domains, operations over parameter field, software modules (applied software) that implement operations, computational nodes, communication channels and other objects of both the subject domains and environment, including the relationships between objects. In comparison to the known tools, used for the development and execution of distributed applications in the current practice, the created toolkits provide executing application jobs in the integrated environment of virtual machines that include both the dedicated and non-dedicated resources of the center. Experiments of solving large-scale practical problems of optimization of multiextremal functions and warehouse logistics show the effectiveness of the developed applications.**

Keywords - distributed computing, subject-oriented application, workflow, toolkits, virtualized resources

I. INTRODUCTION

The rapid advancement of technologies for distributed computing have led to significant changes in the architecture of applications developed in the form of applied software packages [1]. Modern distributed applications are designed to solve large-scale scientific and applied problems in a heterogeneous distributed computing environment. It includes computational nodes connected by a communication network. A computational node is a software and hardware resource, which includes memory modules, one or more multi-core processors, hard disks and system software, which is a set of software tools that support the node operation within the environment. Environment can include clusters with nodes that have different characteristics. The clusters can be geographically distributed and belong to different organizations. As a result, there are new requirements for tools of description and processing of problem-solving schemes of end users that use distributed applications.

In general, the runtime environment architecture of a distributed application includes its applied and system components, input languages, knowledge and calculation bases, user interfaces, computing resources to execute software modules, middleware to support the interaction between software application components and computing resources, the tools of virtualizing components of the application which enable the users to enjoy open and transparent access to these features.

There are two basic approaches to the organization of applied software and solving problems in the environment. Within the first approach, it is created an abstract program following the problem-solving scheme, and then compiled a parallel program based on the obtained abstract program. The second approach is when the problem-solving scheme is executed in the interpretation mode.

An advancement of software that implements technologies of the computation organization within the environment, is the basis for the massive development of distributed applications [2]. However, the analysis of methods and tools for the implementation of distributed computing has revealed a number of the following scientific-technical problems. Tools for development of distributed applications is often oriented to a narrow class of problems from a particular subject domain. The developed applications are poorly integrated due to using different middleware, data formats and protocols of their transfer, and applying of different applied models for programming, planning of computational processes and resource load. The number of potential users of such applications is limited owing to the complexity of their development and usage by end users (specialists in subject domains) to solve their large-scale problems.

Ensuring the effective scaling of the job flow generated by the distributed application is currently one of the most fundamental and practice important research fields in accounting the subject oriented environment [3].

For example, the need to create scalable applications occurs when parameter sweep computations are performed or various hard-search problems are solved.

It is assumed that the scalable application includes a set of application programs for the parallel solution of the problem using different computational units (e.g., cores) in heterogeneous environment nodes and generates a job flows. An important scalability aspect is a problem solving time that decreases with increasing a number of computational nodes used by an application. Thus, a scalable problem has to have an ability to be decomposed into sub-problems, which can be solved as much independence as possible. Creating a system for effective management of job flows of scalable applications in the environment is a complicated and very topical issue [4].

We present two toolkits for development and use distributed applications in the environment that is organized on the basis of resources of a public access computer center. Our main contribution is providing a variety of opportunities to formulate and solve large-scale problems by the toolkits taking into account application subject domains and environment characteristics.

The rest of the paper is organized as follows. In the next section, we give a brief overview of approaches that related to the development of distributed computing. Section 3 describes a conceptual model that includes a comprehensive knowledge needed for the effective distributed computing. Sections 4 and 5 represent two toolkits for the distributed application development. Computational experiments are provided in section 6. The paper concludes with a summary of study results.

II. Related Work

Distributed applications are generally oriented to a class of problems characterized by the following properties:

- The solving of the problem requires the use of large amounts of computational resources (CPU time, RAM, disk space and other characteristics),
- It is possible a decomposition of the general complex problem into simpler (from a computational point of view) sub-problems,
- The process of solving the general problem implies the distributed solving of a set of its interrelated sub-problem,
- There is no intense interaction expected between parallel computing processes,
- The problem allows a decomposition of the data into blocks and the independent parallel processing of these blocks.

For example, problems with parameter sweep computations, as well as many search problems belong to this class.

The well-known tools of distributed computing, e.g., Globus Toolkit [5], HTCondor [6], BOINC [7] or X-COM [8] usually do not fully offer such possibilities of flexible management of the computing process to solve the problem as an experimental prediction of job execution time, event handling, providing the needed reliability degree, and its decomposition into sub-problems.

In current practice, application users can apply workflow management tools. Among them, there are the well known systems Askalon, DAGMan Condor, Grid Ant, Grid, Flow, Karajan, Kepler, Pegasus, Taverna, Triana, UNICORE, and others [9]. However, an analysis of the capabilities of these systems shows that the problems of generating and processing of application scalable flows for the public access computer center have not been solved completely [10].

In contrast to the above-mentioned tools, we represent two toolkits that are based on using a conceptual model of the environment integrating knowledge about both the problem subject domains and application runtime environment. A specialized meta-monitoring system provides all necessary information about the current states of computational resources and processes of the environment for the toolkits and applications.

Language tools of the distributed applications provide the possibility to describe the conceptual models of subject domains, they objects and basic properties, formulate problems, generate jobs, process input data and carry out other necessary operations.

Developed applications are executed in the environment with nodes that use different hardware and software platforms including various operating systems. In this regard, environment segments differ in the level of their performance and reliability.

III. Conceptual Model

The selection of the optimal configuration of the computational system to solve a large-scale problem is determined by the algorithms of constructing an effective scheme of its solving and allocating appropriate resources. The successful functioning these algorithms depends largely on the degree of completeness of information about the specifics of the problem being solved, computational characteristics and rules of system resource usage. Thus, there is a need for the development of a model that can be used in different applications and would allow their developers to provide comprehensive knowledge about the environment in a unified and standardized format into these applications.

We propose a new conceptual model of the environment. It includes five interrelated layers of knowledge. The first three layers represent computational, schematic and production knowledge. The fourth layer provides knowledge about hardware and software infrastructure. Knowledge about administrative policies is described at the fives layer.

Computational knowledge contains information on software modules for solving problems, system modules and auxiliary modules for pre-processing and post-processing of data. System modules implement the planning of computations, generating of jobs, allocation of resources, monitoring of computational processes, dynamic decomposition of problems, etc.

Schematic knowledge includes a variety of objects for describing the modular structure of the model and algorithms for the study of subject domains. The main domain objects are parameters and operations.

Production knowledge defines the rules for applying operations and allows users to select the best algorithms in the current computing situation. The order of applying productions is determined by their priorities.

The knowledge about of hardware and software infrastructure is represented by the characteristics of the nodes, communication channels, network devices, network topology and other similar information. These characteristics also include information about the failures of software and hardware.

The knowledge about administrative policies includes data about users and their jobs, management systems and disciplines of dispatching computational jobs.

The model provides the fundamental basis for the development of computation management algorithms, including algorithms for the job classification, computations planning and resource allocation. Methods and tools of its development are represented in more detail in [11].

IV. DISCOMP TOOLKIT

The DISCOMP toolkit [13] is designed to support key stages of the development and use of distributed applications, characterized by the following features.

Applied components of the distributed application are represented by the modules (programs that are executable in batch mode) that can be implemented in different programming languages (e.g., C, C++, Fortran, Pascal). Modules locate in different nodes. Each node can have multiple modules. It is possible to include legacy or non-portable (located in specialized nodes) software into the distributed application. Data transfer between the modules is carried out using files API.

The system part of the distributed application includes multi-agent components of DISCOMP to manage distributed computing processes and data sharing. These components are platform-independent, and support different operating systems (e.g., MS Windows, Linux and Mac OS X). The set of components to include into the system part is selected by application developers. The features of multi-agent system functioning for managing distributed computing are described in [12].

In the applications developed with DISCOMP, the problem is usually solved according to one weakly changing scheme, which requires dynamic management over the computational process. The problem-solving scheme is constructed in a multi-level parallel form on the basis of a problem formulation in the procedural form: “knowing *M* executes *Q*”, where *M* and *Q* are respectively the environment model and the set of modules required to solve the problem.

The execution of the problem-solving scheme is implemented in the interpretation mode. A preliminary classification of jobs for the problem-solving scheme execution allows to optimally assign resources to the modules. DISCOMP supports the environment resource virtualization. If the hardware and software resources of any node do not match the requirements of the problem-solving scheme module, the virtual machine may be launched for the execution of this module. Moreover, DISCOMP provides the integrated environment of virtual machines using together dedicated and non-dedicated resources.

The environment model and problem-solving schemes are described in text form using the XML. Fig. 1 presents fragments of the text describing the module and its parameters. Fig. 2 shows the problem formulation that includes this module.

```
<!-- Parameter specification section -->
<parameters>
   <parameter name='list' type='filelist'
          filepattern='list_%1.txt'/>
   <parameter name='result' type='filelist'
          filepattern='result_%1.txt'/>
</parameters>
<!-- Module Specification section -->
<modules>
   <module name='solver'>
      <commands os='Linux'>
         <start>./start.sh</start>
         <stop>./stop.sh</stop>
      </commands>
      <parameters>
         <input>
            <parameter name='list'/>
         </input>
         <output>
            <parameter name='result'/>
         </output>
      </parameters>
   </module>
</modules>
```

Figure 1. Module and its parameters

Language tools of DISCOMP provide the setting of conditions for processing events that occur in the computational process. They include such events as starting and stopping the module execution, calculating values of control parameters, forthcoming to limited values of environment node resource characteristics, determining node resource failures and other occurrences in the computational process.

```
<scheme>
   <stage>
      <listmodule name='solver'
       onFinish='checkResult($el_num)'/>
   </stage>
</scheme>
<control><![CDATA[
   function checkListResult (element_num) {
// Get output element value of the parameter
// “result” with the number “el_num”
      var res = DiscompAPI.getLPV('result',
      el_num);
// If element value contain substring
// "RESULT FOUND", then stop all
// modules on current stage and go next
      if ( res.match(/RESULT FOUND/) ) {
      DiscompAPI.stopStageModules (); } }
]]></control>
```

Figure 2. Problem-solving scheme in DISCOMP

The event processing includes the following actions:

- Diagnosis of starting and finishing the module execution,
- Restarting failed modules,
- Selection of a new problem-solving scheme,
- Termination of redundant computational processes when the problem solution is found,
- Identifying and troubleshooting node resource failure, and other operations aimed at improving the reliability of the computational process.

The interpreter of the problem-solving scheme receives the data about states of computing processes and resources required in event processing from a specialized meta-monitoring system [14].

V. Orlando Toolkit

The Orlando toolkit [15] provides users with a graphical language for describing subject domains in distributed applications. It also ensures problem formulations in both the aforementioned procedural and non-procedural form "knowing M, calculate Y for X", where X and Y are respectively sets of initial and target parameters of the problem. In the latter case, we apply an automatic synthesis of problem-solving scheme (abstract program). The problem-solving scheme, formed on the basis of its procedural formulation, can include the branch, loop and recursion statements. Description of subject domains and problem formulations is automatically transferred into the XML terms. The problem-solving scheme is executed in the interpretation mode.

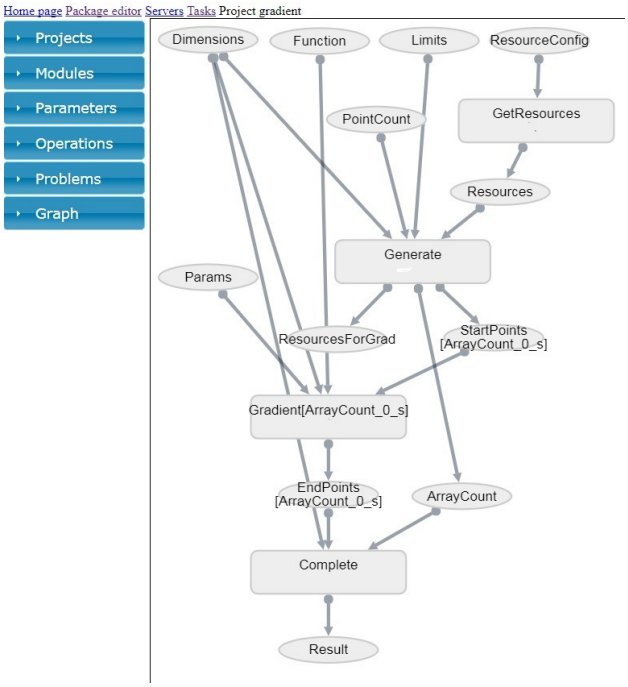

Figure 3. Problem-solving scheme in Orlando

Fig. 3 shows an example of a graphical description of the problem-solving scheme from the application that has been developed with Orlando for optimization of multiextremal functions. The parameters and operations are represented by ovals and rectangles with rounded corners respectively.

Tools for describing the conceptual model also enable to create system parameters and operations, including those representing respectively the data and modules of meta-monitoring system API. Thereby, they enables to test the module execution in environment nodes in the problem-solving process in order to the experimentally predict their execution time and determine the dynamic load balancing among heterogeneous nodes proportional to their computing performance.

An important feature of Orlando is an integration of the developed applications. The integration enables to use fragments of subject domain descriptions, software modules, input data and computation results available in other applications in the process of creating a new application. Therefore, the time needed for the development of distributed applications and computational experiments is reduced.

VI. Computational Experiments

The considered toolkits are used in the public access computer center "Irkutsk supercomputer center of the SB RAS" [16] to develop distributed applications for solving scientific and applied problems from different subject domains. Among them we can highlight the problems of optimal control of dynamic systems [17], a search of the global minimum of multiextremal functions [18], the study of biological resources of Lake Baikal [19], analysis of the energy sector security [14, 20] and optimization of warehouse logistics [21]. The experimental results reported in the above-mentioned publications, show the speedup and efficiency of the computations close respectively to the linear speedup and efficiency equal to one. From 64 to 3500 cores were used in different experiments. The experimental analysis showed that the results on the speedup and efficiency similar to the above-listed results can be achieved in increasing the number of cores of the simulated resources through increasing the dimension of the problem or reducing the permissible computation error resulting in an increase in computational load. In the paper, we provide two examples of the toolkits use.

A. Orlando Toolkit Use

The first example demonstrates the capability of the module execution time prediction within the problem-solving scheme in the application that was developed with Orlando for optimization of multiextremal functions by the multi-start method. Four operations are included in the problem-solving scheme (Fig. 3).

The *GetResources* operation provides the resource performance prediction, their allocation and reservation for other operations using the meta-monitoring system API. It implements an additional stage of the problem-solving scheme in comparison with the classic multistart method and provides the problem decomposition by the *Generate* operation based on heuristic information about resource performance.

As a rule, applied and system software of the known workflow management systems are separated. Thus, in comparison with our tools, it is very difficult or impossible for end users of such systems to implement the module execution time prediction within workflows.

The other three operations implement the standard stages of the classic multistart method. The *Generate* operation generates a set of start points and associates each resource with an array of start points proportional to its performance. Next, the *Gradient* operation implements the descent from the start point to the local minimum point of a multiextremal function using the gradient method. Finally, the *Complete* operation analyzes the results of computations and finds the minimum value of the function. This value is taken as the global minimum of the studied function.

Table 1 shows the results of solving the problem of optimization of the two-dimensional *Griewank* function [22] with 5 million start points on the 10 nodes of two clusters with different performances (5 nodes from each cluster). In Table 1, we also represent speedup (relative to solving the problem on one node with the maximum performance) and the average CPU load for the following three tactics of computing load distribution:

1) Allocation of one array with an equal number of start points to each resource,
2) Forming the excess (in relation to the number of resources) number of arrays with an equal number of start points and sending these arrays to resources when they are released,
3) Assigning to each resource one array with the number of start points, proportional to the resource performance determined by the *GetResources* operation.

TABLE I. COMPUTER CLUSTERS

Computing process parameter	Tactics 1	Tactics 2	Tactics 3
Problem-solving time in seconds	1580	1380	1096
Speedup	4.54	5.20	6.54
Average CPU load	0.60	0.69	0.87

The advantage of the Tactics 3 is obvious. Fig. 4 demonstrates the improvements of computing process parameters in percentages for the Tactics 3 vs Tactics 1 and Tactics 3 vs Tactics 2.

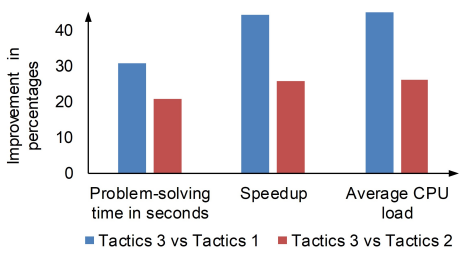

Figure 4. Computing process parameter improvements

The nodes had different numbers of cores (16 and 32) and RAM sizes (32 and 64 GB). The experiment showed that the size of RAM is not significant. Opposite, the total number of floating-point operations performed per second at the node significantly affects on the problem-solving time. In the experiment, the coefficients reflecting the node performance for two clusters relatively the solved problem were equal to 0.49 and 1 respectively.

B. DISCOMP Toolkit Use

The second example shows the effectiveness of the application that developed with DISCOMP for simulation modeling of warehouse logistics. We developed the sweep parameter application and used it in practice at the refrigerated warehouse of the Co Ltd "Irkutsk Khladokombinat" that is the second in terms of a storage volume in Russia from the Urals to the Far East to solve the following optimization problems:

1) Improvement of loading and unloading processes,
2) Optimizing the customer service,
3) Modeling structural and parametric characteristics of the warehouse object re-equipment.

Fig. 5 shows the problem-solving time comparison in dedicated, non-dedicated and together used resources. Obviously, in the last case, the integration of dedicated and non-dedicated resources using the DISCOMP provides a significant decrease in the problem-solving time for three problems. In order not to exceed resource use quotas for center users, DISCOMP used only free slots determining resource cores that are used or can be used during a certain time interval in job management system schedules of non-dedicated resources.

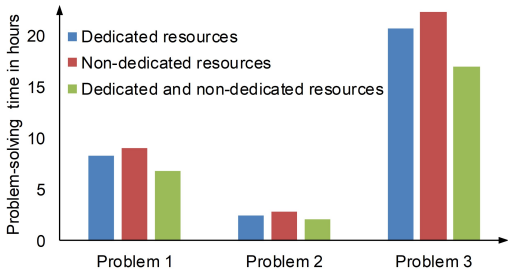

Figure 5. Problem-solving time comparison

Fig. 6 and Fig. 7 illustrate the obtained speedup and efficiency in dedicated and non-dedicated resources used together in comparison to the linear speedup and efficiency equal to 1 correspondingly.

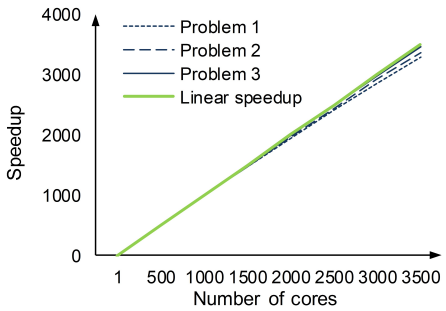

Figure 6. Speedup vs the number of cores

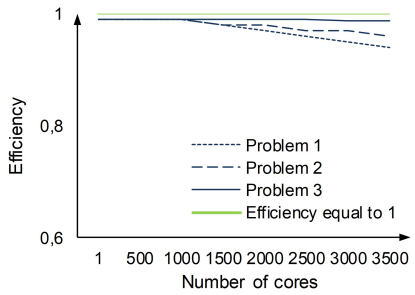

Figure 7. Efficiency vs the number of cores

Thus, the effectiveness of distributed computing with the developed application is obvious.

VII. CONCLUSION

The paper addresses the relevant issue of the application development in a heterogeneous distributed computing environment taking into account the specifics of subject domains of problems that have been solved in the public access computer center. We have developed two high-level toolkits to create and apply object-oriented distributed applications.

DISCOMP is predominantly designed for trained professionals, who are themselves able to describe subject domains and problem-solving schemes in the XML terms. It also provides distributed computing in the integrated environment of virtual machines using together dedicated and non-dedicated resources.

Orlando gives its users a visual graphic interface that makes it easy to perform the creation and use of distributed applications. It enables to use system modules in the problem-solving scheme for the resource performance analysis and prediction of the execution time for applied modules.

Applications developed with the represented toolkits show high effectiveness in solving scientific and applied problems.

ACKNOWLEDGMENT

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IMU based human movement tracking

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Abstract - The paper describes an inertial measurement unit based wearable, rehabilitation movement tracking device, which can be used for human hand movement tracking. Tracking the hand movements of the patient during rehabilitation and tremor assessment is a difficult but very important task. Our realized hardware employs a multi-sensor fusion based solution, where the data is taken from multiple axis accelerometer and gyroscope sensor devices. Multiple movement tracking sensor devices can be combined together and the data can be transferred wirelessly into a central DAQ device. The setup is able to provide real-time measurements and it is under testing in various environments. The paper describes the results of our hardware development with the description of its main functionalities.

Keywords

Patient movement monitoring, tremor assessment, wearable sensor device

I. INTRODUCTION

Human hand motion can be broadly divided into two categories: voluntary and involuntary. Voluntary motion is intentional, such as grasping a glass. Involuntary hand motion can be captured live, when the healthy patient's hand is slightly moving/oscillating, even when he/she is trying to keep it still. This normal movement caused by the small imperfections in the human body's biomechanical feedback mechanisms. Tremor is basically an uncontrolled involuntary movement. Tremor can be a manifestation of a simple muscle contraction, or a standalone disease, or a symptom of other diseases. Neurodegenerative diseases (such as Parkinson disease, multiple sclerosis, or stress/anxiety diseases) cause tremors, but drugs, and other widely consumed psychotropic substances such as alcohol, or caffeine can cause similar side effects. The hand tremor introduces coordination problems, which can be a very unpleasant symptom. The unwanted movements provide important indicator values about the status of the patient. Movement tracking requires high spatial and temporal precision. Accurate hand movement tracking is difficult as the human species developed expertise in hand usage, and humans are able to realize complex, and fast movements with their hands. The focus of our research is to build up a mobile and easy-to-use system, which can measure involuntary and voluntary hand motions in people who have a significant hand tremor.

A. Arm and hand movement parameters

Tremor can attract upper or lower extremities, or other body segments. Physiological tremor, is usually of 8-12-25 Hz frequency [1]. Higher frequencies are likely created in the parts of the arm with lower masses (hand and fingers) [2]. Wrist, elbow and shoulder tremors that occur during intentional movements have tremor frequency components of between 3-7 Hz, with most between 3-5 Hz. A key symptom of Parkinson's disease is a significant resting hand tremor, which stops temporarily when the person consciously tries to keep their hand still. Essential Tremor (ET) /called essential because it has no known external cause/ is usually 4-12 Hz and its amplitude can be worsen with position of the hand. A resting tremor of a Parkinson's disease patient is usually 3-8 Hz. The highest amplitude of hand acceleration during movement is about ±5g. The acceleration from hand vibration in normal people is about 15 mg, with a form of a Gaussian distribution, with a variance of about 15 mg.[3]

B. Tremor assessment approaches

The human hand is consequently sensitive to environmental influences such as gravity force, or additional weight. Stiles et all. [1] has analyzed how hand tremor power spectra is changing when additional mass have been added to the finger and the hand using one-dimensional accelerometer sensors. According to their work every gram of additional mass cause a decreases in the peak frequency of finger tremor with 0.85 Hz, and in the peak frequency of hand tremor decreases with 0.018 Hz. Example of Tremor-Scales is the semi quantitative Bain-Scale [4], or the Glas-Scale test [5], which is gathering information how last week(s) the patient was drinking from a cup. The QUEST (Quality of Life questionnaire) questionnaire collects more subjective and generic information about the patient's status [6,7].

Our paper is organized as follows. In Section II. we provide an overview about existing movement tracking solutions, after that we explain our motivations. In Section IV. we detail the identified requirements of the monitoring sensor device and propose a hardware solution for movement tracking, additionally we introduce its realized

internal architecture, and provides information about its performance. Finally in Section V. we conclude our work.

II. STATE-OF-THE-ART

A. Generic movement tracking solutions

During last decades many movement tracking solutions emerged from different areas, using various technologies such as: video-based image analysis (Zebris SyncLightCam [8], SkillSpector [9]) Qualisys[10], radio frequency/ultrasound based solutions such as Cricket[11], optical (IR) pattern based solutions such as Microsoft Kinect v1/v2 [12], examples of other commercial game controllers like the Nintendo Wii remote/Remote Plus(3-axes accelerometer, Infrared (IR) camera, combined with 3 gyroscopes), PlayStation Move (3-axes accelerometer, two gyroscopes (one with 2 axes and one with a single axis), and 3-axes magnetometer) can be also used to track body movements.

B. Hand movement tracking solutions - glove-based systems

Glove-based systems usually build up from a cloth glove with sensors sewn into it. Such systems use mechanical trackers and non-contact position measurement devices. Examples such devices are: Humanglove - hall-effect sensors based[13]; Smart Glove and Rapael[14] - flex and flexi-force sensors based; 5DT Data Glove Ultra [15]- optical-fiber flex sensors based. Even though these technologies provide motion capture of extremities, they are not really suitable to be used for tremor monitoring.

C. Tremor filtering devices

There are devices on the market to filter the unwanted tremor caused by Parkinson's disease, multiple sclerosis, or old age problems. TechFilter from Technaid Ltd. [16] is an adapter connected between the mouse and the computer. The filter suppresses undesired tremor movement from the overall movement described by the mouse in real-time; it only remains the voluntary part of an action, making easier the movement of the pointer and the access to programs. Tremor filtering is a frequently used feature in tele-operation based robot systems supporting minimal invasive micro-surgery procedures. One good example is the Preceyes eye micro-surgery robot [17,18], which firstly decouples the hand movements from the surgery instruments (tele-operation mode) and removes the involuntary hand movements of the doctor during minimal invasive eye surgery.

III. MOTIVATIONS

The aim of our research work is to design and realize a mobile data acquisition system using wearable sensor(s), to monitor continuously patient's hand movements. We are transmitting the acquired data to a smart phone, for further analysis of all the wanted and unwanted patient micro/macro movements. The realized software and hardware solution is targeting to assess and monitor epilepsy, neurodegenerative diseases, essential tremor, and can be effectively used for drug therapy assessment, or dose setup. The system is able to monitor movements of extremities, and also suitable to capture the movement of other body segments. Our aim is to provide a detailed, quantitative, and objective representation of patient's hand movement/tremor characteristics to the clinicians, thus enable optimized treatment strategies.

IV. THE PROTOTYPE SYSTEM - OVERVIEW

Before we have started to design our prototype system, we have evaluated the available movement measurement technologies. As MEMS (micro-electro-mechanical system) become available on the market-, they have opened up a cost effective and still precise alternative solution to monitor movements. We have build up from scratch various movement tracking devices using different MEMS such as MPU9250 [19], and Xsens MTi-1 [20], and evaluated their performance in-house. From the beginning have declined all potential wired connectivity solutions, as user friendliness, body size independency, and high configurability were important system feature requests. The realized prototype system builds up from sensor device(s) and a main central DAQ device. Each sensor device is communicating with the central DAQ de-vice wirelessly (using WiFi, and alternatively Bluetooth 4.2 Low Energy /LE/ communication). In our setup with WiFi based communication: maximum 16 sensor devices; with Bluetooth based communication maximum 7 sensor de-vices can be used in parallel. Such amount of movement sensors are enough for most of the movement tracking tasks and this statement is especially true for tremor movement tracking.

The central DAQ device can be an Android smart phone, or a tablet or a normal Windows PC. Its main duty is to processes data, archive data for further analysis and optionally can visualize the data on its own GUI. We have successfully integrated the new hardware device with our existing movement monitoring framework [21].

A. Sensor device internal architecture

We propose a low-cost, ergonomic and wireless movement tracking solution based on MEMS inertial sensors. Our solution fuses orientation data from gyroscopes, accelerometers and magnetometers in a low-complexity filter.

The implementation provides an acceptable accuracy combined with low computation, thus making it possible to develop a battery-operated/wearable device.

B. Sensor prototype features

- Sensor dimensions: 15x30x45mm (Height x Width x Length)
- Sensor weight: 12 gr. with the internal Lithium Polymer battery.
- Sensor device operation time: 1 hour.
- Sensor communication interfaces: 2.4 GHz, ISM band using

- Bluetooth® Communication for short range (15m Line- Of- Sight)
- WiFi for long range (100m).

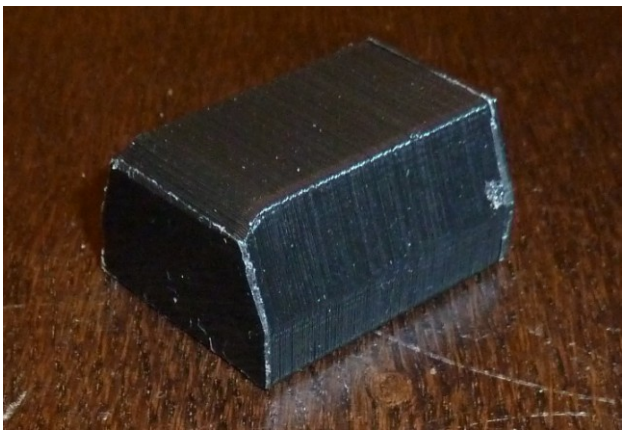

Figure 1. Sensor device prototype

- Sensor sampling rate frequency is up to 500 Hz, the internal update rate is up to 2000 Hz.

a) Sensor data output:

- 3D RAW Data (Acceleration, Angular Velocity and Magnetic Field)
- 3D Physical Data (Calibrated)
- 3D orientation in Quaternions
- 3D Angles (Joints)

b) Sensor hardware accuracy

- The spatial resolution of the sensor works within micro meter range in all axes (3D).
- The temporal resolution of the sensor works within the msec range.
- Static accuracy 0.7 degrees RMS. Dynamic accuracy 1.0 RMS. EKF algorithm is used for the accurate and robust 3D orientation

C. Sensor device internal architecture

The device consists of in-house developed electronics, with integrated IMU and power management, LiPo accumulator, embedded wireless antenna for communication, housing and a fixation strap. The hardware of the sensor device builds up from 6 main components/modules (shown in Figure. 2.):

- The IMU unit is a MEMS based 3-axis gyroscope, 3-axis accelerometer and 3-axis magnetometer. It is communication via an internal I2C bus with the hardware based filter and the MCU.
- The IMU filter unit is a hardware based filter module performs data filtering and sensor fusion using an extended Kalman filter, with autocalibration, low-and high-pass filtering, and magnetic anomaly detection.
- The Central Processing Unit (an MCU) receives the filtered movement information, stores it into the internal data storage and in parallel it transfers automatically it to the DAQ device via wireless communication.
- The Communication Unit is capable to handle to maintain the wireless communication channels: The WiFi sub-unit is capable to send with 10Mbps and the Bluetooth 4.2+ (BLE) sub-unit is able to send information about 9.6 Kbps data rate. An FTDI based communication channel (via USB) is available to realize wired communication with a host PC, but it is only used for firmware update and debugging purposes.
- The Power Management Unit provides the power for the IMU Unit and has an internal charger sub-unit. It is using a rechargeable battery/accumulator and can be charged via the USB connector.
- The Internal Data Storage is used to temporally archive the IMU data. It stores the data in a form of a ring buffer.
- LED indicator is controlled by the Power Management module, which provides visual feedback about the status of the battery. The color of the LED indicator and its flashing sequence provides the information about the status.
- ON/OFF switch is powering up or switching off the sensor device.

D. Sensor device performance parameters

The sensor hardware itself is capable to work with: 16 bit resolution tri-axis gyroscope, 16 bit resolution tri-axis accelerometer combined with a 14 bit resolution magnetometer. The gyroscope supports up to +/-2000 O/sec, the accelerometer supports up to +/-16g, and the magnetometer supports +/-4800 µT measurement range. The system's performance allows up to 500Hz sample rate, making the device usable even for high-speed sport performance analysis in the future. The communication is wireless between the sensor(s) and the DAQ device. Two communication ranges are available in the system: a short range/reduced speed communication for up to 15 meters

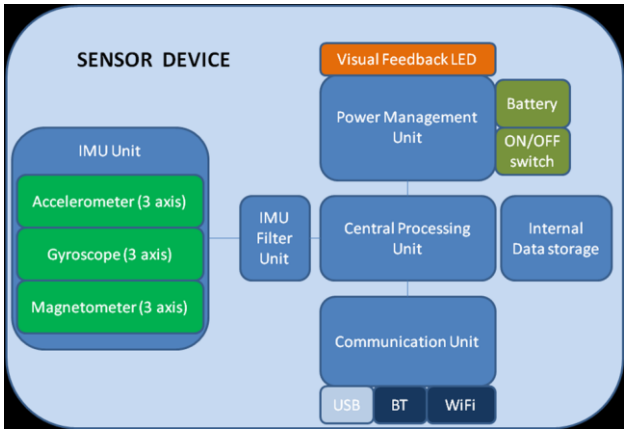

Figure 2. Sensor device internal architecture

and a long range/high speed communication for up to 100 meter.
The sensor device is capable to send raw sensor information via WiFi every 10 msec. The Central DAQ can pull movement data from the sensor device via bluetooth connection every 50 msec. The sensor device's internal storage is able to store movement data for about 25 minutes. Raw and filtered data can be received according to the setup of the movement sensor device.

E. Central DAQ

a) Data acquisition

The data is collected from the sensor devices automatically. Two independent wireless data transfer mode is available in the system for data acquisition.

When the Bluetooth communication is used for data transfer, the Central DAQ is continuously polling the sensor device. We have developed a script based cross platform Android and Windows compatible solution to acquire the data from the sensor devices.

When the WiFi communication is used for data transfer, the sensor device is sending (streaming) the movement data to the central DAQ.

b) Visualization

The new sensor device is combined with our existing data visualization system, which is already integrated with other movement capturing technologies, such as a camera based movement tracking (using Microsoft Kinect) device and an RF based movement tracking system. We are visualizing the movement data on Windows systems.

F. Sensor placement setup for tremor assessment

We are able to use multiple sensors in parallel to measure hand/arm movements. In our setup the sensors are placed on different pre-defined locations:

- P1 - at the tip of the middle finger
- P2 – wrist, upper part
- P3- lower arm

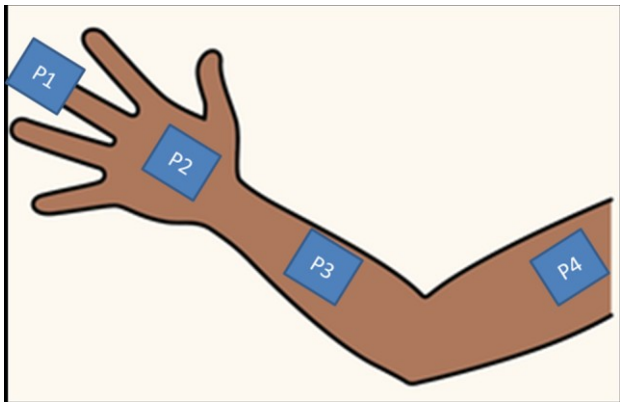

Figure 3. Sensor placement setup for tremor assessment

- P4 - upper arm

Optionally we place one sensor at the neck and one at the sternum region to have a full reference frame. With the sensors in place, we carry out a series of movements that are commonly used by clinicians when assessing tremor by visual observation. Each sensor unit outputs real-time estimates of orientation in 3D, using their Extended Kalman filter to ensure high accuracy and robustness to noise. The position/orientation recordings are used to reconstruct the movements of the individual parts of the arm and we are using FFT analysis to identify and assess the tremor in the spectrum.

V. SUMMARY AND FUTURE WORK

We have designed and realized a small, standalone, wireless, lightweight, IMU based movement tracking device, and built up a movement tracking solution from it. Our research is focusing on the seamless integration of multi-sensor IMU data to enable more objective patient hand movement assessment, which can provide valuable information about the patient's status

Our described system well suited for tremor movement assessment as the realized sensor devices are small, and mobile, thus can be applied quickly and comfortably to the patients. With our solution no cabling is needed to build up a multi-sensor hand/arm movement tracking environment, which is important as error in tremor measurements increases significantly with the introduced weight of the measurement devices and cabling. The spatial resolution of the sensor prototype works within micro meter range in all axes (3D) and the temporal resolution works within the msec range (near real-time). Furthermore, the system can easily be incorporated into existing clinical environment as any smart phone or tablet, or medical PC can acquire easily the data via wireless communication channels. Our IMU based solution has advantages over existing camera/based and wired systems, as it imposes no requirements on the layout of the room. During sensor fusion we are converting 9DOF data to a common representation format. The acquired data is processed and filtered on different levels, and we evaluate/filter sensor data in near real-time. The usage of multiple sensor devices provides us a highly adaptable environment for patient movement tracking and evaluation. The Central DAQ software enables seamless data archiving to do comparative performance analysis and visualization between the patients or retrospective if needed.

VI. ACKNOWLEDGMENTS

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BIOMEDICAL ENGINEERING

A non-arbitrary definition of the analyzing interval of sEMG signal measured during sustained low back extension

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***Abstract* - Recording of surface EMG signals over lower back muscles during sustained exercise protocols used for classification of different categories of low back pain subjects and healthy subjects are typically accompanied with measurement of kinematic parameters elaborating measurements per se and the interrelationship of surface EMG parameters and kinematic parameters. We propose an exercise protocol without measurement of kinematic parameters and examine the possibility to use spectral changes of the surface EMG signals during fatiguing static contractions in defining a time interval to be analyzed. The protocol was applied to fifteen subjects without low back pain and who were able to sustain long static contractions over 100 s. Variability of the slope of regression line that fits values of median frequency of the power spectral density function in a least-square sense was checked versus the duration of analyzed interval and start time selected. This study proposes that muscle contraction start time can be related to distinct spectral change of the surface EMG signal that are consequence of designed test protocol.**

Keywords - biomedical signal processing; surface electromyography; low back extension; low back pain; static contractions

I. INTRODUCTION

Previous research [1]–[8] exploiting changes of spectral EMG parameters during fatiguing contractions to discriminate between subjects with low back pain and those without incorporate kinematic parameters in test protocols. Such approach with kinematic variables as constitutive elements in measurement scenarios inherently requires additional equipment and measurement setup where subject position and movements are limited by recording equipment [5], [6], [8]. However, simpler versions of the measurement protocols without kinematic measurements are potentially in lack of knowledge about information such as the maximum voluntary contraction (MVC), time instance that can be considered to be start time of a contraction or information on exact body position.

Regarding the duration of contractions, independent of whether test protocols were designed to have consecutive contractions or not, a variety of choices exists. Roy, De Luca and Casavant [6] have used contractions with duration below 1 minute in the back pain study without stating exact duration. A more precise information about contraction duration is given in other studies [1]–[3], [5], [7]–[9], where durations varied in range from 5 s to 30 s.

For the purpose of this study there will be no consideration of subjects' body position that have been employed in various protocols designed to induce sustained back extension. It is worth noting that body positions differ from prone positions as we will present in this work, to standing [1], [4], [6]–[8], [10] or semi standing positions [5] using restraining devices. Yoshitake, Ue, Miyazaki and Moritani [11] reported significant difference in factors underlying muscle fatigue in prone position test protocol where subjects performed back extension exercise at angles 0° and 15° with reference to the horizontal plane.

This work focuses only on research papers dealing with classification of low back patients and healthy subjects by use of surface EMG (sEMG) obtained during sustained back extension protocols and where input parameters for classification were derived from spectral parameters. Since the median frequency of the power spectral density function (MDF) was typically used either in a simple form [6], [8] or in a more complex parameters [5], its simplest version, being the slope of the regression line of the median frequency time change (SLOPE), is selected to be used in this work.

It is our aim to demonstrate the influence of contraction duration to SLOPE. Beside the influence of the duration, there is also a lack of information on how the start time of the analyzing interval of sEMG signal is chosen. From the physical standpoint, skeletal muscles need time to reach targeted force level. We hypothesize that analyses which include the sEMG signal part corresponding to contraction segment preceding the moment when the targeted force level is reached, or close to it, can influence the resulting variables derived from spectral parameters. The target of this study was to show whether or not such influence exists in case of sustained back extension exercise where kinematic parameters are omitted as well as upper body restraints. Such result, together with proposed test protocol for sustained back extension, could lead to more extensive research in sEMG based evaluation of low back muscles and potentially

improve ability to differentiate more precisely between low back pain patients and healthy subjects.

This work focuses only on the SLOPE parameter in order to explore effects of choices of start time and duration of the selected interval of sEMG on the results variation. Proper choices are expected to reduce variation and thus improve accuracy in estimation of SLOPE parameter.

II. METHODS

A. Subjects

The limiting factor in selecting subjects for participation in this study was their ability to withstand contractions for more than 100 s in order to be able to estimate the effect of the duration. A total of fifteen male volunteers were included, none of whom have had low back pain in the last five years prior to measurement. Such long duration presented impediment for participation of low back pain patients in the study.

B. Data collection

The sEMG of the paraspinal muscles was recorded using a FREEEMG system (BTS, Milano, Italy). Pre-gelled Ag-AgCl 10 mm diameter electrodes (Ambu-Blue, Sensor, Ballerup, Denmark) were used. Each electrode pair was placed parallel to the direction of the muscle fibres of the *m. erector spinae* 30 mm lateral from the spinous process at L1-L2 interspace. The other pair of electrodes was placed at *m. lower lumbar erector spinae* at L4-L5 interspace and aligned parallel to the line between the posterior superior iliac spine and the L1-L2 interspace. After placement of the electrodes, the skin impedance was measured and was less than 5 kΩ in each subject. Data were collected at a rate of 1200 Hz using a 12-bit resolution. The sEMG signal was bandpass filtered at 20-400 Hz with a common mode rejection ratio of >100 dB at 65 Hz, and input impedance of >100 MΩ.

C. Testing procedure

Each subject was familiarized with the procedure and instrumentation. Then, the skin over lower back was shaved and cleaned with abrasive paste and alcohol. The electrodes were placed and subjects were instructed to stand on the tilting device. Subjects were instructed to hold their hands crossed having palms placed on chest. Feet and hips (pelvis) were the only body parts in contact with the tilting device creating the supporting points. In order to place subjects into horizontal position as in Fig. 1 a medical staff gradually and carefully tilted the device until horizontal position was reached. Thus, their own upper body weight was used to produce local muscle fatigue of the lower back muscles.

To achieve sustained contraction subjects were instructed to withhold horizontal position of the body as stable as possible without movements and as long as possible. The subjects were returned in the upright position upon their request.

D. Data analysis

Figure 1. The tilting device with subject placed in horizontal position

Prior to data analysis all raw electromyograms were visually inspected for signal quality. If any signal was corrupt with motion artefacts the corresponding subject was excluded from analysis or reordered for testing.

Signal processing was performed in MATLAB.

Spectral parameters

MDF is used to describe spectral changes during fatiguing contractions, where MDF is calculated from spectrogram [12]. Having in mind that sEMG signals might not satisfy the stationarity condition, a previously developed method was used to calculate spectrogram [13].

A rate of the MDF decay during the selected interval of sEMG, being the slope of regression line that fits values of MDF in a least-square sense (SLOPE), was used as an indicator of muscle fatigue [12], [14].

Envelope of the sEMG

For each sEMG signal a point in time was found when its RMS envelope reached maximum. Since recording, for each subject, results in four sEMG signals there were in general four different time instances when correspondent RMS envelopes reached maximum value. Therefore, the earliest point in time of the four time instances was defined to be a common referent time instant when RMS envelope reached maximum value: t_{MAX}.

It remains open for further studies whether the point in time t_{MAX} corresponds to the exact or approximate moment when subject reaches horizontal position.

Start time and duration

For the purpose of further analysis, start time of the analyzing interval of sEMG signal, t_S, is defined in reference to t_{MAX}: $t_S \in [t_{MAX} - 3, t_{MAX} + 9]$, where unite is second with resolution of 0.5 s. Beside the start time, duration of the selected interval is varied in range $\Delta T \in [40, 80]$ s in steps of 10 s.

Approach to statistics

For sEMG signals the SLOPE is calculated for all combinations of ΔT and t_S.

In order to quantify the amount of variation of SLOPE resulting from different start time and duration combinations, standard deviation of SLOPE was calculated for each muscle site for all durations ΔT and for three different ranges of start time: (A) $t_S \in [t_{MAX} - 3, t_{MAX} + 9]$, (B) $t_S \in [t_{MAX}, t_{MAX} + 9]$ and (C) $t_S \in [t_{MAX} + 3, t_{MAX} + 9]$. To further outline the standard deviation, average values were calculated for all five durations of the selected interval, where grouping was done for *m. erector spinae* at L1-L2 interspace (hereinafter: L1L2 group) and for *m. lower lumbar erector spinae* at L4-L5 interspace (hereinafter: L4L5 group). The reason for grouping arises from expectation that symmetrically positioned low back muscles at same spinous level behave similarly under same conditions when subjects are not individuals exposed to extreme trainings or working conditions that would significantly create a misbalance in left to right properties of the muscles as, for example, in varsity rowers [7].

III. Results

A typical example of recorded signal and its envelope is presented in Fig. 2.

An example of median frequency of the power spectral density function is graphically presented in Fig. 3 for two muscles sites, where (a) is MDF of *m. erector spinae* at L1-L2 interspace, (b) is MDF of *m. lower lumbar erector spinae* at L4-L5 interspace, and their regression lines (c) and (d), respectively.

The results showed that for all fifteen male volunteers median frequency of the power spectral density function measured over *m. erector spinae* at L1-L2 interspace was always lower than one measured over *m. lower lumbar erector spinae* at L4-L5 interspace.

The change in average values of standard deviations for different combination of both parameters ΔT and t_S is shown in Fig. 4.

IV. Discusion

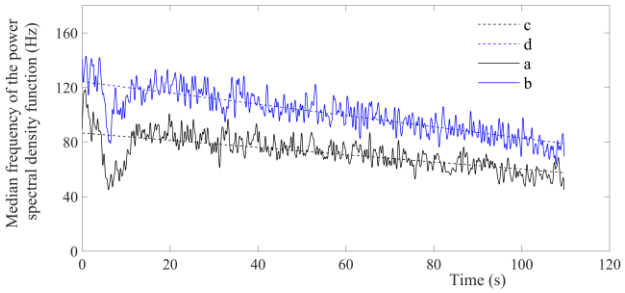

Figure 3. MDF time change and the accompanying regression lines for sEMG signals recorded over musles of the same subject. (a) MDF of right *m.erector spinae* at L1-L2 interspace, (b) MDF of right *m. lower lumbar erector spinae* at L4-L5 interspace, and their regression lines (c) and (d), respectively.

Omitting kinematic parameters

Measurement of sEMG signal over low back muscles lacking kinematic parameters may seem deficient when there is no measurement of MVC or time when certain force level is reached. Still, the testing procedure we propose results in sEMG signal having distinct change in RMS envelope of the sEMG signal at or close to the moment when subject reaches prone position. This was rather simple way to define a time moment when targeted contraction level started.

Start time of the analyzing interval of sEMG signal

The results of our study, as depicted in Fig. 4, suggest that choice of the start time of the analyzing interval of sEMG signal reflects on variability of SLOPE parameter. This was valid for both groups, L1L2 and L4L5. If the start time was chosen to be at the moment when RMS envelope of sEMG reached maximum value or 3 s before that moment, (A) and (B) in Fig. 4, the variability of SLOPE parameter was larger than in case when start time was delayed 3 s from the maximum value, (C) in Fig. 4.

Duration of the selected interval of sEMG

Fig. 4 also shows that independent from the choice of start time longer durations of the selected interval of sEMG used in analysis lead to smaller variation of the

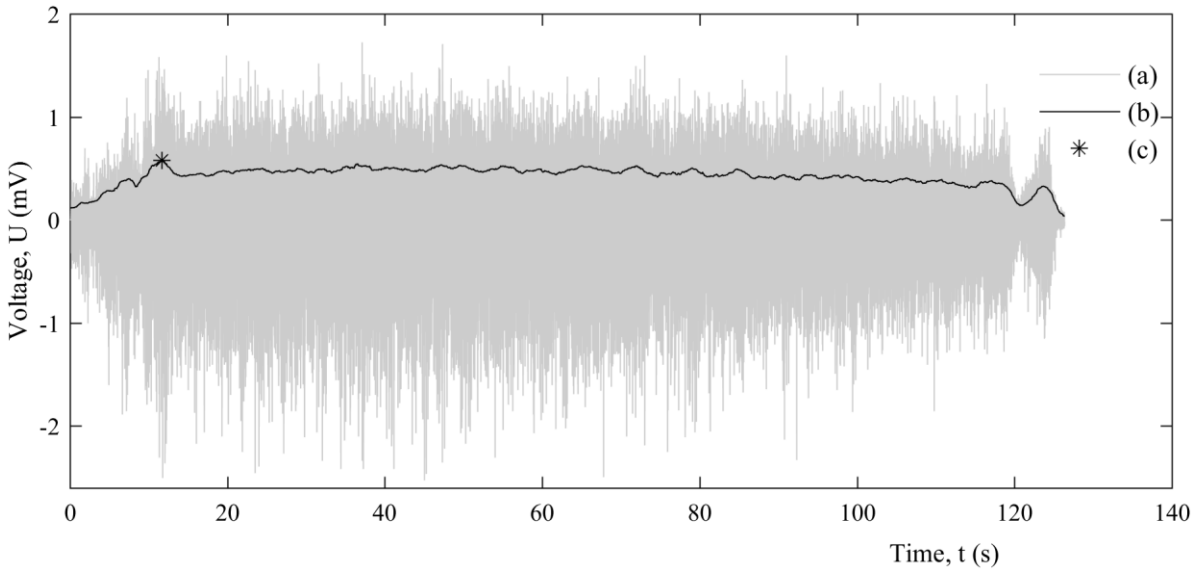

Figure 2. Example of a (a) recorded sEMG signal, (b) its RMS envelope and (c) maximum value of the RMS envelope

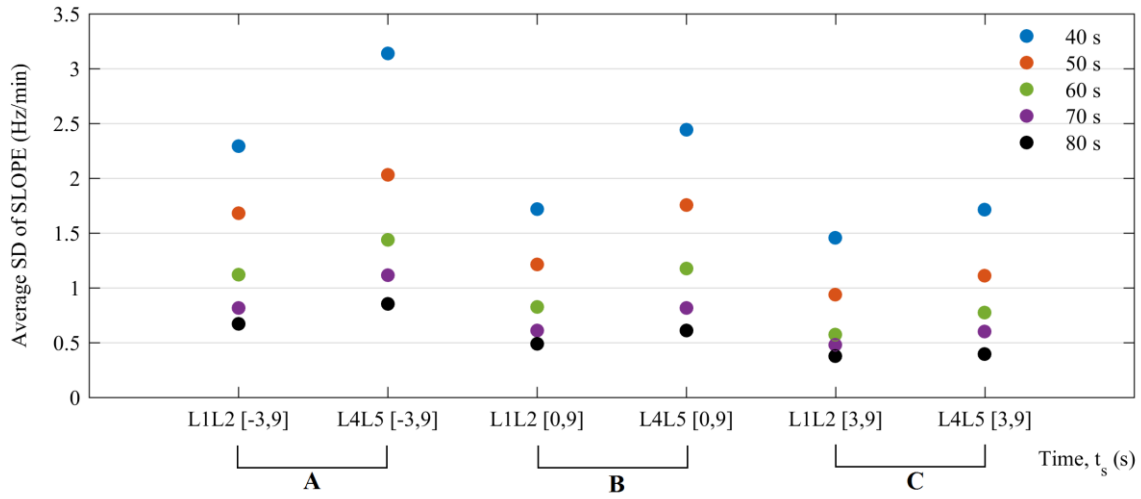

Figure 4. An average standard deviation of the SLOPE parameter for L1L2 and L4L5 groups, where start time of the selected interval is varied: (A) $t_S \in [t_{MAX} - 3, t_{MAX} + 9]$, (B) $t_S \in [t_{MAX}, t_{MAX} + 9]$ and (C) $t_S \in [t_{MAX} + 3, t_{MAX} + 9]$. It is done for different durations of the selected interval ΔT. All time variables are in seconds.

SLOPE parameter. This was valid for both groups, L1L2 and L4L5.

Onset of EMG activity

Unlike researches dealing with onset of EMG activity [15], [16] our approach did not include any onset detection, but rather avoids initial part of the contraction which causes increased variability of sEMG variables as a result of proposed test protocol. The exact time of the onset of EMG activity and interrelationship of the onset between different recording positions might offer additional information in researches dealing with healthy and back pain subjects.

Transferred variation

It can be expected that parameters calculated from or including the SLOPE parameter inherit its variability to certain extent, depending on the formulae and variability of the other parameters. It remains open, especially for short contractions up to 10 s [1], [2], [5], [7], [8] to check if variation of parameters calculated from the SLOPE parameter can be further improved.

Nevertheless, prone position without any restraining cannot prevent torsion or ensure stable sustained back extension at certain force level in a same manner as measurement provided with restraining device [1], [4], [5], [7], [8].

Simplification

Unlike specially designed devices and measurements from time of the low back pain classification beginnings [6], [17], [18] nowadays measurement and instrumentation has advanced to the point when we are able to use high quality electrodes wirelessly connected to measurement instrumentation and when spectral parameters of surface EMG signal was a choice from several available options [12].

The test protocol in this study as a whole was rather simple for implementation and most surely financially less burdensome than protocols relying on specially designed restraining devices.

V. Conclusion

We have introduced the exercise protocol for sustained low back extension without measurement of kinematic parameters. The results show that RMS envelope of the recorded sEMG has maximum value during initial part of the test protocol and can be used as a reference point to define start time of the analyzing interval of sEMG signal. Furthermore, the results show that selection of start time and duration of the analyzing interval influences variability of the slope of regression line that fits values of median frequency of the power spectral density function in a least-square sense.

Based on the results, we conclude that the start time of the analyzing interval should be defined as the time instant when RMS envelope of the sEMG signal reaches its maximum value or should be delayed relative to its maximum value. Also, the variability of the slope of regression line increases with shortening of the analyzed sEMG segment.

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A comparative study on miniature retroreflectors for totally implantable hearing aids using an optical detection of the incus vibration

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Abstract **- Optical interferometric detection of the middle ear ossicle vibration is used to get an acoustical signal needed for a totally implantable hearing aid (TIHA). In order to improve the reflectivity, we have attached a lightweight piece of retroreflector to the incus. Three different kinds of retroreflectors were investigated here, using a modified fiber-optic Michelson interferometer, based on a single mode 3x3 coupler and a high-coherence VCSEL light source. The sinusoidal vibration of the target was produced by a PZT, in the acoustic frequency range with amplitudes in the range of several picometers to hundreds of nanometer. The quadrature signals were captured and demodulated while the position of the probing beam to the retroreflector were changing. The evaluation of retroreflectors and probe beam collimating techniques was made in respect of the maximum signal-to-noise ratio and the minimum detectable amplitude of vibrations.**

Keywords - interferometry, fiber-optic sensors, non-contact vibration measurements, totally implantable hearing aid;

I. INTRODUCTION

Totally implantable hearing aids (TIHAs) are nowadays a demand for the millions of people suffering from some kind of hearing impairment. They are potent to overcome a number of drawbacks associated with conventional hearing aids such as stigmatization, feedback noise and certain limitations concerning the daily activities [1]. Despite of a permanent effort in the totally implantable hearing field to find a clinically proved solution [2], there is a number of challenges mostly associated with reliability issue of the sensing part, i.e. microphone [3].

We already demonstrated that a contactless technique based on the optical interferometry can be used for detection of the middle ear ossicle vibration to get an acoustical signal needed for a TIHA [4]. Basically, it is a miniature fiber-optic vibrometer acting as a microphone that allows implantation in the middle ear of a leaving organism. The main target could be one of the hearing ossicle, either hammer or incus. We previously found that both ossicles behave as a non-cooperative diffusive target characterized with a pretty large roughness of about 15 μm p-p [5] causing a significant decrease of reflectivity of optical beam. In order to improve the reflectivity, we have attached a lightweight piece of retroreflector to the incus.

Retroreflectors are well-known optical devices aimed for increasing the target reflectivity and reflecting back the optical beam towards the light source. They find a broad applications in different fields including common everyday use as traffic signs and security patterns [6] and high precession laser interferometric distance measurements and tracking systems [7, 8, 9]. Some kind of retroreflective means have applied in the biomedical field as well, specifically for the investigation of the middle ear acoustic response by Voss et al. [10] and Willi [11] for investigation of acoustic response of the human cadaver middle ear utilizing a laser Doppler vibrometer (LDV).

In this paper we investigated three kinds of commercially available retroreflectors; the 3M cat's-eye reflective tape made of barium titanate glass beads of 50 μm in diameter, with and without silicon resin coating, and two Nippon Carbide corner-cube (CC) retroreflectors with 80 and 240 μm of the pyramid height. These retroreflectors are made of polycarbonate (PC) plate coated with a thin aluminum (Al) layer. The retroreflectors were investigated by using a modified fiber-optic Michelson interferometer, based on a single mode 3x3 coupler, which provided a pair of quadrature signals.

II. PRINCIPLE OF OPERATION

Basically there are two kinds of retroreflectors which are widely used in laser interferometric sensing systems: cat's-eyes and corner-cubes. Their main function is to provide a high parallelism between the reflected and the incident beam, over a relatively large dynamic range of incident angle of a collimated beam. The cat's eye retroreflectors have a relatively simple construction, typically made of glass beads of high index of refraction. Theoretically, the acceptance angle of a spherical cat's-eye retroreflector is as large as 360°. In practice, it is often limited to 180°, due to immersing the glass beads into the adhesive substrate, as shown in Figure 1a. An ideal spherical retroreflector in air, made of glass having index refraction n=2, with half-sphere coated by a metal layer onto the back side, demonstrates a 3 dB decreased

reflection efficiency to about 45° of the light incidence angle [12].

The impinging light beam can be assumed to be a planar wave since it is nearly collimated by a lens in the front of the fiber, and the distance to the retroreflector is usually many times larger than the beads diameter (≈ 50 μm). There is a number of different light trajectories that come in interaction with a cat's retroreflector, as illustrated in Figure 1a. Only few of them fulfill the back reflection condition, such as in the case of the middle and right beads. The collimated light beam strikes the first surface of the bead, refracts and reflects from the bottom side and again refracts and leaves the bead as a collimated light of the same direction as it was at the beginning.

However, there is a number of parasitic beams that appear due to specular reflections from the substrate or due to scattering between the neighboring beads and substrate. Such beams could lead towards the noise generation and artifacts occurrence in the final results, decreasing in that way the overall accuracy and sensitivity of the system.

A special type of cat's-eye retroreflectors, where the glass beads is covered by a thin layer of a silicone resin, is schematically presented in Figure 1b. In this, very practical case, new interfaces appears. They negatively contribute to the back-reflection, because the majority of the rays is lost in the number of refractions. Just a small portion of the impinging beam is really reflected toward the collimator. This situation can be improved by carefully redesigning the bead index and by reducing the thickness of the coating silicone layer.

Corner-cube retroreflectors (Figure 1c) are even more sensitive than the previous counterparts mostly due to reduced acceptance angle of about 15°. The reflection efficiency drops for about 3 dB, because of necessity that impinging optical beam has to be reflected from all of three sides of the reflector. Also, a small lateral displacement of the corner cube reflector causes two fold larger lateral displacement of the reflected beam that can miss the entrance aperture of the collimator. In our case of having a permanent moving target such as incus in different directions makes the situation even more complicated. However, these retroreflectors are more stable and not wavelength dependent.

The measurement of very small amplitude of vibrations of the retroreflective target was based on a Michelson interferometric configuration, realized by a 3x3 single mode fiber-optic coupler (Figure 2). The two output arms of the coupler are the sensing (SEA) and reference arm (REA) of the interferometer while the third, needless one, is cleaved at 8° to suppress the back reflections. The central input arm is connected to the laser source (LS) via an optical isolator (OI). The other input arms are connected to InGaAs photodiodes (PD1 and PD2), which provide the two quasi-quadrature interferometric signals.

The probe beam was emitting from the SEA, collimated by a miniature spherical lens and directed towards the vibrating target. The target was a PZT road, equipped with a small piece retro-reflector (REF). The REA, being approximately equal in the optical length to the sensing one, including the free space path to the bone, was terminated by an Au sputtered surface layer (Au Mirror).

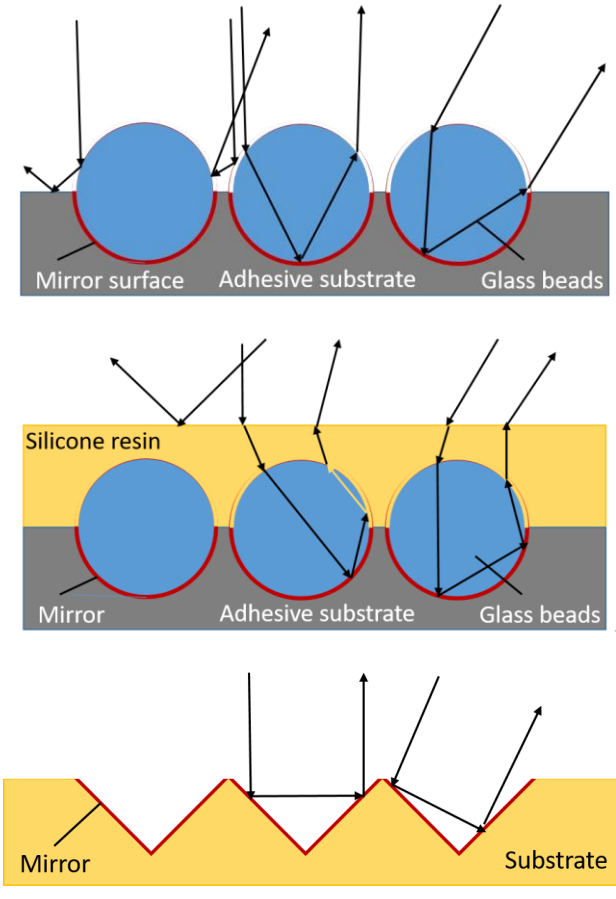

Figure 1 Schematic presentation of different retroreflectors: a) cat's-eye without coating, b) cat's-eye coated with silicone resin, c) corner cube

A vibration of the target changes the length of the optical path in the SEA and, consequently, the optical phase difference (OPD) between the two coupler arms. This OPD's changes generate the raw interferometric signals in PD1 and PD2, which can be represented by:

$$V_{PDX}(t) = X_{DC} + X_A \cos\left(k \cdot V \sin \omega t + L(t)\right)$$
$$V_{PDY}(t) = Y_{DC} + Y_A \cos\left(k \cdot V \sin \omega t + L(t) + \Psi\right) \quad (1)$$

where V and ω are the amplitude and frequency of the target vibration; Ψ is the phase shift introduced by the 3x3 coupler, approximately 120°; X_{DC} and Y_{DC} are DC signal levels; X_A and Y_A are interferometric term amplitudes, which depend on the target reflection, the coherence degree between the beams and the alignment and state of polarization of the probing beam. *L(t)* is a quasi-random motion of target (e.g. incus, or PZT rod), mainly caused by the environmental influences. This motion, usually much larger than amplitude of the vibration being measured, causes the signal instability and neither photodetector signal alone can provide a stable sound detection. However, the constant phase shift *Ψ*, generating the additional signal in the quasi-quadrature relationship, allows us to eliminate the influence of *L(t)* by the suitable

signal processing algorithm, described in [13]. In the phase recovery process, the influence of variable amplitudes X_A and Y_A is also removed.

III. EXPERIMENT

Testing setup consists of a fiber-optic configuration based on a 3x3 single-mode optical coupler, which has three output arms. One of them, called sensing arm (SEA), is terminated by a miniature spherical collimator from Corning, 220 μm in radius, designed to have the in-front working distance of 2 mm, as is shown in inset in Figure 2. The collimator generates a beam spot of about 70 μm in diameter.

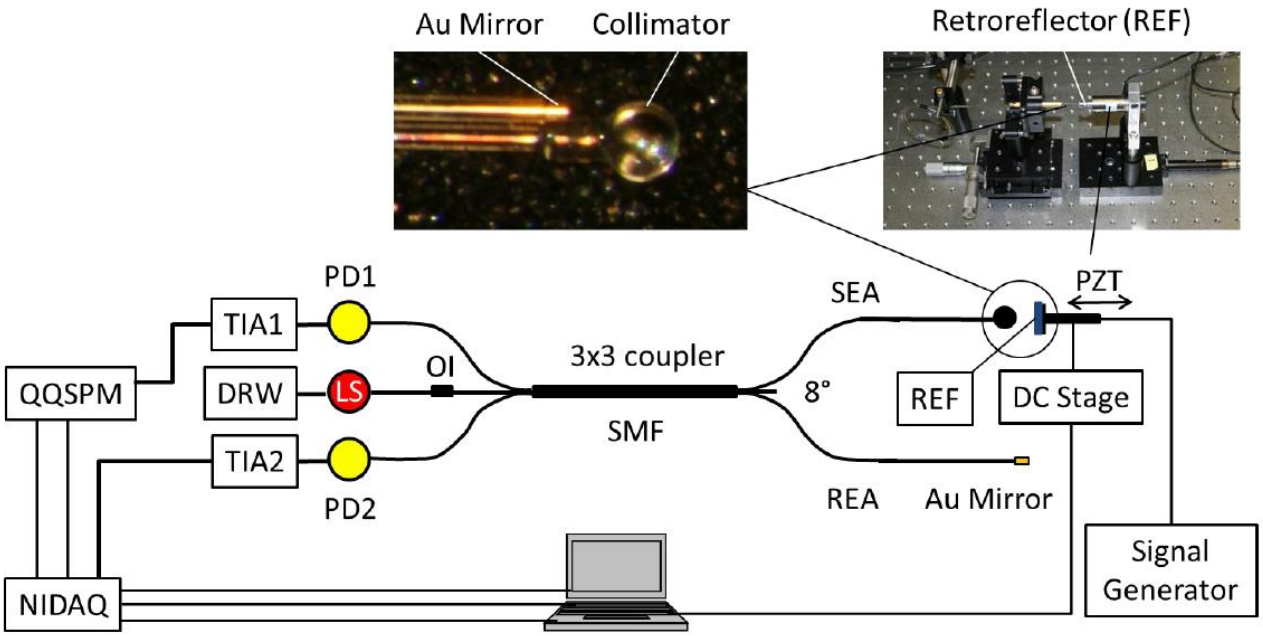

Figure 2 Schematic presentation of testing setup of quasi-quadrature signal processing module (QQSPM), PD1, PD2- InGaAs photodiodes, LS-laser source (VCSEL), DRW-driver, OI-optical isolator, REF-retroreflector

The pieces of subjected retroreflectors, of 5x5 mm^2 and 1.5x1.5 mm^2 in size, presented in Figure 3, were firmly fixed onto the calibrated PZT actuator or a cadaver incus bone [13] as a substrate. Two kinds of retroreflector scanning experiments were performed; in axial and in perpendicular directions (denoted by red arrow in Figure 3), in respect to the optical beam. The first scanning was done in order to determine the coupling curve and working distance of collimator, by moving the subjected retroreflector away from the collimator for 2500 μm, with the speed of 250 μm/s, utilizing a motorized DC stage. The second scanning was performed in the same way in order to determine the periodicity and reflection efficiency of the retroreflector.

The PZT actuator was used to produce the sinusoidal target vibrations of different frequencies from 100 Hz to 8 kHz, in the nanometer range. The second fiber-coupler arm, called the reference arm (REA), is terminated by an Au mirror produced by gold sputtering upon the tip of optical fiber. The length of these two arms are set to be almost equal with a difference of about 0.5 mm, which was sufficient to provide a stable interference signal. As we can see, the both arms are arranged to be in a close proximity as it is planned to be in the final implantation of the sensing head. The third arm is inactive and its end is cut at about 8°, to suppress the useless back reflection radiation.

The central input arm of the central fiber-optic coupler is connected to an optical isolator (OI) and further to the pigtailed VCSEL diode, as a high-coherence light source (LS) that emits radiation at 1325 nm. The VCSEL diode is driven by a constant current supply module (DRW) at 3 mA. Two other input arms are connected to the InGaAs photodiodes (PD1 and PD2), accompanied with transimpendance amplifiers (TIAs), further connected to the quasi-quadrature signal processing module (QQSPM), for providing on-line signal processing and delivering a stabilized output signal as the final result of measurement.

This signal has been further acquired by a 16 bit National Instruments digital/analogue acquisition system (NIDAQ) with 100 kS/s for 10 s of acquisition time, simultaneously with two photodiodes signals out of TIAs, In this way we were able to provide both raw interference photodiode signals necessary for the off-line signal processing by the arctangent algorithm and to compare these results with the on-line signal processed data from the QQSPM.

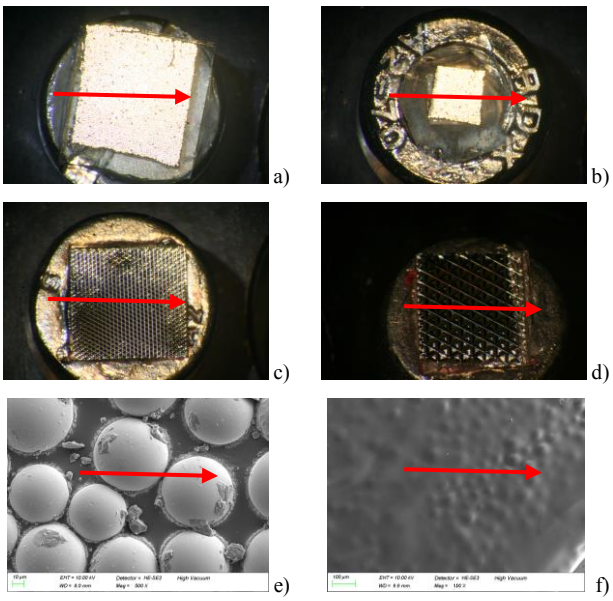

Figure 3 Retroreflectors: a) 3M cat's-eye 50 µm barium titanate glass beads without silicone encapsulation, b) 3M cat's-eye 50 µm barium titanate glass beads, encapsulated by silicone c) Nippon Carbide Al coated polycarbonate corner-cube 80 µm pyramid height (NC80), d) Nippon Carbide Al coated polycarbonate corner-cube 240 µm pyramid height (NC240); e) SEM image of 3M cat's-eye retroreflector without silicone coating, f) SEM image of 3M cat's-eye retroreflector with silicone coating; Red arrow shows scanning direction of the light beam.

IV. Results and Discussion

Figure 4 demonstrates a typical coupling curve obtained by scanning the cat's-eye retroreflector without silicone coating in the axial direction for 2500 µm that corresponds to 10 s of acquisition time with speed of 250 µm/s, in respect to the impinging optical beam. We can see the interference records of the two quasi-quadrature raw photodiode signals (red and black traces). The constructive interference signal exists in the whole scanning range due to the high coherence length of the VCSEL diode that is over 5 mm. The first 250 µm of the distance is a delay between the acquisition and DC stage starts. Maximum signal occurs at about 2 mm and this determines the optimal working distance of the spherical collimator in respect to the retroreflector. We can also see that the maximum interference signal is not so sensitive against the collimator-reflector separation as long as the reflector position is within 2 to 2.5 mm that is important for a real application in the middle ear.

Figure 5 presents raw photodiode signals obtained by scanning the retroreflective targets in perpendicular direction for 2500 µm, with speed of 250 µm/s in respect to the impinging collimated optical beam. In Figure 5a we can see a number of sharp peaks that reveal a strong back reflected signals. Periodicity of the 3M cat's-eye signal is about 50 µm that corresponds to the average diameter of the glass beads. Inset in Figure 5a depicts a back-reflected signal, which spans over about 30 µm and then diminish laterally in dependence on the position of the optical beam. However, the periodicity is not persistent all the time along the scanning path due to the random glass beads distribution and different size of the beads as we can see in Figure 3a and a SEM image in Figure 3e, respectively.

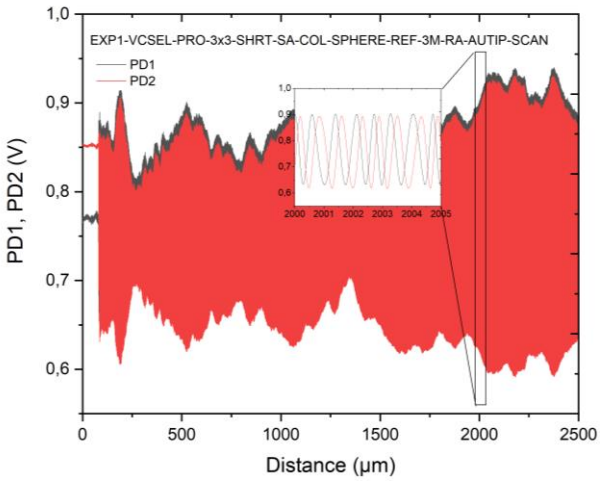

Figure 4 Two raw photodiode signals (red and black traces) obtained by scanning in the axial direction denote the coupling curve of the cat's-eye retroreflector without silicone coating. Inset presents a close look at the interference signals.

The original retroreflector features are compromised by applying a thin layer of an implantable grade silicone resin, NuSil 8440 on the top surface of the reflector acting as an encapsulation enclosure. As we can see in Figure 5b, there is a smaller number of the retroreflective peaks. Their intensity is much smaller compared to the previous case. It could be explained by majority of the specular reflection and divergence of the impinging optical beam as we pointed out in Chapter II. The main evidence for such an explanation is a SEM image of the coated retroreflector presented in Figure 3f. In order to preserve the retroreflective behavior of such a target, it is important to allow a fine adjustment of collimating optical beam in respect to the retroreflector.

Figure 5c and 5d show a small signal modulation obtained by testing the corner-cubes retroreflectors with 80 and 240 µm of pyramid height. The signals are very weak and could be barely used for our purpose to increase the incus reflectivity. However, the experiments with other different shape of pyramid array remain to be conducted.

Further investigation was performed by excitation of the 3M cat's-eye retroreflector without silicone coating at 1V and 1 kHz using a calibrated PZT actuator. The retroreflective target was shifted in 5 µm steps for 150 µm in orthogonal direction in respect to the impinging optical beam using a motorized DC stage.

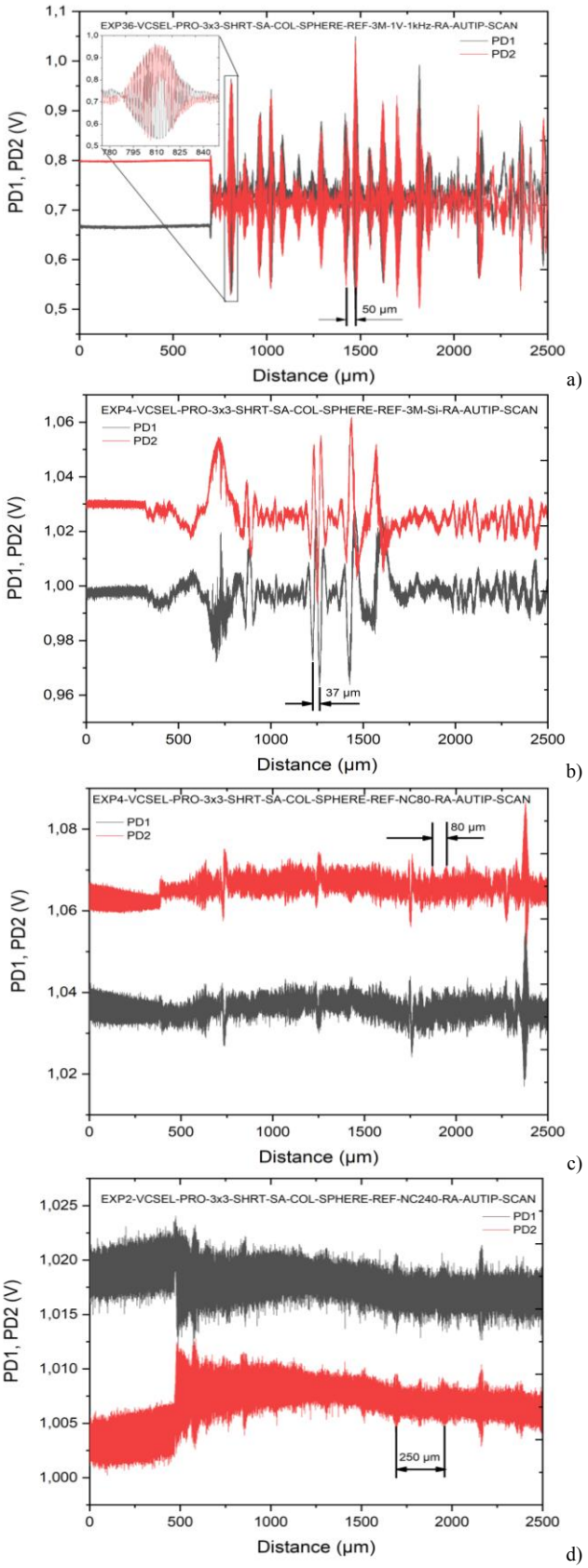

Figure 5 Two raw photodiode signals (red and black traces) obtained by perpendicular scanning denote the periodicity of the retroreflective structure; a) 3M cat's eye without silicone coating, b) 3M cat's-eye with silicone coating, c) corner-cube NC80 µm, d) corner-cube NC240 µm

In Figure 6 we present how signal-to-noise-ratio (SNR) and measured amplitude of the target vibration depend on the position of the optical beam hitting the retroreflector. As we can see, there is a periodicity of SNR starting from about 30 dB at the beginning of measurement (arbitrary chosen point at the middle of the retroreflector), then reaching a relatively low value of about 7.5 dB at around 35 µm distance and afterwards rising up again to about 30 dB and keeping this value for about 30 µm of scanning distance. Such a behavior can be explained by the retroreflector periodicity and zoomed signal shape presented in Figure 5a. There are also some artifacts associated with parasitic signals back-reflected from the retroreflector, as is explained in Chapter II.

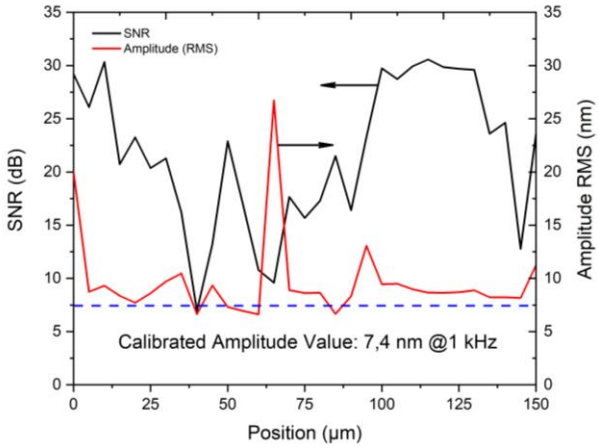

Figure 6 The signal-to-noise-ratio and the measured amplitude of vibration vs. the position of the optical beam; the real (calibrated) amplitude of 7.4 nm is denoted by dashed line

For the sake of estimation of the accuracy, the real value of amplitude vibration, obtained by independent calibration (by Polytec vibrometer) is presented as dashed line. There is a good agreement between the calibrated (blue, dashed line) and measured value (red line).

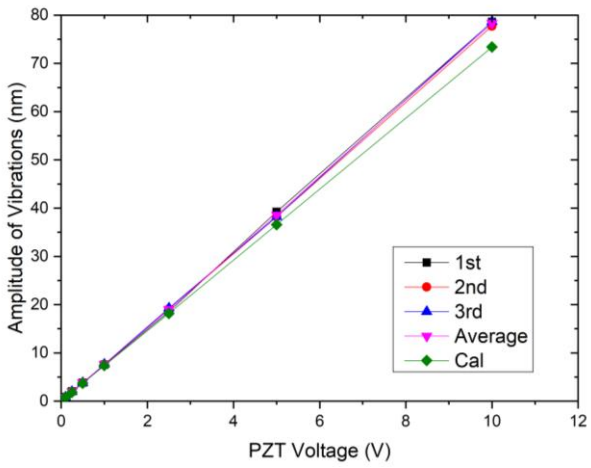

Figure 7 Amplitude of 3M retroreflective target vibrations obtained by PZT sinusoidal actuation by 0.05, 0.1, 0.25, 0.5, 1, 2.5, 5 and 10 V for constant frequency of 1000 Hz; Calibration data (green)

Diagram in Figure 7 presents results of the 3M retroreflector target vibrations produced by using a calibrated PZT actuator exposed to sinusoidal vibrations driven by 0.05, 0.1, 0.25, 0.5, 1, 2.5, 5 and 10 V for constant frequency of 1000 Hz. Measurements have been performed for at least three subsequent experiments. We can see a very good reproducibility between the three measurements and a good agreement with the calibrated values denoted by green trace. The overlapping degree depends on the amplitude of vibrations and spans from 74% to about 94% for minimum to maximum amplitude of vibrations respectively.

V. CONLUSION

A comprehensive testing and experimental validation of different retroreflective targets have been done utilizing a fiber-optic sensing interferometer and a calibrated piezoelectric transducer (PZT). We found that 3M cat's-eye retroreflector without silicone coating demonstrated the best characteristics in respect to the SNR and minimum detectable amplitude of vibrations. The overall sensitivity of about 3-6 pm/√Hz, over the acoustic frequency range, was achieved. A very good reproducibility and accuracy of measuring was obtained in experiments with calibrated piezo actuator vibrating with amplitude of 7.4 nm, @ 1 kHz, over the surface of the glass beads retroreflectors.

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Three-Year Experience with a Wireless ECG Sensor

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Abstract - **The success of performing long-term ECG measurements depends on how much the device is interfering with the user. A small and unobtrusive sensor on the skin in conjunction with a smartphone today presents a viable option because such a configuration allows also online access to cardiac services. Despite the limited choice of electrode placement, it has been shown that the ECG sensor may replace the ambulatory ECG (Holter ECG) in many cases. In this paper, we present our experience on setting up an ECG sensor to obtain the best information about heart arrhythmias. We also add experience in unconventional use of the sensor in abdominal ECG and recommendations for the future use of such devices.**

I. INTRODUCTION

The quality of ECG recordings depends largely on the electrodes, especially if ECG is measured for days. A stable long-term galvanic contact with the skin is of high importance if standard adhesive ECG electrodes for Holter monitoring are used. If the ECG device is small, lightweight and with short wires, like the patch-type ECGs, the user quickly forgets that he/she has the device on the body (unobtrusiveness). Than the main problem with prolonged ECG measurements is the sensitivity of the skin (skin irritation) to the compounds of the self-adhesive ECG electrodes, which happens with a considerable percentage of subjects (43% [1]). If this is the case and if the system is designed so, the user can reposition the device on another location on the body by using new electrodes and continue the measurement. It is of great help if the user can see the ECG signal on-line on an appropriate display, such as a smartphone. If the user is not involved positively in such procedures, it is likely that he/she will end the measurement prematurely.

In this paper, we present measurement results from our three-year experience with a one-channel ECG device (ECG sensor) attached to the skin with two standard Ag/AgCl electrodes and connected wirelessly to a smartphone where the measurements are stored. In particular, we present examples that show the particularities and problems encountered during the measurements. The paper is organized as follows. Section II gives details about the performed measurements and the involved subject, the ECG sensor and the measurement procedure; Section III presents and discusses some of the most particular and problematic measurements; and finally, Section IV concludes the paper and gives recommendations for future users on how to improve the quality of their measurements.

II. MATERIALS AND METHODS

A. Subjects

In the year 2015, users of the ECG sensor were colleges and their friends who wanted to see how the sensor works in everyday life, at night, during sport activities and even at the dentist. The ECG sensor, coupled with a smartphone for displaying the measurements, allowed the users to see his/her ECG on-line on a display, in contrast to the measurement of a standard 12-channel ECG when the person is lying and has no visual access to the measurements. In the years 2016 and 2017, when a commercial version of the ECG sensor was available (Savvy ECG [2]), many users measured their ECGs not only a day or two, but for weeks and months.

In total, we collected around 530 days of ECG recordings from 67 people. We had two groups of users. In the first one are 50 volunteers who approached us to test the Savvy ECG sensor. We have data about age and sex for this group. In the second group, there were 17 people for whom we received ECG recordings from a pilot study that is still ongoing at the Community Health Centre Ljubljana (CHC Ljubljana). We do not have any data about age or sex about the second group. The data for both groups are summarized in Table 1.

B. ECG sensor

Savvy ECG (Saving, Ljubljana) is one-channel ECG device and is the core of a system for personal cardiac monitoring. It is a small (dimensions: 130 x 35 x 14 mm) and light (weight: 21 g) body gadget fixed to the skin of the user by two standard self-adhesive electrodes. In most cases, self-adhesive wet Ag/AgCl electrodes (Skintact, T60) were used. The Savvy sensor measures a single lead ECG, differentially between the two electrodes at the distance of 8.5 cm. The sensor is covered with a waterproof and biocompatible plastic housing. It has a long autonomy (up to 7 days) and a low power wireless connection (BT4) to a Smartphone or other personal device. The ECG is sampled at 125 Hz and transmitted wirelessly to a person's smartphone running the application MobECG (Saving, Ljubljana) for visualization and interpretation of the measurements. We used the program VisECG (Jožef Stefan Institute, Ljubljana) for presentation and analysis of the recordings.

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TABLE I. RECORDINGS FROM TWO GROUPS WITH TOTAL OF 530 DAYS OD ECG RECORDINGS

Groups	*Participants*	*Sex (male/female)*	*Age (mean ± SD)*	*ECG (hours)*	*Hours/recording (average)*
Volunteers	50	24/26	52.1±19.2	12186	156
CHC Ljubljana	17	-	-	533	31-

The Savvy sensor is the commercial version of a previous differential ECG body sensor prototype intended for personal cardiac monitoring [3]. The device can support solutions to every-day problems of the medical personal in hospitals, health clinics, homes for the elderly and health resorts. Its exceptionally lightweight design allows for unobtrusive use also during sports activities or during exhaustive physical work. The ECG measurements obtained with the sensor are already proven to be suitable for medical use, e.g., monitoring in cardio oncology [4] and reconstruction of the standard 12-chanell ECG [5-7]. Even though the ECG is obtained only from one differential lead, it has been demonstrated that the quality of the signal is sufficient for basic ECG analysis, like heart beat detection [8] and detection of heart rate variability [9], or more advanced ECG analysis, like clustering of heart beats [10]. Moreover, the sensor has been used also in veterinary for successful monitoring of the cardiac activity in dogs [11, 12].

C. Placement of the ECG sensor

The ECG sensor has a short flexible wire that connects the body of the sensor (holding one electrode) with the second electrode. There are nine recommended positions of the ECG body sensor [13], which can provide appropriate amplitude of the measured ECG signal. Usually, the sensor is placed on the position of the V1 and the V2 leads of the standard 12-channel ECG such as that the voltage difference V2-V1 is measured. This position is taken as the one that is not obtrusive for both woman and men. Furthermore, in the V2-V1 lead, the P wave is often present with enough amplitude to be used in the analysis of arrhythmias.

III. RESULTS

In this section, we present some of the measurement results with examples that show the particularities and problems encountered. All ECGs are shown with speed 25mm/s and without using any additional filtering. A mark of 1 mV is present at the beginning.

A. Measurement examples

In Fig. 1, an example of a quality recording is shown. Such high QRS amplitude is seldom seen in lead V2-V1. Although the P wave is small (0.06 mV) and biphasic, it is still usable for analysis of time intervals. The small P waves in the V2-V1 lead, in comparison to the QRS, is a sign that the ECG sensor is not placed optimally for monitoring atrial signals. In such cases, we can also see that the shape of the P wave is changing throughout the breathing cycle (not present in Fig. 1). This condition is rarely seen in standard 12-lead ECG leads.

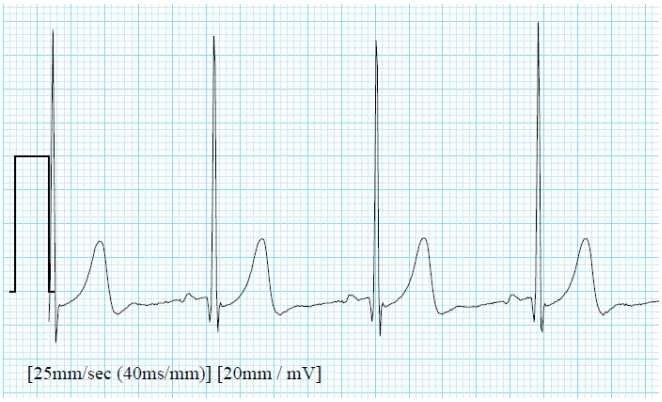

Figure 1. ECG (lead V2-V1) at 3:35 PM at rest with small P wave amplitude and large QRS

During sleep, a person often turns in bed. This situation is shown in Figure 2, where the amplitude of the ECG waves is at first small. When the body turns in sleep, the base line changes, myopotentials appear and finally the amplitude of the ECG waves is stabilized at a much higher level. Such changes are often seen in the V2-V1 lead during sleep. The presence of myopotentials indicates muscle effort; therefore, in such recordings, it is recommended not to filter them out.

Figure 2. Large amplitude change in the V2-V1 lead during sleep (ECG recording from the same person as in Fig. 1)

Atrial fibrillation produces irregular ventricular rhythm. In Fig. 3, the atrial signal is clearly seen in the V2-V1 lead although the amplitude of the QRS in this lead is low. The ECG was recorded early in the morning when an electro conversion from atrial fibrillation to normal rhythm was planned.

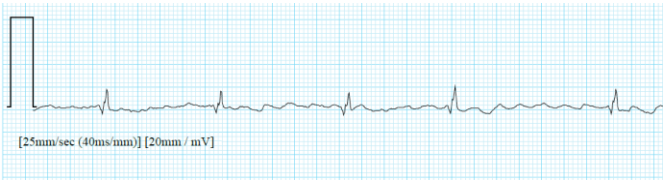

Figure 3. Atrial fibrillation and low QRS voltage in V2-V1. The wavy line is the signal from the fibrillating atria

After the electro conversion, the atrial fibrillation disappears. The heart is in the sinus rhythm and the ECG sensor at position V2-V1 clearly shows the P wave with an amplitude of 0.15 mV and small but clear QRS complex (Fig. 4).

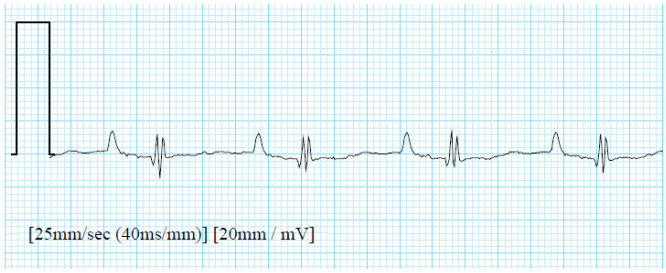

Figure 4. ECG from the same person as in Fig. 3 a day after electro conversion was successfully performed

An example of a recording during sleep, which documents many asystoles of more than 3 seconds (two of them present in the figure) is shown in Fig. 5.

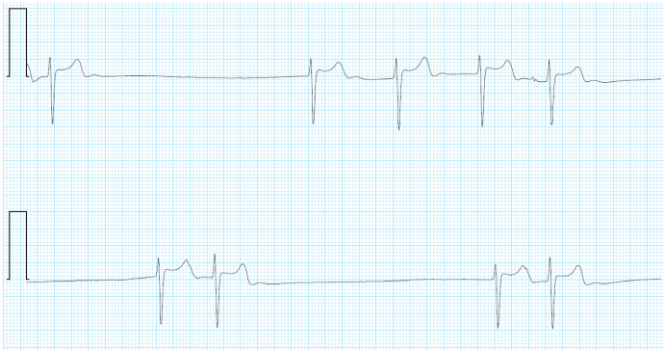

Figure 5. Arrhythmia in sleep. Long pauses lasting more than 3 seconds

B. Quality of the recordings

As already mentioned in the Introduction, good electrodes are required to make good ECG recordings. We got many bad ECG recordings, especially if they were made while moving the body (doing sports, walking, etc.). We have found that partially dried electrodes were often used in such cases. Although the electrode manufacturer (Skintact) warns that electrodes are only usable for 7 days once the pouch is open, the instructions are written on the back side of the pouch with letters that are too small to be seen by the users. In addition, users usually do not follow the instruction how to handle an already open package – "Close the opened pouch and fold-over top of pouch once or twice." Failure to observe these instructions leads to poor recordings because the electrodes become dry and lose their properties (low impedance, low noise) in a very short time.

C. Unconventional use of the ECG sensor for abdominal ECG

A modified ECG sensor with higher amplification of the analog input was used to measure tiny cardiac signals from the fetus on the mother's abdomen. More details are reported in a previous paper [14]. One example of the recording, where no filtering has been used, is shown in Fig. 6. The amplitude of the signal from the heart of the fetus is only 10-15 microvolts. By shielding the sensor with hands only, it was possible to block the power-line interference (50 Hz) completely. This successful measurement was made at home by expecting parents themselves.

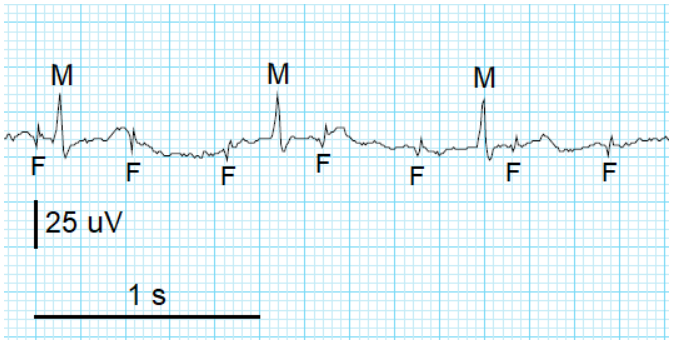

Figure 6. Abdominal ECG with QRS complexes of the mother (M) and the fetus (F) in the 5th month of pregnancy

IV. CONCLUSIONS

In three years of performing measurements with the wireless ECG sensor, we have gathered experience that can be useful for future users to improve the quality of their measurements. It can be summarized as recommendations for future use as follows:

a) For long-term ECG measurements, users should be involved in procedures in a positive way, so that the ECG sensor represents an assistant rather than a burden. On-line ECG display on the smartphone can greatly help if the user is aware at least of the basics of the ECG.

b) The user needs to be informed about the appropriate placement of the electrodes and the manipulation with the ECG sensor and the smartphone. Otherwise, the measuring equipment becomes a black box. If a user cannot handle the devices alone, another person (caregiver) should assist him/her.

c) For high quality recordings, the electrodes should be handled carefully according to the manufacturer's instructions. Otherwise they will get dry (especially wet Ag / AgCl electrodes) and the quality of ECG will be lost.

d) Using two proximal electrodes - as is the case with our ECG sensor with a distance between the electrodes of around 8 cm - it is normal that the amplitudes of the ECG waves are effected both by breathing and, in particular, by the position of the body (on the side, on the back). Such phenomena are not seen in the standard 12-lead ECG.

e) The myopotentials present in unfiltered ECG recordings help to identify the underlying conditions. Therefore, it is not recommended to use additional filtering.

f) In our measurements, the best placement of the ECG sensor is on the positions of the V1 and the V2 lead of the standard 12-lead ECG. At these positions, the sensor measures the voltage difference V2-V1 with good atrial signal (P wave) in many cases. If the P wave should be used

in the analysis and the amplitude is not large enough, the ECG sensor should be repositioned to obtain higher P waves.

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Impact assessment of the morning gymnastics “1000 movements” via ECG and sport test

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Abstract – In Slovenia every morning around 3000 elderly subjects (average age 68 years) take part in half an hour gymnastics entitled “1000 movements” in the open air. It is organized by a volunteer Society named »Šola Zdravja« (hereinafter in English “School of health” (SOH)). The Society is financially supported by Ministry of Health due to the satisfaction of the gymnastics participants, high yearly growth rate of the membership, the expansion to the new local communities. Namely, healthier elderly population significantly lowers the costs to the Health system. At the same time the positive developments generated the need to estimate the benefits of the morning exercise objectively. The aim of this study is to develop the aforementioned evaluation methodology using the questionnaires, measurement of ECG by wearable body sensors and fitness tests for elderly people. The interdisciplinary project consortium consists of a primary medical institution, a scientific research institute and a gymnastics Society.

KEY WORDS: Gymnastics “1000 movements”, questionnaire, wireless ECG, fitness tests for elderly people

I. INTRODUCTION

Physical inactivity is a global phenomenon, with estimates of one in four adults not being active enough [20]. The consequences of physical inactivity cannot be disregarded, with heightened risk of developing chronic degenerative diseases such as cardiovascular disease, cancer, respiratory diseases and diabetes. These noncommunicable diseases are said to account for almost two thirds of deaths globally [19].

Over the past fifteen years there has been a dramatic increase in research of quality of life [11] that has rapidly become central to the literature on older adults [7]. In fact, in the epidemiological study of chronic disease, traditional medical outcomes, such as morbidity and mortality, are now commonly augmented by measures of patients’ health- related quality of life (HRQL) [6]. In recent years’ physical activity is a viable public health intervention for increasing or maintaining quality of life among older adults [14].

More than 4 decades of epidemiological, clinical, and laboratory-based research have established the role of regular physical activity as an important determinant of health and functioning as people age [1, 2, 18]. In 1995 the Centres for Disease Control and Prevention (CDC) and the American College of Sports Medicine (ACSM) published a preventive recommendation that “Every US adult should accumulate 30 minutes or more of moderate-intensity physical activity on most, preferably all, days of the week” [10].

In Slovenia every morning around 3000 elderly subjects take part in half an hour gymnastics entitled “1000 movements” [4] in the open air. The exercises are organized by Society entitled “Šola zdravja”, in English “School of health” (SOH). It is a volunteer institution, well connected to the local communities. There are 140 groups covering around 50% of Slovenia. It was established in Celje and Piran in 2006, and the growth rate is 20% per year. The SOH management provides a yearly plan of educational seminars for the instructors which come out of the motivated and capable members. Each SOH group has at least 3 instructors among their members, which assures continuous presence of at least one instructor every morning from 7:30 to 8:00 a.m., 6 days per week (except Sundays and holidays), during whole year. The changing weather conditions present no obstacle for the exercise; only in rain the group finds a sheltered place, also outside.

No special sports dress is required for the program which consists of 50 different drills gathered in subgroups focused on the following body parts or goals: arms and shoulders, neck, trunk, balance and legs. The training is considered for several dimensions of exercises: aerobic exercise training (AET), resistance exercise training (RET), flexibility exercise to preserve or extend range of motion (ROM) around joints, and balance training designed to increase lower body strength and reduce the likelihood of falling [1].

Structured exercise programs are a type of physical activity and have been found to be beneficial in older

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people [12]. The benefits of exercise depend on continued participation; however, a change in lifestyle to include regular exercise is difficult for many people of all ages. Older adults have more co-morbidity, less social support, and more disability and depression than the general population; these factors have all been associated with lower exercise adherence in people with particular health conditions [3, 8]. In order to develop effective strategies for increasing participation in structured exercise programs by older adults it is important to understand the individual, social, community and demographic factors associated with adherence to this health-promoting behaviour [3, 16].

Figure 1: Gymnastics "1000 movements" (foto: Dunja Wedam).

In the next section methodology of measurements is described. Then preliminary results of measurements are shown, and the paper concludes with discussion.

A. *Results of the Questionnaire 2015/2016 for the newly established groups of the Society "School of Health"*

In 2015 in order to acquire objective opinion on the benefit/impact of the morning gymnastics, the Questionnaire related to the Society and »1000 Movements« gymnastics was prepared. In the period from September 2015 and September 2016 it was distributed among the newly established groups from several Slovene regions.

The short content of the questionnaire, questions:

1) Gender/ sex
2) Where have you gotten the information for the Society and »1000 Movements« gymnastics?
3) How long do you exercise (in months)?
4) What attracted you to join the Society?
5) Are you active in some other physical activities?
6) Observations related to changes in your mobility and quality of life after 5 months or more of continuous exercise (6 times weekly); Improvements, worsening, unchanged
7) What the »1000 Movements« exercise means to you?

In total 260 athletes/ participants from 21 newly established groups responded, results:

1) Gender:

92, 69% women 7, 31% men; Average age 64 years

2) Source of information for the » 1000 Movements« gymnastics:

Friends and acquaints 72,31 %; relatives 2,69 %; your personal doctor 0,77%; media 7,69%; I saw the athletes during exercises 9,23%

3) The majority of 260 athletes exercised for 4 -5 months already

4) Reasons to join the groups:

Adherence of the members 40,38%; exercises in open air 77,38%; easy exercises for majority of body muscle groups 68,85%; morning training 60,77%

5) Other sport activities and behaviour:

Walk 46,15%; other gymnastics 46,54 %; socializing 40,38%

6) Balance:

Major improvement 30,77%; 36,54% moderate one; Dizziness: improvement 36%; Movement of shoulders: improvement 44%; Bending of the upper body: improvement 56%; Squat on flat sole: improvement 51%, …

7) What the »1000 Movement« gymnastics means to the majority of the population:

Morning gymnastics is important for them as it strengthens their health, improves their shape and flexibility, enhance self-image, and strengthens socializing with new friends. The gymnastics reshaped their life style, life is better organized because of early waking up and cyclic daily rhythm, it is a friendly beginning of the day.

The successful operation of the Society is based on the effective management and the work of over 600 instructors and 140 group leaders. In the year 2017 the combined workload of around 60.000 hours was done. The estimated value of the volunteer work is 500.000€. This enthusiasm is based on the belief that at advanced age health and joy of life are the main values of the quality of life.

II. METHOD

B. Study Population

In the proposed study it is planned that 10 subjects will be involved. The first cycle of three evaluation techniques (Questionnaire, Sport test for elderly and ECG measurements) will be performed the first week of the exercises of the new participants. The second one will be after three months of exercises. All participants will sign informed consent for participation in the study. We will also obtain permission from Slovenian National Medical Ethics Committee.

C. Questionnaire

The 2018 questionnaire will be very similar to the one used as shown in the preceding paragraphs. A few additional problems will be added; e.g. warming up of cold hands and feet.

D. Fitness Tests

In 2017 in 9 SOH new groups nearly 100 participants were tested using Senior fitness test – SFT that assesses flexibility, balance, coordination, strength, velocity and endurance in order to measure the initial status of the subjects [15].

In the abovementioned study modified SFT tests were used: 30-s chair stand; chair sit-and-reach; back scratch; 6 min walk; deep squat; 8-ft up-and-go.

For the proposed study original test without any modification will be used.

E. ECG Measurements

The measured ECG data will be obtained from the medical graded wireless ECG body sensors [17] (see Figure 2). The sensor is unobtrusive for users because of its small dimensions, flexible design, more than seven-day autonomy and simple use, and therefore appropriate for continuous measurements during gymnastics activities. ECG measurements run continuously in the background and do not interfere with the usual mobile phone functions. However, short interruptions in measurement can always be present, for example, due to lost radio connection [5]. A preliminary pilot study confirms that wireless ECG body sensor can be used during moderate physical activities.

In this study the first ECG measurement will be done in a week of new subject starting exercise of gymnastics "1000 movements" [4]. The planned duration of measurement will be 48 hours. The second measurements will be done after three months of morning gymnastics. The duration of these planned measurement will be 48 hours as well. The potential changes in cardiovascular activity due to 3 months of exercising will be recorded during the comparison of two measurements.

Figure 2: Wireless ECG sensor position in observed measurements

The measured ECG data, that are continuously stored in the mobile phone memory, can at any time be transferred to a personal computer, including when the current measurement is still running. Further analysis is currently possible with an open source program VisECG [9] (available on http://www.savvy.si) that was developed from its research prototype version.

The VisECG program is not a replacement for standard Holter analysis programs that are able to perform a complete ECG analysis and present the results in the means of a few characteristic numbers that can be used for fast diagnosis. On the contrary, the VisECG approach provides a simple graphical presentation of BPM curve and assume an active engagement of medical expert that can devise a fast diagnosis from the long-term measurements by visual inspection.

III. PRELIMINAR RESULTS

A. Questionnaire

In the questionnaire almost all participants included in this study reported that gymnastics "1000 movements" presents satisfaction and socializing for them, but just 60% of them reported that this gymnastics present healthy life and general well-being to them; 80% of participants reported they now take a walk more frequently, and some of them reported they started to cycle and swim more often; 20% of them reported they do not need any other activity but these gymnastics. Also, 80% of participants reported they now have more friends and better social life. All participants reported they have better balance, and 80% reported they have stronger arms and shoulders; 60% reported they have less pain in legs and they have more flexible back.

B. *Fitness Tests*

The preliminary results of the Senior fitness test – SFT in 2017 and compared to those in 2018 gathered on 4 athletes only, reveal slightly positive results, but it is too early to weight the sensitivity and validity of the method.

The results of tested group are the following:

Table 1: First test, made on 13th of April 2017

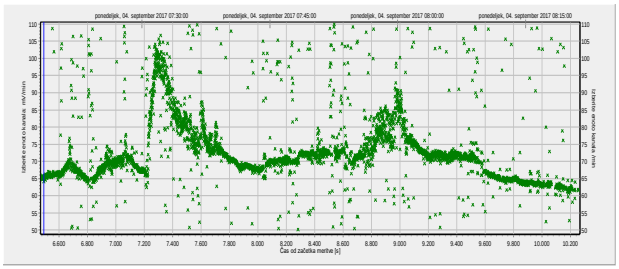
Test			Value
1.	Sit-to-stand (1 minute)		37,2
2.	Back scratch	R.	15,7
		L.	19,9
3.	Chair sit-and-reach		40,2
4.	Deep squat		2,6
5.	Step over	R.	2,8
		L.	2,7

Table 2: Second test, made on 1st of March 2018

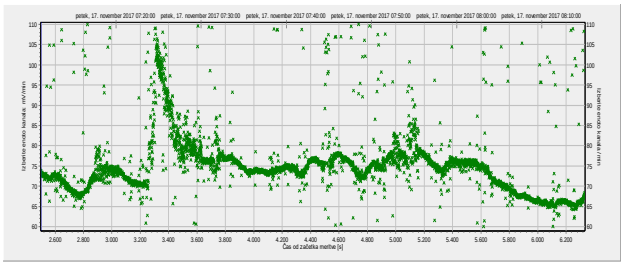
Test			Value
1.	Sit-to-stand (1 minute)		37,2
2.	Back scratch	R.	17,9
		L.	19,9
3.	Chair sit-and-reach		43,8
4.	Deep squat		2,5
5.	Step over	R.	2,5
		L.	2,5

Results of the first test show that measured subjects already participate in some other physical activities, because results are very close to the results of second test and to the maximal result for this population.

C. *ECG*



(a)



(b)

Figure 3: HR of one measured subject during gymnastics in the period of three months, (a) September 2017 (b) November 2017.

In measured ECG it is visible that heart rate (HR), approximately half an hour before starting activity was 65 beats per minute (bpm) in first measurement, and almost 75 bpm in second measurement. After the beginning of activity HR starts to rise sharply and, in both measurements, it reaches peak at the level of approximately 105 bpm.

When cardio-vascular system adopts to physical activity, and the stable state is established, HR stabilized at the level between 70 and 75 bpm in first measurement, and at the level between 75 and 80 bpm in second measurement.

Approximately half an hour after finished activity HR stabilised at the level which was approximately 5 bpm lover than before start of activity, i.e. 60 bmp in the first measurement, and 70 bpm in the second measurement.

IV. Conclusion and Discussion

The evaluation methodology presented in the paper, preliminary tested on a few subjects, is planned to be tested on the group of up to a hundred subjects. It is expected that the qualitative and quantitative data should highlight the positive psychophysical impacts of the aforementioned gymnastics and reconfirm the belief of the participants in beneficial effects of the gymnastics; better flexibility of the body, its position, increased strength, better cardiovascular fitness and better general well-being. Besides, there is a strong social factor of this gymnastics as well. Participants socialize after physical activity and that could be an additional reason that subjects feel better after few months of participating.

There are several open questions in the application of the described methodology. It is expected that the questionnaires, one at the beginning and one after 3 months of practicing the exercise, will generate very complex description of the advancements in body activities and social life. But the data are qualitative.

For the first time the ECG measurements will be available for comparison, but it is risky to judge in advance what changes in the ECG might be generated by the 3 months of the morning gymnastics. Nevertheless, for the first time the doctors will be provided by the ECG data during normal daily activities at the onset and after 3 months of exercise. It might considerably influence the treatment of their patients in in the sense that they might proscribe less medication, and advise more physical activities.

The used sport tests for elderly are primarily designed for the tests of independent mobility at home while the gymnastics “1000 movements” is composed to activities in open air in changing weather condition and changes of nature over the year. Thus, the said tests are not completely comparable, but are nevertheless widely used.

Finally, the elderly population of the participants are very determined to participate the half an hour exercise however they do not wish to be burdened further. It is the classical problem of the fact that any measurement activities influence the measured system. In our case the measured subjects are very sensitive, thus one should be very flexible to redesign the methodology in order to lessen the burden on the subjects’ life as much as possible.

The dissemination of this innovative morning gymnastics to the majority of the ageing population could considerably reduce the costs to the Health system [13]. The good practice could be transferred to other EU regions which might generate new business opportunities, as well.

ACKNOWLEDGEMENT

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(Updated February 2018).

Evaluating telemetric ECG body sensor signal in exercise stress test: Pilot study

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Abstract – The aim of this pilot study is to find out a maximal heart rate that can be assessed with telemetric ECG body sensors during exercise stress tests. Twenty subjects were randomly divided into two experimental groups. A first group of ten subjects has been tested on a treadmill and a second group of ten subjects on a cycle ergometer. Two different types of electrodes and two different sensor positions have been used on each subject by a concurrent use of two ECG sensors. Every subject made two exercise tests on the same exercise device: in the first tests both ECG sensors are attached to self-adhesive skin electrodes on the body, while in the second test, with the same electrodes, sensors are additionally fixed with self-adhesive tapes. The obtained measurements have been compared on both exercise devices, i.e., treadmill and cycle ergometer, regarding the type of electrodes, ECG sensors' positions, and the sort of sensors fixation. The results show a significant difference between non-fixed and fixed electrodes at sensor position LI on a treadmill (p=0,05), and between non-fixed positions LI and LS (p=0,001), and fixed positions LI and LS (p=0,024) on a cycle ergometer. The heart rate has been superiorly detected on the cycle ergometer and with the ECG sensor in position LI, either with non-fixed or fixed electrodes (p=1,000).

KEY WORDS: ECG body sensors, Exercise stress tests, Treadmill, Cycle ergometer

I. INTRODUCTION

Exercise stress test (EST) provides information that is useful for the diagnosis and evaluation of cardiac disease [13]. EST may be used for diagnostic, prognostic, therapeutic, and functional applications especially in regards to exercise prescription [14]. Understanding the purpose of the individual exercise test allows the test supervisor to determine appropriate methodology and to select test end points that maximize test safety and obtain the required diagnostic and prognostic information.

EST is typically conducted using a treadmill or a cycle ergometer, with monitoring of the ECG – electrocardiogram [1], ventilatory threshold [2], blood pressure [11], heart rate [8], oxygen consumption [7], general patient self-reported effort (e.g., by a Borg Scale test) and physical appearance – including chest pain and dyspnea [9]. Cardiovascular risk assessment has great importance for exercise prescription with the goal of improving clinical outcomes [5]. Until now, EST with ECG monitoring should be done only in laboratory conditions.

Even with the best laboratory EST, and with the best equipment for diagnosis there are still many sudden deaths between professional sportsmen and recreational athletes during physical activity. The need is to bring new equipment such as wireless ECG in sports to prevent such events.

The aim of this pilot study is to find out if it is possible to measure ECG signal with telemetric ECG body sensor during running or cycling in regular conditions. Considering that EST with ECG monitoring is usually conducted in laboratory conditions, we need to find out if it is possible to measure ECG during regular sports activities because that will be a big advantage for prevention of sudden death [3].

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II. METHOD

A. Study Population

Twenty subjects participate in the presented pilot study, 11 males and 9 females, age between 19 and 23 years (20,3 ± 1,03). All of them are students at the Faculty of sport and physical education at the University of Belgrade. All participants are healthy and without known previous cardiac problems.

Twenty subjects were randomly divided into two experimental groups, the first group was tested on Track Master TMX428 treadmill (6 males, 4 females), and the other were tested on Monark 928E cycle ergometer (5 males, 5 females). Before measurements, we explain the study purpose and the protocol to each participant and obtain signed written consent for participation in the study.

B. ECG Data Acquisition

ECG measurements during EST, have been made by wireless ECG body sensors, described in details in study Trobec et al. [15]. The body sensor is light and non-obstructive for users, which admits long term-exercise ECG measurements. The sensor is fixed on the body via

two self-adhesive skin electrodes. An Android application, MobECG, that runs on a smartphone, captures and displays the measured data and saves it in the smartphone memory for further processing.

There are nine positions of ECG body sensor recommended [15], that can provide appropriate amplitude of the measured ECG signal (see Figure 1). Because it is evident that muscular activity could disturb the ECG signal [15], we chose two positions, marked by LS and LI respectively, where the influence of muscular disturbances is expected to be minimal (see Figure 2).

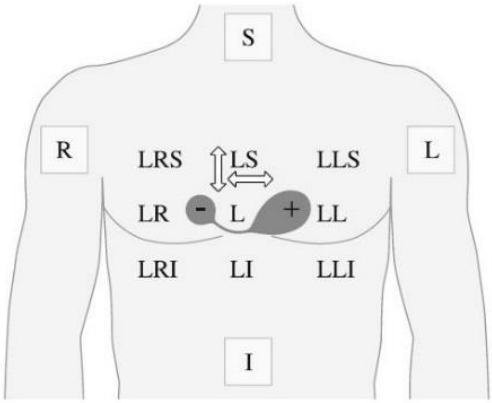

Figure 1. Labeled positions of the sensor obtained by translation in a 5 cm mesh.

ECG electrodes were positioned 5 cm apart [6]. Before positioning of electrodes, we clean the skin of subjects with diluted ethanol. Then we stick four electrodes, two for LS position and two for LI position, and connect two ECG body sensors.

Figure 2. LS and LI positions of sensors and electrodes.

Two different types of standard ECG Skintact electrodes were used for all measurements: PREMIER (T-60), recommended for general use in ECG measurements, and type ELITE (FS-VB01), recommended for Holter measurements. Electrodes were originally packed and used according to manufacturer's instructions.

All subjects have made two tests on the same device with two ECG sensors on different positions. In the first tests ECG body sensors were just attached to the electrodes (see Figure 2), while in the second test sensors were additionally fixed with a self-adhesive tape. To fix the sensors, medical Omniplast tape 1,25 cm, produced by Paul Hartmann AG, Germany, specially designed to fix Holter electrodes was used (see Figure 3). Both parts of sensors were fixed separately with two, approximately 15 cm long stripes of tape.

We found out that both types of electrodes need a few minutes to achieve adequate skin contact that is necessary for recording an optimal ECG signal. Therefore, after the placement of electrodes and sensors, the ECG recording starts, and every subject rests for five minutes before the start of EST.

C. Exercise Stress Test Protocol

EST tests were conducted using a RAMP protocol with linear intensity increments until exhaustion [4, 12]. The RAMP protocol on a treadmill starts with the speed of 5 km/h for females and with 7 km/h for males. The running speed increases for 1 km/h in every minute until exhaustion, which was typically less than 20 km/h. On the cycle ergometer the RAMP protocol starts with the load of 50 W for females and with 75 W for males. The speed of cycling 60-70 rpm was the same for all subjects and during the whole test. The load increases 25 W in every minute until exhaustion.

Figure 3. ECG body sensors additionally fixed with Omniplast tape.

D. Data Collection

After each EST the subjects sit down and rest for five minutes, while the ECG is still recorded. In the period of resting we observe how the HR is getting stabilized. After five minutes, the ECG measurements stops, and the subject is getting ready for second test. Pause between two tests was 30 minutes.

Before, the second test, with additionally fixed electrodes, we clean and dry the skin around body sensors with diluted ethanol and replace the electrodes if necessary, additionally fix the sensors with self-adhesive tape, start the ECG recording of the second test and proceed with five minutes resting period, followed by the next EST under RAMP protocol.

E. ECG Analysis

The measured ECG data, that are continuously stored in the mobile phone memory, can at any time be transferred to a personal computer, also while the current measurement is still running. The further analysis is currently possible with a custom open source program VisECG [10] (available on http://www.savvy.si) that was devised from its research prototype version. The VisECG program comprises the following basic functions:

(i) conversion of binary ECG files to VisECG native format,

(ii) global time-overview of measured data files, marked with basic statistical properties, e.g., amount of lost data, mean values, etc.,

(iii) signal preprocessing and adaptive beat detection,

(iv) visualization of selected ECG measurements in their full resolution, and with corresponding events, e.g., QRS time with R-R intervals, and

(v) generation of different ECG reports in the form of pdf files.

The VisECG program is not a replacement for standard Holter analysis programs that are able to perform a complete ECG analysis and present the results in the means of a few characteristic numbers for fast diagnosis. On the contrary, the VisECG approach provides a simple graphical presentation of heart rate (HR) with beats per minute (BPM) curve and assume an engagement of medical expert that can assess the HR by a visual inspection of BPM curve.

To analyse the BPM, we use computerized adaptive HR detector, based on a derivative of QRS complex in the ECG signal. In cases when the detector indicates some unexpected behaviour of the heart rhythm, signal was visually checked by a sports medicine expert.

F. Statistical Analysis

The statistical analysis was conducted using IBM SPSS Statistics 20 software. Descriptive statistics was made for all measurements, to compare the ECG from the first and second test (non-fixed versus fixed sensors), and from two different positions by paired samples t-test, and to compare two different types of electrodes by independent samples t-test (equal variances assumed).

III. Results

A. ECG Measurements Overview

The analyzed ECG measurements have been grouped in folders, named by depersonalized identification of analyzed subjects. All analyses were conducted using the VisECG software. A typical BPM curve of a stress test, including initial and final 5 min rest period, is shown in Figure 4. Small crosses indicate actual R-time (x-coordinate) and HR (y-coordinate).

The most difficulties with the detection of BPM signal appear closer to the limit of subjects' tolerance. In such cases, a medical expert has visually checked the ECG signal. In some cases, he found normal ECG, the erroneous BPM was a consequence of false software detection (see Figure 5), often because of excessive artefacts; however, in most cases software detector made a correct decision, even that the ECG signal was not optimal (see Figure 6). Note, that all measurements and results were visually checked and confirmed by a medical doctor.

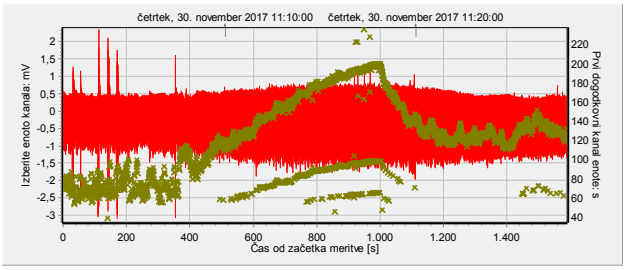

Figure 4. Typical pattern of detected BPM with adaptive HR detector on a derivative of ECG signal.

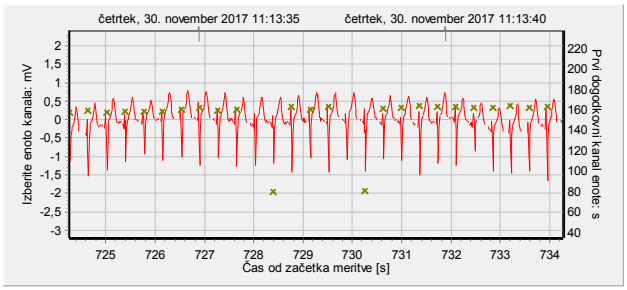

Figure 5: Visual inspection of ECG signal with detected heart beats, still at acceptable level.

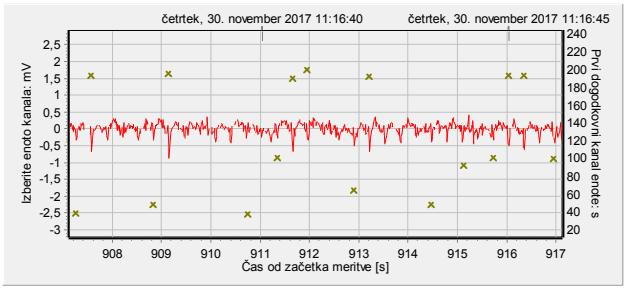

Figure 6: Visual inspection of deficiently detected heart beats, using computer supported QRS detector.

B. Statistics

The intensity of ETS can be characterised by maximal loads. The final speed on the treadmill was for females, between 14 and 16 km/h, and for males, between 15 and 19 km/h. The maximum load on the cycle ergometer was for females, between 150 and 200 W, and for males, between 225 and 300 W. Descriptive statistics of the measure results is presented in Table 1.

Table 1: Descriptive statistics of treadmill and cycle ergometer test. Legend: LS and LI - two positions for non-fixed ECG sensors; LSP and LIP - two positions for fixed ECG sensors; ALL – average of LS, LI, LSP and LIP, SD – standard deviation and HR – heart rate.

	Sensor position & fixation	Descriptive Statistics Treadmill						Descriptive Statistics Cycle Ergometer					
		Average resting HR [b/min]	Load with still assessable HR [km/h]	HR at load in previous column [bpm]	Maximum HR [bpm]	Stabilized HR [bpm]	Time to stabilized HR [min:sec]	Average resting HR [bpm]	Load with still assessable HR [W]	HR at load in previous column [bpm]	Maximum HR [bpm]	Stabilized HR [b/min]	Time to stabilized HR [min:sec]
Mean	ALL	93,63	11,95	168,43	212,68	109,48	2,35	91,13	186,25	174,25	195,53	110,90	2,30
	LS	80,60	10,40	156,60	212,60	108,70	2,40	83,10	147,50	155,40	195,90	112,40	2,50
	LI	80,40	11,00	162,40	212,10	107,00	2,40	83,70	205,00	183,90	194,30	112,50	2,50
	LSP	106,90	12,90	177,60	211,80	111,00	2,30	98,70	177,50	173,00	195,90	109,50	2,10
	LIP	106,60	13,50	177,10	214,20	111,20	2,30	99,00	205,00	184,70	196,00	109,20	2,10
±SD	ALL	16,41	3,96	28,18	8,67	13,11	0,48	11,86	50,94	19,21	7,17	9,68	0,56
	LS	5,74	4,09	28,17	10,92	13,60	0,52	10,95	38,10	24,21	6,74	9,50	0,53
	LI	8,72	3,89	35,41	11,62	14,57	0,52	11,05	45,34	6,33	7,01	8,82	0,53
	LSP	12,43	4,18	20,83	7,05	13,03	0,48	7,13	46,85	17,23	8,45	10,32	0,57
	LIP	11,70	3,38	24,22	4,24	12,81	0,48	7,13	45,34	7,42	7,36	11,00	0,57

Descriptive statistics of treadmill test show the maximal load where ECG signal is still acceptable for assessing HR at position LS at 10,4 km/h (± 4,09 km/h), and at position LI at 11 km/h (± 3,89 km/h), but when sensors were additionally fixed results improved to the level of 12,9 km/h (± 4,18 km/h) at position LSP, and to the 13,5 km/h (± 3,38) at position LIP. Descriptive statistics indicate differences between non-fixed and fixed ECG sensors in both positions, e.g. resting HR is slightly higher with fixed-position, because tests with fixed sensor positions have been done after the tests with non-fixed sensor positions.

Descriptive statistics of cycle ergometer test show the maximal load where ECG signal is still acceptable for assessing HR at position LS at the load of 147,5 W (± 38,10 W), and at position LI at the load of 205,0 W (± 45,34 W), what is also maximal load. When sensors were additionally fixed results at position LSP improved to the load of 180 W (± 46,85 W), and at position LIP result was maximal, the same as in the first measurement. An example of ECG signal during visual inspection is shown in Figure 7 for LS (above) and for LI (below).

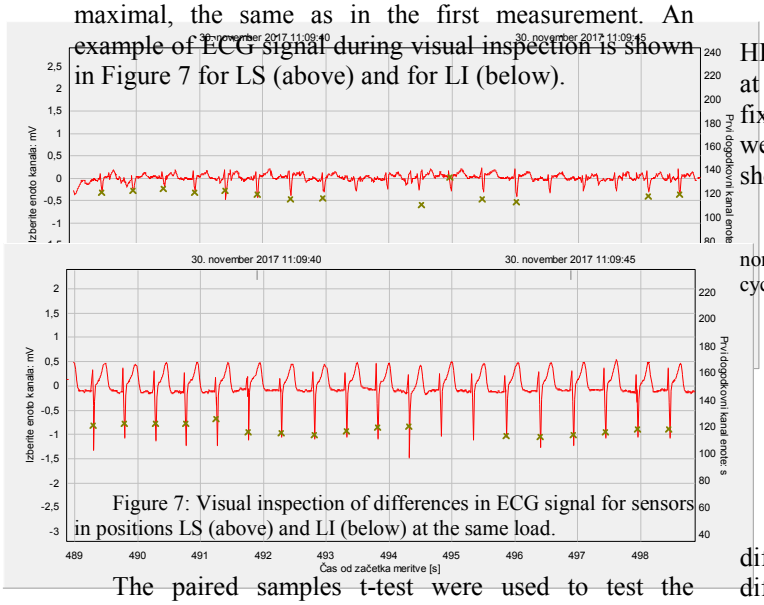

Figure 7: Visual inspection of differences in ECG signal for sensors in positions LS (above) and LI (below) at the same load.

The paired samples t-test were used to test the significance of statistical differences between maximal assessable HR BMP obtained by fixed and non-fixed sensors on treadmill and cycle ergometer. Differences have been taken as statistically significant if $p \leq 0,05$, through the whole paper. Significant statistical differences are marked by an asterisk. The results are shown in Table 2.

For the treadmill, there is a statistically significant difference between non-fixed and fixed ECG sensors LI-LIP on position LI, but there is no significant statistical difference on position LS.

For the cycle ergometer no statistically significant differences between non-fixed and fixed ECG sensors have been found, neither on position LS, nor on position LI, evidently, because of both positions provide equal quality level of measurements.

Table 2: Paired samples t-test of maximal assessable HR on non-fixed and fixed sensors.

Device	Positions	Sig. (2-tailed)
Treadmill	LS – LSP	0,082
	LI – LIP	0,050*
Cycle Ergometer	LS - LSP	0,081
	LI – LIP	1,000

Statistical significance of differences in load, where HR can still be reliably assessed, between measurements at LS and LI sensor positions, separately for non-fixed and fixed electrodes, and for treadmill and cycle ergometer, were also tested with paired samples t-test. The results are shown in Table 3.

Table 3: Paired samples t-test for load with still assessable HR for non-fixed and fixed sensors at LS and LI positions, and for treadmill and cycle ergometer.

Device	Positions	Sig. (2-tailed)
Treadmill	LS – LI	0,673
	LSP – LIP	0,696
Cycle Ergometer	LS – LI	0,001*
	LSP – LIP	0,024*

On a cycle ergometer, there is a significant statistical difference between loads with still assessable HR on two different positions LS-LI in the test with non-fixed and fixed ECG sensors. Measurements from LI position provide higher assessable loads in both cases.

On a treadmill, no statistically significant differences have been found between loads with still assessable HR, neither on non-fixed nor on fixed ECG sensors.

Comparison of ECG signal amplitudes in measurements with two different types of electrodes was made by visual inspection (see an example in Figure 8).

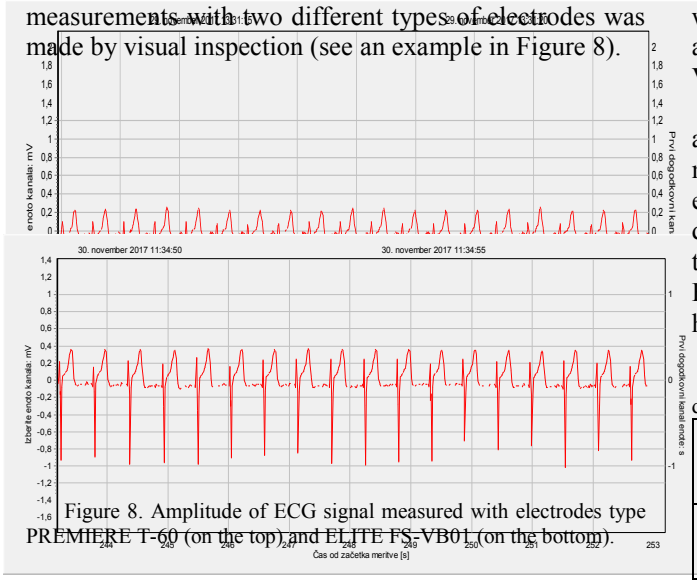

Figure 8. Amplitude of ECG signal measured with electrodes type PREMIERE T-60 (on the top) and ELITE FS-VB01 (on the bottom).

Amplitudes from electrodes of type PREMIERE T-60 were mostly between 0,6 mV and 1,0 mV, while amplitudes measured with electrodes of type ELITE FS-VB01, were mostly between 0,2 mV and 0,6 mV.

After visual inspection and determination of ECG amplitudes, independent samples t-test was made for all measurements together, from treadmill and cycle ergometer. Results are given in Table 4. We see that the differences between amplitudes of measured ECG with two types of electrodes are statistically significant. Electrodes of type PREMIERE T-60 provide significantly higher amplitudes.

Table 4: Independent samples t-test for amplitudes, measured with different types of electrodes.

	t-test for Equality of Means		
	Sig. (2-tailed)	Mean Difference	Std. Error Difference
PREMIERE – ELITE electrodes	0,000*	0,30	0,07

IV. Discussion

Wireless ECG body sensors can be successfully used for exercise stress tests on a cycle ergometer where the measured ECG signal is of adequate quality. In position LI, both tests, with non-fixed and fixed sensor, provide ECG measurements that enable a reliable determination of HR, during entire tests, so it is not necessary to fix sensors with additional tapes during test. However, position LS results are worse. With non-fixed sensors approximately 60% of the measured ECG signals are of adequate quality to assess the HR, also at the highest loads. With fixed sensors the ECG signals improves and provide approximately 75% of the measurements with adequate quality. We found statistically significant differences between ECG measured in both positions in the first test (Table 3, non-fixed sensors), and also in the second test (fixed sensors). We suggest to use sensor positions LI where ECG signals are near optimal during the whole test.

On the treadmill the quality of ECG signals is not as good as on the cycle ergometer. In the first test approximately 60% of the ECG signals from both positions are useful, and in the second test situation improved to approximately 75% of the acceptable ECG signals. There were only a few tests where the whole ECG signal was of adequate quality. Also, on the treadmill results are better at sensor position LI, but we found no statistically significant difference between ECG signals obtained from both sensor positions in both tests. However, when sensors were additionally fixed difference between both measurements at position LI become statistically significant (see Table 2.). Even that differences between positions are not statistically significant we suggest to use ECG sensors in position LI, where ECG measurements on the treadmill were of higher quality.

The reason why results on the treadmill are worse than on the cycle ergometer is in the fact, that external forces that act to the body, and consequently on the ECG sensor skin contact, are much higher during running than during cycling. Also, during a maximal running speed the upper part of body moves much more than during cycling. The external forces, as a consequence of intensive activity, disturb the skin-electrode conductivity, which results in a significant ECG base wandering with a frequency similar to the HR. Obviously, such disturbances induce many false detected beats by the HR detector.

We have tested only two different types of electrodes during EST, because, based on preliminary tests, they were selected as the best performing. Higher amplitudes of ECG signals were measured with electrodes of type PREMIERE T-60.

Our research confirm that wireless ECG body sensors can be used for non-obstructive measurements of ECG during cycling, slower running or jogging, if the monitoring of heart rhythm is in question. With such a telemetric approach it is possible, for the first time, to measure ECG signals in real conditions, e.g., when users are cycling or running in nature, during a significant activity. The analysed measurement methodology cannot completely replace the EST in laboratory, but obtained results can provide basic information about the heart rhythm status. In the case of any detected abnormality, users can be directed to further diagnostics with a standard stress test and medical personnel.

V. Conclusion

The aim of this pilot study was to test the hypothesis if wireless ECG body sensors can be used for the EST. Results show that the ECG body sensor are completely useful for the EST on a cycle ergometer. On treadmill, in

most cases, the ECG sensor provides adequate results only for running speed up to 14 km/h.

The present results motivate us for increasing the study population to increase the confidence of the obtained results.

A potential lack of this study is that only one type of electrodes was used on each device. To confirm which electrodes gives better results during the EST both types of electrodes should be tested on both devices. Finally, some alternative types of sensor fixation should be verified in order to prevent extensive movement of ECG sensors.

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Practical usage of IJS VisEcg framework for processing ECG data

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Processing of medical data has been long reserved for researches in the field. There were numerous attempts at creating unified tools for reading and processing them, however existing solutions are either cumbersome to use or proprietary with bad documentation. We present a new framework for interaction with ECG domain problems. VisECG framework aims to simplify process of gathering and processing of ECG medical data, and therefore ease the learning curve for new researches in the field. Its design enables a standardized access to multiple file formats and interfaces currently used in the field of ECG research. We developed simple applications using the framework as a core interface to access, process and write data. In the article we present our implementation and evaluate usability and functionality of the framework and produced applications.

Keywords - ECG, processing, framework

I. INTRODUCTION

Applicative use of latest research achievements occurs after the issue has been studied thoroughly and efficient solutions have been developed. Latest trends in software development value short development and implementation times. During our work on processing of ECG signal we realized that there is no efficient and easy to use framework for processing biological signal. This also means that applications using state of the art algorithms demand additional time for developing basic functionality. Complicating the matter further for developers, is a fact that manufacturers of medical equipment do not disclose their proprietary file formats or processing techniques [1,2].

VisEcg framework desires to alleviate the problem by combining most of the existing open source frameworks and techniques and provide modern interface to processing of the signals. Manufacturers usually still support export of gathered data to at least one open medical format.

II. EXISTING SOLUTIONS

There are multiple existing solutions for accessing and processing medical data. They vary from open source to completely proprietary. Ones relying on support of community have a tendency to be unmaintained and archaic.

A. PhysioNet WFDB toolbox

Probably best known amongst researchers in ECG field is WFDB toolbox [3]. It offers bindings for multiple programming languages, and most importantly, built-in access to PhysioBank databases. Together with relatively good documentation and examples this enables novice researches to quickly gain basic understanding and interaction with the signals. However, WFDB toolbox tools were designed and programmed some time ago. Its codebase is written in C and is hard to modify or maintain. Supported file formats are also mostly proprietary, and are not easily exported from modern devices. Development seems to have ceased, and MIT has started to migrate functionality to native python toolbox for easier maintenance in the future.

B. Biosig

Biosig is a software library for biomedical signal processing. It is able to process EEG, ECG, ECoG and other signals [4]. It supports a plethora of standardized file formats and provides interface to Octave and Matlab environments. It is used in several open source projects. It also offers basic signal processing capabilities. It does lack documentation or examples. However, it is useful for its wide support of file formats.

C. Open ECG Project

More than 20 years ago there were already talks and initiatives to provide interoperability and conformance of standards [5]. Using HL7 and SCP-ECG as a base upon which to build future standards and functionality. As of 2017 however, web pages and documentation of the project are no longer available.

D. RHRV project

RHRV project is an open source package for R environment, providing additional enhanced capabilities for HRV analysis [6]. It is limited to R, and therefore specialized. It does provide very good and structured documentation, with capabilities that should be implemented in a general purpose framework.

E. VisEcg

VisECG software is a version of Pcard software, that is being developed at Jožef Stefan Institute [7]. It has been updated with new capabilities over the years, staying relatively up to date. Software is not medically certified,

and uses proprietary file formats to save data. It offers basic signal processing, and semi-automatic heart rate detection. It does offer long term overview of measurements, and statistics about it. Program itself is not easily upgradable and should be updated to a newer coding practices.

III. VISECG FRAMEWORK

VisECG framework is being developed with the goal of simplifying the work processes related to ECG analysis, and therefore ease the learning curve for new researches in the field. Its design enables a standardized access to multiple file formats and interfaces currently used in the field of ECG research. It has been designed in a modular way, so that future enhancements and functionality should be added easily. Design of the framework also enables developers to cherry pick the functionality they need, and not introduce additional dependencies and bulk to their codebase. Already implemented modules include the support for WFDB and BioSig functionalities.

A. *Dependencies*

VisECG framework uses existing tested libraries upon which it builds. It is programmed in C++ language, which enables the programmers to get good performance out of their hardware, and interoperability with other programming languages and existing solutions.

Main libraries that are used are the already mentioned WFDB and BioSig. They are well tested by the community and they offer the ability to load and/or store cover most of the open file formats that are currently used in cardiography.

VisECG framework covers all file formats it supports under a single abstraction layer. This makes future additions to the file format ensures that in the future support for new file formats can be implemented if necessary, without changes to the processing layer.

Other dependencies are minor in comparison. The developer must have access to an up to date C++ compiler that supports C++17 revision of the ISO/IEC 14882 standard. Optional dependencies include *OpenMP* implementation, to provide multithreading, *curl* library for on-the fly file acquisition from databases and *zlib* and *libm* for additional file format support.

Framework also uses *MeshlessMachine* [8] for enhanced signal processing. Dependencies shown in Fig. 1 are the defaults that are provided. During framework build, user can choose which functionality he wishes to obtain.

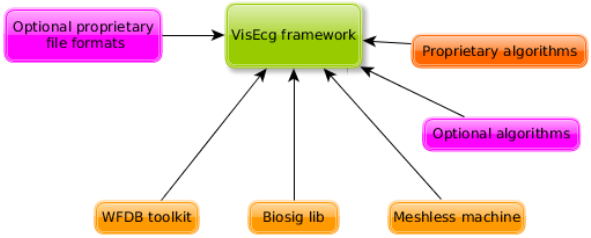

Figure 1. VisECG framework dependencies graph

B. *Functionality of the framework*

Framework is planned to cover wide variety of usages. Here we will present some of the basic and broadly used functionality that has already been implemented and tested. Due to being in the development phase, new functionality is planned to be added on a monthly basis. The extensibility of the framework enables and even welcomes such development approach. Small functionality modules can be easily added on the existing framework base.

1) *Accessing ECG files in multiple formats*

One of the important enablers of any kind of ECG analysis is the ability to access existing databases of measurements. The framework already supports the developers with means of interaction with most of the open file formats in addition to some low-level signal processing options.

A good example of how the process of dealing with various file formats is simplified is given by file format converters. A minimal working example of such a file converter code is given in Fig. 2. The framework reduces the amount of coding necessary to absolute minimum and makes possible to encode straight-forward tasks with minimal amount of code, even though C++ is being used, which is among the more verbose programming languages.

```
#include "nekgeFile.h"
#include "s2File.h"

int main(int argc, char **argv) {
  auto m1 = s2File::openFile("Input_file.s2");
  NekgeFile::saveFile(m1, "Output_file.nekge")
}
```

Figure 2. Simple file format conversion using VisECG framework. The code demonstrates how an input file in s2 format can be converted to nekge file format.

When opening a file, end user is interacting only with the exposed parts of the framework, i.e. its *Measurement* class, the structure of which is shown in Fig. 3. The single class abstraction greatly simplifies the interaction and the programmer does not need to be aware of any underlying differences between file formats or different file format capabilities. When opening any file, programmer will be given the same representation of measurement, containing signal, metadata and any additional information, depending on the file format used.

Storing files, as demonstrated on the same example, is also straight-forward and very abstract. Due to the

differences between file formats though, some information might not be available in the desired target format. In such cases, the framework does a so-called *best effort* conversion while saving the measurement. One of the examples of such limitation is the sampling frequency, for which the various file formats impose various limitations; e.g., some file formats only accept-integer values. VisECG framework rounds the frequency and saves samples as-is. It is up to the developer to be aware of such limitations and pre-process the data before saving, to ensure data is saved as desired.

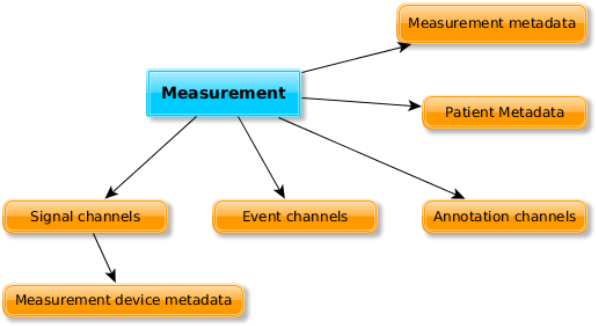

Figure 3. Exposed measurement data. The most fundamental class of the framework – Measurement – contains the data types that can be stored in a any of the known file formats for ECG measurements.

2) Resampling

An option is implemented for resampling of the ECG signal, using an algorithm based on moving least squares (MLS), demonstrated in [9]. There are also some simpler options available for resampling and filtering of the signal, which are exposed from the underlying WFDB library. These depend however, on the user of the framework including WFDB library into his build.

3) Annotations and VisECG file format

The existing ECG formats almost uniformly lack the options for annotating ECG measurements. When VisECG was developed, one of the basic functionality requirements was the option for displaying and editing annotations. Therefore, powerful notion of annotations was added to the very core of the VisECG framework. VisECG classifies the data it stores into three classes:

Annotations are stored in proprietary *.nekge* file formats (VisECG native file formats) with equal expressive power as the numeric data. VisECG classifies all the data it stores as measurement signal channels, event channels, and annotation channels.

Signal channels comprise regularly sampled data – most frequently ECG measurement (one or more leads) but it is not limited to ECG. Any number of measurement channels can be included in a file, a feature that is rarely found in established ECG file formats. Signal channels can also be sampled using different frequencies, and time offsets.

Event channels store all non-regularly sampled data as a stream of pairs *<time, value>*. This makes them useful for storing beat locations, beat rate and other results of post-processing ECG data. Again, any number of event channels can be stored in a single file.

Annotation channels are an extension to the event channels. They store data streams of quadruplets *<time, duration, value, text>*. By including the field *duration*, Annotation channels gain the ability to store events as well as intervals. One use of the field *value* is for classifying annotations, e.g., based on the annotation source, they can be classified into user, doctor, and system annotations. Another use for the value is to give annotations a numeric code, e.g., atrial fibrillation, extra systole, etc., and reserve the field *text* for additional info. More uses are possible and will be exploited in the future for mimicking annotation storage of other file formats, which are currently lacking this important type of information.

4) Detectors

Some of the functionality of the framework is optional. Beside choosing library dependencies, users can also opt to include additional proprietary file formats or algorithms included in the framework. These parts are shown in pink on Fig. 1.

Currently, the optional algorithms consist of several experimental heart beat detectors, detector comparators (methods for comparing and evaluating beat detector algorithms) and specific file format readers/writers.

The optional beat detection algorithms are adaptations of the ones found in VisECG program [10], and the interfaces to the existing and more thoroughly tested algorithms found in the included libraries.

5) Deployment

Due to our minimization of dependencies and strive for standardized code, we can deploy functionality on wide range of devices. So far we have produced builds for Windows and Unix operating system, but have plans to implement some of the functionality on embedded and mobile devices. We have also produced proof-of concept implementations that run on highly parallelized Xeon Phi co-processor for high throughput signal processing.

C. Usage

One of main goals of the framework is to simplify the interaction of the programmer with the framework. Short snippet of code shown in Fig. 2, showcases how to open a file, and save it into another file format.

```
#include "nekgeFile.h"
#include "s2File.h"
#include "signalResample.h"

int main(int argc, char **argv) {
  auto m1 = s2File::openFile("Input_file.s2");
  for (const auto &ch: m1.getSignalChannels()) {
     SignalResample::resample(ch, 250);
  }
  NekgeFile::saveFile(m1, "Output_file.nekge")
}
```

Figure 4. format conversion with additional resampling

This simplicity allows efficient development and usage of measurements containing biological data. Fig. 4

showcases a similar problem, but with an additional step of resampling all signal channels to 250Hz. We can observe that there are minimal changes to the code. Such functionality gave us the option to quickly produce file specific format converters with minimal changes. These file format converters were later tested using commercial software that successfully imported and analyzed produced measurements. Note that although it would be nearly trivial to make a general converter between all the supported file formats, this is not attempted, due to incompatibilities of the formats. The frameworks' principle of using the best effort conversion simplifies programming greatly, but is not appropriate for backing the general conversion. Some conversions are simply not possible without some interactive component of without some additional knowledge of the measurement contents. Note that the problem is only in storing files, where the file format specifications are a limiting factor. Loading measurements from files has so far been implemented in completely lossless manner; the framework can store everything it can read.

D. Visualization

Through the usage of the existing open-source visualization software, the authors have realized that one prevailing limitation. No software can efficiently show the measurement data on the screen. This has triggered a desire to add some visualization to the framework. The decision was changed, however, to rather make visualization a use-case for the framework. The framework without any specific visualizations thus remains more light-weight and portable.

The use-case for visualization application was selected based on the requirements that were not met by any existing software. The application can be instructed to open a file and *play* it on the screen in real-time. The first measurement channel is taken from the file and displayed in graphical form on screen as an animation. The heart rate channel is also read from the file and its instantaneous value is displayed in numeric form alongside the raw measurement.

Fig. 4 shows the application output that uses the framework for file manipulation, and can show a week of measurement in real time without delays, leveraging OpenGl for output of millions of data points. This software has already been used for generating a public outreach. An ECG measurement animation was exported and later synchronized with a video of the measurement taking place in a dynamic and stressful environment.

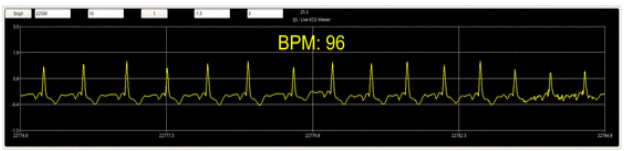

Figure 5. Using OpenGL to efficiently output ECG data

IV. CONLUSION

A framework has been developed which is able to cover ECG measurements in a layer of abstraction, which was so far lacking. This layer successfully covers some of the more known open formats for ECG measurements. As it is written in C++, based on libraries in C and C++, and not depending on any graphical interface, it offers high portability. It can be used on PCs, high performance computers, and embedded computers alike. Several use-cases have been presented that leverage the framework functionality on standard PCs, in applications that are of a broad use or cover a niche use-case.

Since VisECG framework is being actively developed, the future work plans are considerable. One of the main goals is to implement complete visualization of the measured signals (ECG or otherwise) combined with a user interface that would give access to the processing functions. Such program would replace the aging VisECG application. An important goal is also an introduction of the option to communicate with the framework over the Internet, and serve ECG data as a Cloud service. The service would centralize the access to processing and storage, simplify manual data gathering and development of personalized processing algorithms. As a byproduct, after being active for some time, the Cloud service could generate a large database of measurements, which could be used for additional research, knowledge discovery and education.

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Calculating the effectiveness of some important anticancer herbal compounds against the main hallmarks of cancer

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Abstract – There is a mounting evidence that certain herbal compounds express strong activity against various types of cancer cells. Curcumin from Curcuma longa, resveratrol from Vitis vinifera, and artemisinin from Artemisia annua are few examples from the longer list of more than fifty anticancer herbs known. This is mostly due to the extreme complexity of cancer processes that an exact mechanism of anticancer activity of these compounds is still unknown. However, with the rise of powerful supercomputers and the advanced in silico models of cancer, our chances to understand these processes increased, and now we are in place to deliver more effective therapies than ever before. KEGG (Kyoto Encyclopedia of Genes and Genomes) cancer pathways are example of such in silico models. From KEGG cancer pathways, we were able to identify sixty-two oncogene proteins involved in the development, proliferation, angiogenesis, metastasis and resistance of cancer. From them, we selected those having the largest number of hits in Pubmed database related to each of these cancer hallmarks, and use supercomputer for docking simulations between them and certain anticancer herbal compounds. Significant activity of anticancer herbal compounds against oncogene proteins was found. We hope our research will setup pathways towards more effective therapies.

Key words: anticancer herbal compounds, in silico models of cancer, hallmarks of cancer, oncogene proteins, interaction between molecules.

I. INTRODUCTION

There is a mounting evidence coming from many in vitro and in vivo experiments that certain herbal compounds express strong activity against various types of cancer cells. Curcumin, the most active curcuminoid from spicy herb Curcuma longa is probably the most researched anticancer herbal compound (AHC). Clinical trials with curcumin are underway, some of them with positive results [1]. Besides, resveratrol from Vitis vinifera, beta-glucan from Maitake mushroom, artemisinin from Artemisia annua, hirsutine from Uncaria tomentosa, muricatetrocin from Annona muricata, astragalosides from Astragalus membranaceus, epigallocatechin gallate from Camellia sinensis, and gleditsia saponin C from Gleditsia sinensis are often used either to complement standard anticancer therapies, or alone, mostly in cases when due to the type of cancer, its localization and condition of the patients, surgery, chemotherapy and radiation therapy are not applicable. Each of these compounds express activity against one or several cancer hallmarks [2], i.e. sustained angiogenesis, tissue invasion and metastasis, Krebs cycle, proliferation, mytochondrion, evading apoptosis, insensitivity to anti-growth signals, resistance to chemotherapy, block of differentiation and microtubule. For example, curcumin induces apoptosis in cancer cells [3], while both curcumin and epigallocatechin gallate downregulate angiogenesis of cancer, but not normal cells [4]. Many other herbs express anticancer properties, some as Gleditsia synensis by lowering cyclooxigenase-2 (COX 2) related inflammation and nitric oxide production (5). Many other anticancer herbal compounds work together with other anticancer herbal compounds, like curcumin with resveratrol, or with chemotherapeutics like genistein with arsenic trioxide [6]. With few examples, an exact mechanism of most AHCs activity against cancer is still not known. This is mostly due to the complexity of cancer. For example, in some types of cancers like melanoma and lung cancer in smokers, there is more than hundred oncogenes involved [7], each of them upregulating one of more proteins that drive cancer toward immortality, metastasis, and finally patients death. And besides huge improvements in cancer research in the last decade, these capabilities and their mechanisms are still not fully understand. The main reason is the complexity of these mechanisms, driven by genome instabilities. This complexity is also one of the reasons why we still do not have a medicine for cancer.

II. KEGG HALLMARKS OF CANCER AND THEIR DRIVERS

There are many in silico models of cancer available, each trying to describe the process of cancer in its own way. One of the most complete in silico models of cancer is Kyoto Encyclopedia of Genes and Genomes (KEGG) [8]. KEGG is a database resource for understanding high-level functions and utilities of the biological system, such as the cell, the organism and the ecosystem, from molecular-level information, especially large-scale molecular datasets generated by genome sequencing and other high-throughput experimental technologies. KEGG resources may be accessed from entry points classified in three groups: data-oriented, organism-specific and subject-oriented entry points. More specifically, KEGG knowledge about cancer pathways is represented in form of directed graphs, which are accessible either from data-oriented entry point named KEGG PATHWAY, or from subject-oriented entry point named KEGG Cancer. Besides human cancer pathway, cancer pathways for many other species like mouse, dog, gorilla etc. are available.

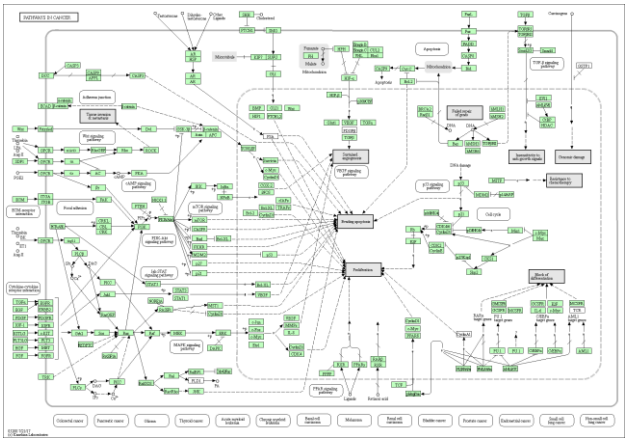

Fig. 1: KEGG graph showing pathways in cancer. While graph nodes represent genes and proteins taking part in the process of cancer development, metastasis, proliferation and other cancer hallmarks, vertices describe causative links between them.

From preceding graph the block matrix is constructed, with each block reflecting action of oncogene protein(s) on cancer hallmark, i.e. sustained proliferation, tissue invasion & metastasis, Krebs cycle, proliferation, mytochondrion, evading apoptosis, insensitivity to anti-growth signals, resistance to chemotherapy, and block of differentiation. For example, block reflecting influence of oncogene proteins on sustained proliferation looks like:

TGFB1	transforming growth factor beta 1
TGFB2	transforming growth factor beta 2
TGFB3	transforming growth factor beta 3
PTGS2	cyclooxigenase 2
NOS2	nitric oxide synthase, inducible
PGF	placental growth factor
VEGFA	vascular endothelial growth factor A
VEGFB	vascular endothelial growth factor B
VEGFC	vascular endothelial growth factor C
VEGFD	vascular endothelial growth factor D
MMP1	matrix metallopeptidase 1
MMP2	matrix metallopeptidase 2
MMP9	matrix metallopeptidase 3
CXCL8	interleukin-8

Table 1: Matrix block reflecting the action of oncogene proteins on sustained proliferation in KEGG. Elements of the first column are names of oncogenes involved in the process of sustained proliferation, while second column elements are proteins coded by these genes.

Each of these cancer hallmarks has number of oncogenes involved, as shown in the following chart:

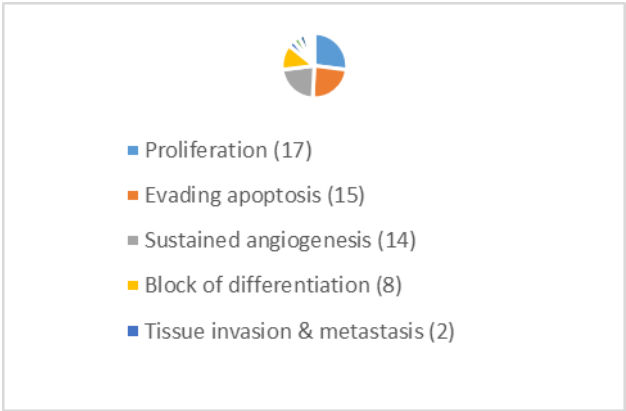

Fig. 2: Pie chart showing the number of oncogene proteins participating in specific cancer hallmarks. Altogether, there are sixty-two proteins directly involved in the carcinogenesis.

In [9] and [10], authors analysed nine anticancer herbal compounds (AHC) for their bioavailability and toxicity: curcumin, beta-glucan, artemisinin, gleditsia saponin C, hirsutine, astragaloside IV, resveratrol, muricatetrocin B and epigallocatechin-3-gallate. Besides in vivo and in vitro experiments, it is possible to validate anticancer effectiveness of these compounds in silico, via computer driven biomolecular simulations. Simulating affinity of each of these compound on each oncogene protein means 567 biomolecular simulation. As two or more compounds can work in synergy, like curcumin and resveratrol do, one can simulate affinity of anticancer herbal compound pairs on oncogene proteins. According to the binomial distribution law for this case, there are 36 pairs, 84 triplets and so on, as given the next:

#AHCs	#AHC permutations	#simulations
1	9	558
2	36	2232
3	84	5208
4	126	7812
5	126	7812
6	84	5208
7	36	2232
8	9	558
9	1	62

Table 2: The number of biomolecular simulations depends on number of AHCs within simulation box. For one AHC, number of simulations is 558, for two 2232 and so on. Exploring the full protein-AHC combinatorial space would require 31682 simulations.

Even on machine with many processors, docking simulations between certain oncogene proteins and AHC compounds can last for a while. Besides, concurrent therapy with too many AHC compounds at the same time may increase the risk of interactions between them. Nevertheless, even exploring the relative small 62 x 1 protein-AHC space (62 oncogene proteins and one AHC) would need 558 simulations. Besides, each cancer type is slightly different in gene protein expression. Therefore, search for most effective mixture of several AHCs would be reasonable only when specific cancer type is confirmed by histological assessment, all oncogene proteins identified by genome wide analysis of cancer cells, and toxicity of AHC mixture ruled out. For these reasons, we simulated docking of AHCs with only those oncogene proteins firing the highest number of hits from Pubmed search.

Cancer hallmarks	Max Oncogene Proteins
Sustained angiogenesis	vascular endothelial growth factor A
Tissue invasion & metastasis	Rho associated coiled-coil containing protein kinase 1
Krebs cycle	fumarate hydratase
Proliferation	cyclin-D1
Mitochondryon	Apoptosis regulator Bax
Evading apoptosis	kalikrein related peptidase 3
Insensitivity to anti-growth signals	mothers against decapentaplegic homolog 2
Resistance to chemotherapy	melanogenesis associated transcription factor
Block of differentiation	colony stimulating factor 3 receptor
Microtubules	kinesin family member 7

Table 3: Max Oncogene Proteins are oncogene proteins returning the highest number of hits in Pubmed database when searched for phrase <protein_name> AND <cancer_hallmark_ name>. The only phrase not returning any hit was <kinesin family member 7> AND <microtubule>. That does not mean no related research exists in Pubmed: For example, slightly different search phrase <kinesin family member 7> AND <cancer> phrase fires out 39 hits. Last column contains Protein Data Bank IDs.

III. THE RESULTS

There is a number of computer programs able to simulate molecular docking and estimate free energies of bindings between proteins and small molecule ligands [11]. They run various scoring functions, the most used are force-field-based, empirical, and knowledge-based [12]. While more advanced scoring functions usually deliver more accurate results, they may burden computational resources. Autodock Vina from Scripps Institute [13] is a molecular docking program with good accuracy of free energies of bindings, and relatively moderate burden of computational resources. This is especially important when screening many receptors with thousands of ligands. For this, we choose Autodock Vina for screening interactions between small molecules and oncogene proteins. We used PDB files of oncogene proteins from from Protein Data Bank [14], PDB files of drugs from Drugbank [15] and chanonical smiles of AHCs from Pubchem]16]. Smiles served as an input for smiles to pdb file translator machine [17]. The docking, i.e. affinity results, are in the table next, and abbreviations are as follows: **C** - curcumin, **R** – resveratrol, **B** – beta-glucan, **A** – artemisinin, **E** – epigallocatechin-gallate, **H** – hirsutine, **G** – genistein, **IM** – imatinib, **BV** – bevacizumab, **EV** –everolimus, **AS** – aspirin.

	C	R	B	A	E	H	G
metastasis (ROCK)	-6.9	-6.5	-6.9	-7.2	-8.6	-7.0	-7.4
angiogenesis (VEGF)	-6.4	-6.2	-6.2	-6.0	-7.4	-5.8	-6.8
chemoresistance (C47N)	-7.0	-6.7	-7.0	-7.5	-6.7	-6.1	-6.0
mytochondrion (1F16)	-6.4	-6.8	-6.3	-7.2	-7.1	-7.0	-7.4
block of differentiation (2D9Q)	-6.4	-6.7	-6.1	-6.7	-7.6	-6.7	-7.2
krebs cycle (4HGV)	-6.4	-6.7	-1.4	-4.5	3.3	1.4	-5.6
insensitivity to anti-growth signals (1KHX)	-6.4	-7.0	-6.0	-8.6	-7.6	-7.1	-7.8
evading apoptosis (2ZC1)	-8	-7.1	-7.1	-8.8	-8.2	-8.4	-7.6

	IM	BV	EV	AS
metastasis (ROCK)	-7.0	-5-5	-8.7	-5.7
angiogenesis (VEGF)	-5.8	-5.3	-8-3	-5.3
chemoresistance (C47N)	-6.2	-4.6	-7.1	-4.2
mytochondrion (1F16)	-6.7	-5.5	-8.0	-5.7
block of differentiation (2D9Q)	-6.7	-5.2	-8.2	-5.8
krebs cycle (4HGV)	12.3	1.2	22.4	-6.1
insensitivity to anti-growth signals (1KHX)	-6.9	-5.0	-7.7	-5.8
evading apoptosis (2ZC1)	-7.3	-6.3	-9.7	-6.1

Table 4 : Affinity values are in kcal/mole, for each protein and small molecule pair. As a rule of thumb, significant affinity is at -6.0 kcal/mol values and bellow [18], lower is better . To check the binding strength of AHCs, we included several powerful standard chemotherapy drugs in these experiment: Imatinib (Gleevec), Bevacizumab (Avastin) and Everolimus (Afinitor). Afinitor expressed the best affinity against seven cancer hallmarks (green), but the worst one against 4HGV protein involved in Krebs cycle. Resveratrol was the only small molecule found to express the significant affinity to 4HGV, but failed to show significant activity against C47N protein responsible for chemoresistance.

Additionally, we performed the virtual docking of forty molecularly targeted standard chemotherapy drugs. Only two of them, cetuximab and alectinib, expressed significant binding activity against all receptors, i.e. ROCK, VEGF, C47N, 2W99, 1F16, 2D9Q, 4HGV, 1KHX and 2ZCL. And with -11.8 affinity value against 2ZCL protein responsible for evading apoptosis, cobimetinib achieved the best score at all. This is important, because both artemisin and genistein achieved -8.8 and -8.4 values respectively, thus proving that anticancer herbal compounds are able to meet affinity values comparable to those of standard chemotherapy drugs.

IV. Conclusion and the Future Work

Virtual screening of several anticancer herbal compounds revealed their significant binding affinity with a certain oncogene proteins driving main cancer hallmarks, comparable to some of the most advanced standard chemotherapy drugs. By taking into the account their relative low toxicity, these herbal compounds are efficient in cases of cancer types and/or stages where standard chemotherapy drugs are not effective or not applicable, e.g. due to their toxicity. Besides, they may serve as an adjunct substance to standard chemotherapy drugs to enhance their effectiveness, such as resveratrol to inhibit 4HGV in Krebs cycle. While oncogene proteins we analyzed are important drivers of cancer hallmarks, they are not the only ones: typical cancer pathway in KEGG database consists of several hundreds of proteins involved in the mechanism of carcinogenesis, and interactions between them. Thus, it may happen that a certain small molecule inhibits oncogene protein, but also one or more proteins that work against carcinogenesis. In addition, a mixture of two or more drugs is often more efficient than a single drug. Exhaustive search for the ideal mixture through the combinatorial space is computationally expensive, but may lead towards the discovery of the more effective anticancer therapy for the specific cancer type. Therefore, lowering carcinogenesis of the specific cancer type with arbitrary mixture of drugs and on a wide proteomics scale is the next big challenge and deserves the further work and investment.

V. Acknowledgment

We gratefully thanks members of Kanehisa Labs for developing and maintaining KEGG database. Without them, our understanding of cancer pathways would suffer a lot. Protein Data Bank entries where essential for our in silico modeling and in silico understanding of cancer, therefore thanks to all contributing to and maintaining it. Besides, Autodock Vina from the Scripps Research Institute was and will be the basis for our continuous research. All Vina docking simulations run on Bura, supercomputer at Rijeka University.

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Robust breast cancer classification based on GA optimized ANN and ANFIS-voting structures

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***Abstract* - With rising cancer rates in world, it is important to incorporate all possible ways in order to prevent, detect, and cure this disease. Breast cancer presents one of those threats, and bioinformatics field must work towards finding models to fight against it, with one of them being creation of classification model for that kind of illness. Using machine learning techniques in order to make these classifications is one of those ways. It is widely known that ANN (*Artificial Neural Network*) and ANFIS (*Adaptive Neuro-fuzzy Inherent System*) can significantly upgrade any kind of classification process, and in that way, help in biomedicine and cancer treatment. Furthermore, more objective models for classification must be developed, regarding both time and resources, in order to get optimal results. In this paper, GA (*Genetic Algorithm*) algorithm that optimize ANN and ANFIS has been used to make classification of breast cancer diagnosis. It is shown that GA optimization of ANFIS and ANN parameters results in creating model with better accuracy comparing to basic classifiers. Voting method has been used on such GA ANFIS optimized structure, in order to achieve model with higher reliability. Final score of computed models was determined using external validation, based on 4 most relevant clinical metrics: sensitivity, specificity, accuracy and precision.**

Keywords - biomedical engineering; ANFIS; ANN; GA; breast cancer; higher reliability testing; clinical metrics; external clinical testing;

I. INTRODUCTION

Breast cancer is known to be most commonly diagnosed cancer in women. In average, every 2 minutes a woman is diagnosed with some kind of breast cancer [6]. Probability of getting this illness grows with age. There are 2 types: benign and malign. Malign types can be cured, but with good timing and precise diagnosis. If the benign type is diagnosed, that doesn't necessarily mean that it is not dangerous at all, because it could grow large enough to harm patient's body. Proper treatment is required.

Therefore fast, affordable, and early diagnosis is very important, so it can be treated properly, with minimal impact patient's health. Also, it very important to have diagnosis model that is reliable and with optimal or suboptimal precision, evaluated with relevant medial metrics, so that any diagnose can be considered most valid, in order to make treatment plan as good as possible.

Many machine learning techniques are being used in order to make breast cancer classifications optimal. In this paper, some of related articles and work will be analyzed.

Also, optimized ANN and ANFIS models will be used on WDBC (*Wisconsin Prognosis Breast Cancer*) dataset, and detailed results and conclusions will be provided.

The rest of the paper consists of five sections. In section 2, some of the related work is referenced and described. In section 3, dataset and way of project implementation is presented. In section 4 given results are elaborated. In section 5 conclusions are made.

II. STATE OF ART

Fusion of medicine and machine learning is "hot" topic, so more than a few related articles can be found, including topics relevant to breast cancer.

Some articles contain summaries of overall work in this area. Paper [3] shows overall analysis and related work in terms of breast cancer diagnosis and machine learning techniques, such as SVM (*Support Vector Machines*), RVM (*Relevance Vector Machines)*, GRNN (*General Regression Neural Network*) and other. Paper [4] develops approach towards breast cancer diagnosis using ANN in combination with differential evolution algorithm. Cancer classification using algorithms such as linear regression, decision tree, KNN (*K Nearest Neighbors*) and Naive Bayes, in combination with different versions of GA, is demonstrated in [1], and results are presented with accuracy metric. Paper [8] also includes overall analysis of various machine learning algorithms (FUZZY, ANFIS, SVM, ANN, LVQ (*Learning vector quantization)* etc.), that were used in breast cancer diagnosis. Comparison of ANN and SVM methods is made in [2], using accuracy and precision as metrics, with WPBC (*Wisconsin Prognosis Breast Cancer*) as relevant breast cancer dataset. Paper [5] makes research that include usage of ANN in medical diagnostics, such as breast cancer, cardiac arrhythmia disease and audio recordings of Parkinson disease. In [7], breast cancer classification is made using radial basis and back propagation neural networks. 3 datasets were used: WDBC (Original), WDBC and WPBC. Results were represented with accuracy, precision and recall metrics.

In [15] [16] [17], ANN - only approach on breast cancer classification is demonstrated. Some ANFIS approaches on various types of cancer classification are shown in [18] [19] [20]. Other articles include machine learning techniques and medical diagnosis, such as [9] [12] [13] [14].

Most of the work shown above show algorithm accuracy based on percentage of correct hits in training process. In addition, if it is mentioned that there were

training and testing sets, it was not anywhere explained that testing set was not part of algorithm training in any way. For example, MATLAB embedded distribution of dataset might not be considered as precise and reliable as full external clinical validation, that is in this paper proposed.

To be more precise, word "robust" for paper's title means that this paper offers higher reliability of overall performance and results. Higher reliability can be described in 3 steps, as shown in "Fig. 1".

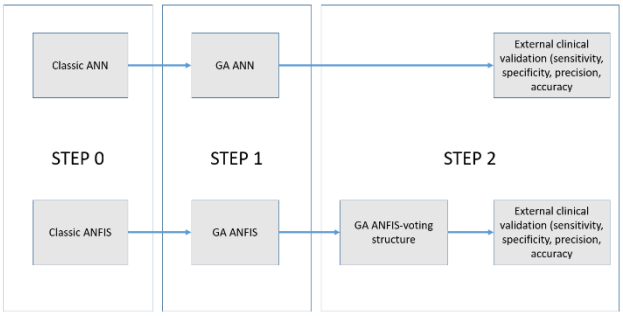

Figure 1. 2 step high reliability result performance

Step 0 delivers classic classification that include basic ANN and ANFS. This is not considered as contributing factor of this paperwork, because almost all of the references and relevant papers include this kind of analysis. It can be pointed out that this paper includes both ANN and ANFIS, not just one method.

Step 1 delivers GA ANN and GA ANFIS optimization, which can be considered as some contributing factor. It gives better results than classic classification, but still some of mentioned work include some kind of optimizations for ANN or ANFIS. It can be pointed out that both ANN and ANFIS are optimized, while references include optimization of only one method.

Step 2 consists of final optimization, includes ANFIS-voting structure, along with final external clinical validation (with 4 metrics) for both methods. In this way, higher reliability is made, differing this paper from all referenced work.

For this paper's demonstration, WDBC (*Wisconsin Prognosis Breast Cancer*) dataset will be used, to make detailed analysis of results, including all 4 main medical metrics for evaluation.

III. DATASET AND EXPERIMENT MODEL DESCRIPTION

WDBC is well known dataset used for machine learning purposes [21]. Dataset that was being analyzed in this paper contains 699 samples. It contains information gathered from digitalized images of sampled breast mass taken from patients, including class containing cancer type: benign (numeric value for benign cancer is 2) and malign (numeric value for malign cancer is 4).

There are 9 relevant dimensions in dataset:

- Clump Thickness
- Uniformity of Cell Size
- Uniformity of Cell Shape
- Marginal Adhesion
- Single Epithelial Cell Size
- Bare Nuclei
- Bland Chromatin
- Normal Nucleoli
- Mitoses

All dimensions have allowed values from 1 to 10.

Some samples had missing values, so they were filtered, and final number of samples entering experiments was 683. For ANFIS modeling, normalization data to values from -1 to 1 was made. As for ANN modeling, normalization was a feature.

20 samples were used for external testing, and were not part of training process. It is important to note that external test dataset contained 50% of each class, making testing even more precise.

As mentioned, for external clinical validation, 4 relevant clinical metrics were used: sensitivity, specificity, accuracy and precision [11]. Formulas for these metrics are given below [10]:

$$Sensitivity = \frac{TP}{(TP + FN)} \quad (1)$$

$$Specificity = \frac{TN}{(TN + FP)} \quad (2)$$

$$Precision = \frac{TP}{(TP + FP)} \quad (3)$$

$$Accuracy = \frac{(TP + TN)}{(TP + FP + FN + TN)} \quad (4)$$

Where TP, FP, TN and FN are defined as:

- TP (*True positive*) - Sick people correctly identified as sick (with breast cancer)
- FP (*False positive*) - Healthy people incorrectly identified as sick (with breast cancer)
- TN (*True negative*) - Healthy people correctly identified as healthy
- FN (*False negative*) - Sick people (with breast cancer) incorrectly identified as healthy

All experiments and model creation were done in MATLAB [22].

A. ETFSA nntool

ANN and ANFIS breast cancer classification was done with GUI (*Graphical User Interface*) tool named ETFSA nntool, tool developed by team of students and professors of Faculty of Electrical Engineering in University of Sarajevo. Authors of this paper were part of team. As mentioned, it is MATLAB tool with GUI, which gives options of creating different models for classification. Some of options include 2 layer, 3 layer, or Genetic Algorithm optimized ANN, normalization of data, creation of external testing data, that is not included in MATLAB training/testing, normal or SOM (*Self Organized Map*) distribution of training/external testing data etc. Program

offers creation of multiple ANN-s with parametrized number of neurons per layer, number of layers etc.

When ANFIS is considered, ETFSA nntool is capable of delivering ANFIS GA optimization, with voting method.

Not all possible variations of optimization are shown in this paper.

B. *Classic optimization ANN*

These kind of parametrized ANN optimizations can be described as small scaled combinatorics ANN optimization. In this paper, all optimization without GA is named classic optimization ANN, in results section. ETFSA nntool is shown in "Fig. 2".

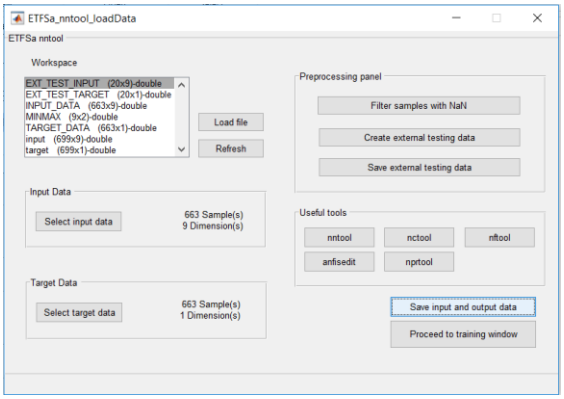

Figure 2. ETFSA nntool, with loaded WDBC dataset

After selecting all options, selects and delivers ANN model with best results achieved. Model can be validated with external validation set with 4 relevant medical metrics, as shown in "Fig. 3".

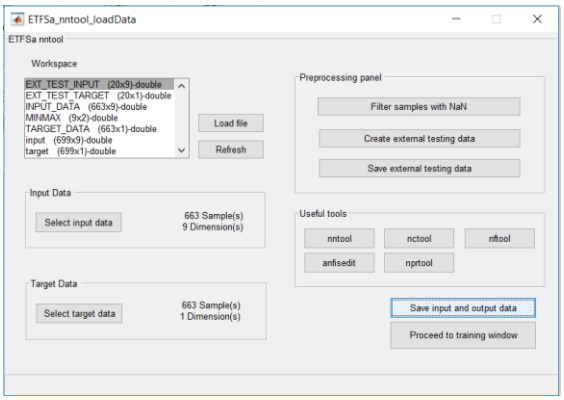

Figure 3. ETFSA nntool, with loaded WDBC dataset

C. *GA ANN optimization*

As for GA ANN part, GA was used to find optimal parameters for ANN, in order to have best results possible. This is called GA optimization ANN in results section.

Also, ANN parameters that were optimized using GA were:

- TeR - Test Ratio
- L(1) - Transfer function of layer 1
- L(2) - Transfer function of layer 2
- NoN - Number of neurons
- TrR - Training ratio
- VR - Validation ratio

Detailed GA ANN process is shown in "Fig. 4".

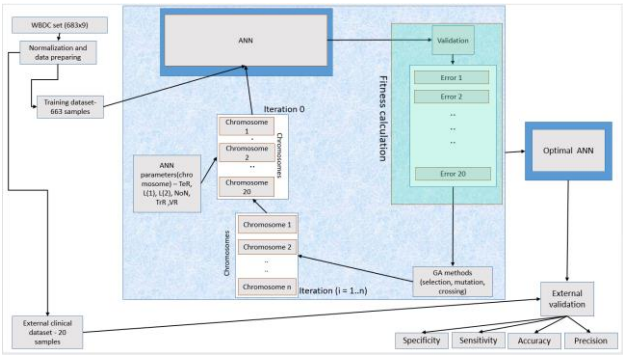

Figure 4. GA ANN detailed structure

D. *GA ANFIS-voting method*

ANFIS classification is done using GA algorithm for finding optimal parameters for ANFIS model. As mentioned, ANFIS model was created and trained in MATLAB, so all parameters are relevant to MATLAB functions that create that model. There are 2 modes ANFIS can work with, grid partitioning and subtractive clustering. Given the fact that analyzed dataset contains more than a few dimensions, and that grid partitioning method can have difficulties with that many dimensions, subtractive clustering was used.

Parameters that were part of GA ANFIS optimizations are:

- RoI - Range of Influence
- SF – Squash Factor
- AR – Accept Ratio
- RR – Reject Ratio

E. *ANFIS voting method*

It is known that ANFIS as classification tool can have problems with execution, if processed data has large number of dimensions, regardless of the fact that subtractive clustering method is used. Also, if that kind of data is combined with many samples provided, it can be difficult to optimize results, and to make model work in real time, and on simple computer unit. In addition, if ANFIS is optimized with GA algorithm, like in this paper, provided computer resources can be insufficient.

WPBC data has 9 dimensions and 699 samples, so using pure GA ANFIS classification was impossible to model, considering that experiments were done on laptop-like computers. Instead, ANFIS voting method was used.

Standard, widely known ANFIS model logic is shown in "Fig. 5" (only 5 samples in figure are shown, for demonstration purposes).

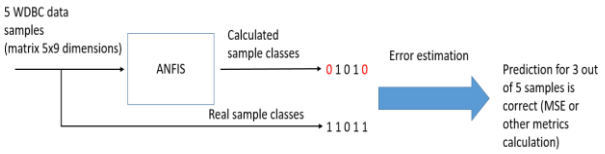

Figure 5. Standard ANFIS classification

In addition, ANFIS voting method is shown in "Fig. 6" (For demonstration purposes only 5 samples in figure are shown).

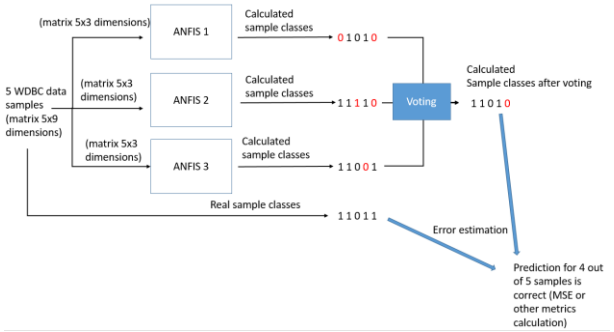

Figure 6. ANFIS-voting method

It can be seen that there are 3 ANFIS models. Input data is divided into 3 parts. Samples with first 3 dimensions are processed to first ANFIS model, next 3 dimensions are processed to second ANFIS model, and remaining 3 dimensions are processed to third ANFIS model.

Each of ANFIS models gives its own results, estimated classes. Resulting classes are handed to voting system, and class with most votes is the final class of process. It is necessary to use odd number ANFIS models, in order to objective and more reliable majority voting classification.

This model is less time-consuming, but also more precise in class detection. In addition, it is possible to build model that is capable to process n – dimensional data. The less dimensions each particular ANFIS receives, the more efficient whole system becomes. Nevertheless, it is important to find optimal balance between number of dimensions and classification precision.

For WPBC dataset, 3 ANFIS models were optimal. Detailed GA ANFIS process model is shown in "Fig. 7".

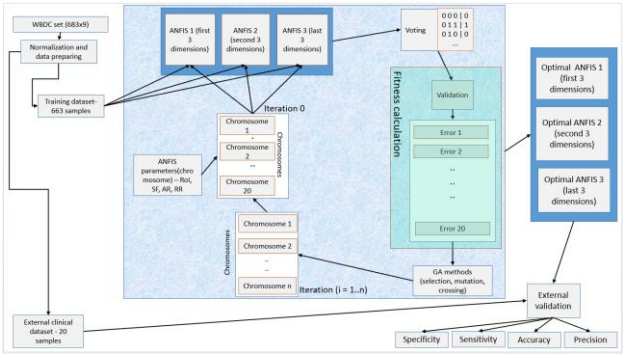

Figure 7. Detailed GA ANFIS-voting structure

IV. RESULTS AND DISCUSSION

Results are shown in "Table 1" and "Table 2", with precision of 3 decimal places.

TABLE I. FINAL EXTERNAL CLINICAL VALIDATION RESULTS

	ANN (no normalization, classic optimization)	ANN (with normalization, classic optimization)
Sensitivity (Recall)	0.800	0.800
Specificity	0.800	0.800
Accuracy	0.800	0.800
Precision	0.800	0.800

TABLE II. FINAL EXTERNAL CLINICAL VALIDATION RESULTS

	ANN (no normalization, GA optimization)	ANFIS-voting structure (with normalization, GA optimization, voting method)
Sensitivity (Recall)	0.900	1.000
Specificity	0.800	0.800
Accuracy	0.850	0.900
Precision	0.818	0.833

MATLAB performance plots (Mean Square Error throughtout epochs) are shown on "Fig. 8" "Fig. 9", for ANN classic optimization and ANN GA optimization.

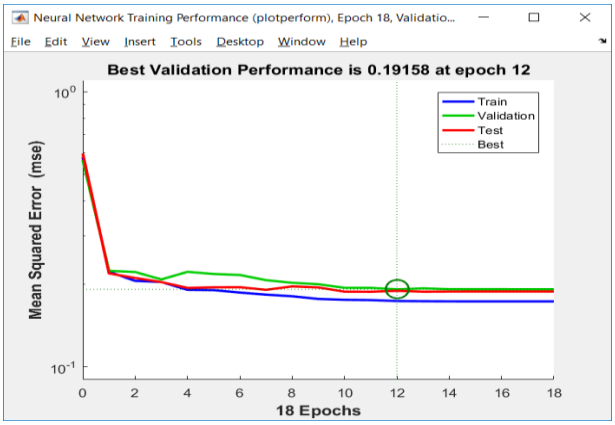

Figure 8. ANN classic optimization performance plot

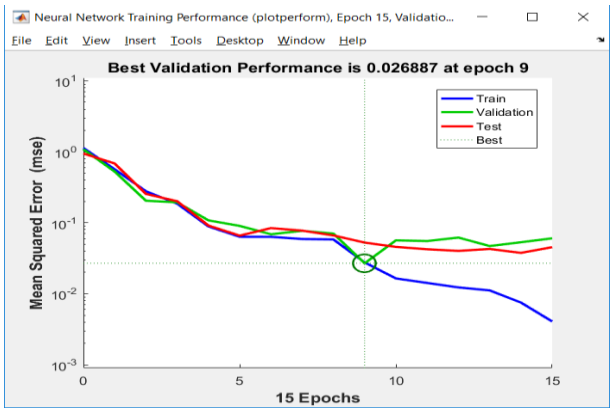

Figure 9. ANN GA optimization performance plot

Membership functions for ANFIS 1, 2 and 3 model, that are parts of ANFIS-voting structure, are shown in "Fig. 10", "Fig. 11" and "Fig. 12". As mentioned, each ANFIS model responds to different 3 input dimensions.

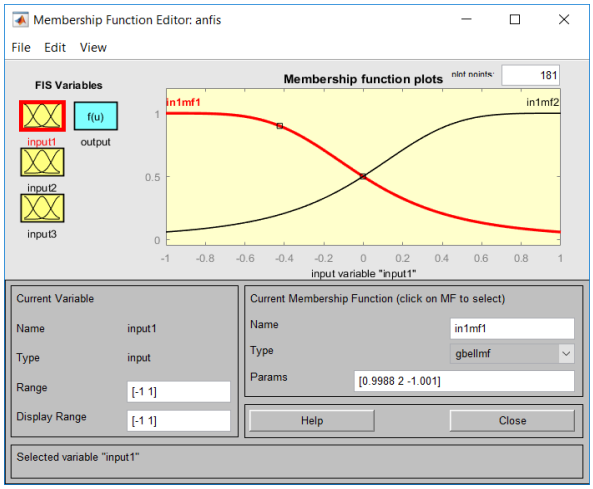

Figure 10. ANFIS 1 – membership functions for first 3 dimensions

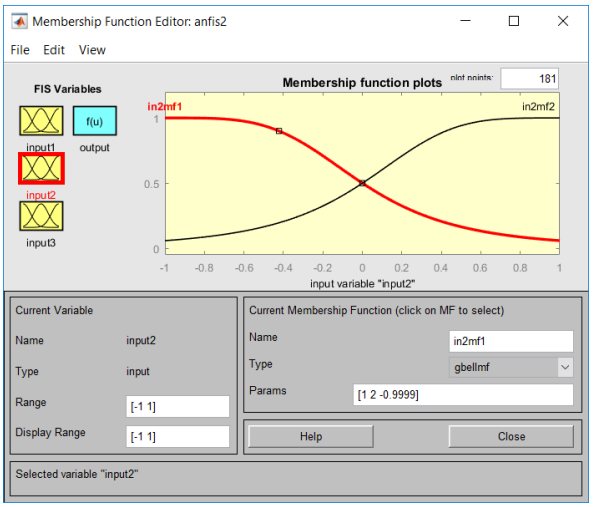

Figure 11. ANFIS 2 – membership functions for second 3 dimensions

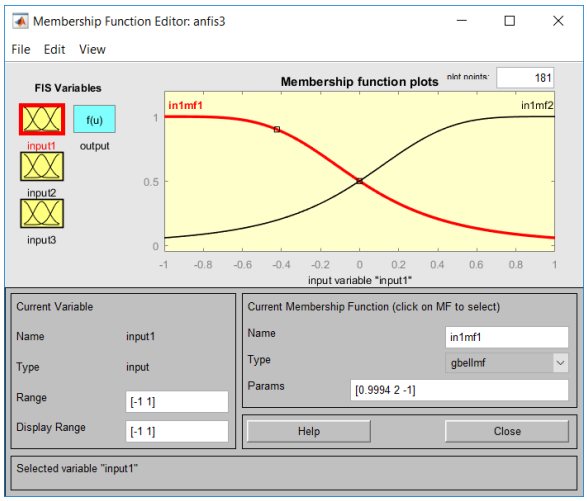

Figure 12. ANFIS 3 – membership funcions for last 3 dimensions

It can be concluded that normalization had no meaningful effect on results, when ANN is analyzed. As mention earlier in paper, normalization of dataset has to done for ANFIS modeling, in order to get optimal results, in both precision and real time processing.

Specificity was not changeable in all cases, but it can be seen that other metrics were significantly optimized, especially sensitivity on ANFIS modeling. Considering that external set for testing contained only 20 samples, it is obvious that great improvements were made.

It can be seen that ANFIS GA voting method had best results, with each individual metrics (except specificity that was same for all methods). Still, it had slightly higher time execution than ANN, so in order to choose best method for practical use, it is necessary to evaluate priorities over time and results.

V. CONCLUSION

This paper demonstrated possible optimizations on well-known methods, such as ANN and ANFIS, making those models more powerful and efficient. Results were presented in all 4 important medical metrics, which makes complete medical analysis more contributing.

ANFIS GA model, featuring voting method, showed best results, and presents efficient way of processing complicated and high demanding data in reasonable time frame. It was shown that this type of structure is a powerful tool which can be used on large and complex datasets, and give more objective results, considering voting segment which provides majority voting feature.

External testing was done, with proportional class density, along with 4 medical metrics. In that way, this paper is differentiating from publications that use same dataset for model training/testing, or publications that use MATLAB testing ratio as performance measure. More objective model lifecycle was made.

Future research publications will include other datasets, based on more optimization techniques, such as GA, ANN, ANFIS, deep learning ANN, advanced image processing & pattern recognition etc.

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Improving the dynamics of off-line time synchronization in wireless sensor networks

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***Abstract* - The time synchronization in wireless sensor networks (WSN) is a well-known issue. One of the approaches to the problem is by using off-line algorithms, meaning that the exchange of signaling messages for synchronization of individual clocks does not take place. Such an approach is typically based on a linear regression, which serves as an estimate of the actual ratio of the clock rates in the network. Due to the ever changing conditions in the network, where the wireless channel reliability and clock rates vary over time, the method needs to adapt dynamically. In the process of adaptation, discontinuities of determined linear regression lines may appear, which causes sudden time offsets. In this article, new procedures are proposed to cope with the varying conditions in such a way as to achieve as seamless transitions as possible. It is shown that unless such procedures are used, time offsets in the order of up to half a second may appear as peaks observed in the transition from one state to another. The proposed method reduces the offsets by an order of magnitude. The effectiveness of proposed solution is demonstrated on a specific case of wireless sensor ECG measurements.**

***Keywords* – WSN, ECG, time synchronization, clock drift, clock offset.**

I. INTRODUCTION

Nodes of the wireless sensor network experience clock drift that varies in time and between nodes. Therefore a dynamic and adaptive strategy is required for the synchronization of sensor nodes clocks to the hub node clock. The problem is referred to as the time synchronization problem in wireless sensor networks (WSN) and has been studied thoroughly in the past. It differs from the clock synchronization in conventional computer networks, due to the WSN limitations in terms of energy, bandwidth, storage and computational resources.

Numerous protocols such as the well-known RBS [1] and the TPSN [2] have been proposed with the motivation to compensate for the clock drift and the clock offset. Examples of well-defined problem statement of time synchronization in WSN together with an overview of existing solutions can be found in [3][4][5]. Most of the proposed solutions are based on the exchange of messages among the wireless nodes, which help them establish local clock rates and local times of the neighboring or reference nodes. Their own clock is then either adjusted instantly or left running as it is and then translated later to selected reference time in the process of data fusion, according to time-translation tables. Linear regression is commonly used for clock drift compensation. The pioneering theoretical studies have later been complemented by some of the more practical-oriented work, focusing on specific wireless technologies, such as the widely used Bluetooth standard. For example, a time synchronization approach for the multi-hop Bluetooth networks is presented in [6], while the authors in [7] and [8] break the problem in the Bluetooth LE even down to the hardware level.

The most parallels to our work have been found in the work presented by Wåhslén et.al. [9][10]. Their approach is different from the others and similar to ours in the sense that the focus is given on a concrete WSN application with actual measured data, the fusion of which has to return reasonable results in practice. Their goal was to achieve synchronism of the data gathered from two cases, first from multiple sensors for the purpose of athlete monitoring in a kayaking sports case, and second for monitoring of heart and respiration of prematurely born infants. They tried three different strategies [9]: (i) synchronizing all the sensors by message exchange, (ii) synchronizing each sensor separately at the controller node by using linear regression and (iii) clock synchronization by using broadcast. For the purpose, they used two different wireless technologies, the Bluetooth piconets and the ZigBee/IEEE802.15.4. Their analysis showed that the approach with single clock synchronization, performed at the controller node (mobile phone), which is based solely on the timestamps, outperforms the other two methods, which require signaling message exchange in the WSN network. The single clock synchronization method is described in more details in [10]. It basically selects the packets with presumably lowest waiting time at the outgoing and incoming buffers, and then performs a linear regression in order to calculate the new corrected timestamps for all the packets. The observed synchronization error achieved by their method is 1-2 samples, corresponding to 10-20 ms time error at 100 Hz sampling rate.

The following paper presents and improvement of our previous work, originated in 2010 [11]. A methodology was proposed for off-line time synchronization based on a simple linear regression [12], which was later extended by decomposition of the signals to a certain number of blocks, achieving a better capability of the system to adapt to the ever changing conditions [13]. It was later discovered, that the transitions from one block to another cause undesired discontinuities, which cause further non-synchronism, observed as sudden time offsets. The motivation of the method proposed in this paper is to

eliminate discontinuities in such a way as to reduce offset peaks to a minimum and thus improve the overall synchronization.

The paper is organized as follows. In the next section, the problem is stated and the methodology is proposed. Section III describes the performed experiment. The results are given in Section IV. The paper concludes in Section V.

II. Problem Statement and Methodology

Clock correction is performed on one sensor at a time using the timestamps put on the same communication packet by the sensor and by the hub. The data available is therefore: $t_{sensor}(n)$ and $t_{hub}(n)$ for $n \in [1, N]$, where N is the number of packets in the measurement. In an optimal system, the ratio between the timestamps $t_{sensor}(n)/t_{hub}(n)$ should be constant for all n, however it varies with n due to the wireless protocol, which causes waiting times in buffers on the transmitting and receiving ends, as well as by transition time between the physical OSI layer and the application layer. These variations are treated as noise with regard to the estimation of required clock correction.

The goal is to split the data series into short blocks and use a piecewise function of local (per block) clock estimates for reconstructing real time of the data points. The two challenges here are:

- the shorter the block, the more its local estimate will be susceptible to noise; and
- the noise is not uniformly distributed across the measurement but is sometimes clustered and very local, causing the confidence into different local estimates to vary.

Therefore, the measurement is segmented into M blocks $B=\{B_m\}$, $m=[1, M]$, with each block covering a limited range of input data points: $B_1=[1, b_1]$, $B_2=[b_1, b_2]$, …, $B_M=[b_{M-1}, b_M]$, $b_M=N$. Input data points b_m are called border points, since they are located on borders between blocks. To limit the influence of noise, blocks are classified as either good or bad according to the amount and locations of detected noise in data points. Good blocks cover the areas of low noise while bad blocks cover the rest. We propose an initial strategy for separating good blocks from bad blocks.

The procedure examines the time differences between each pair of the received packets, as determined by the hub node. Good measurement blocks are those where the time interval Δt_i between each of the pairs i is:

$$\Delta t_i < 5 \cdot T_P, \tag{1}$$

where T_P is the nominal packet period. In the presented experiment, this means that sampling periods longer than about 500 ms are considered faulty. The length of a good block needs to be at least $300 \cdot T_P$, which is about 30 s in practice. The rest of the measurements are designated as bad blocks. The threshold values listed above were determined empirically, based on several trials performed on measurements with obvious irregularities. The values should be adjusted in the future by researching what works best on a larger sample of measurements.

Since the clock drift is dynamic, good blocks are not allowed to be too long and are split into parts shorter than 15 minutes. This maximum length of good blocks is a trade-off between the response speed to dynamic clock drift and the sensibility to noise in the data point timestamps.

Sensor clock is then estimated on the good blocks by using linear regression, which produces linear function $f_m(n)$, defined on the range defined by the block B_m. For bad blocks, no estimation is performed since it would produce low quality results. Thus, the goal for clock reconstruction is partly fulfilled as local clock estimates $f_m(n)$ are available for data points that lie within good blocks. In [13], the goal was completely fulfilled by assigning the average estimated clock rate of the whole measurement to the bad blocks, resulting in the piecewise linear estimate of sensor clock rate to be defined on the whole data range $[1, N]$. Although the resulting estimate corrected the clocks well it was still suffering from two issues. Bad block corrections were far from optimal and the piecewise estimate was not continuous, and caused sudden time offsets in the corrected clock. An example of a discontinuous behavior is illustrated in Figure 1.

The presented paper chooses to improve on [13], by properly addressing the described deficiency. A better – more local – estimate is made for bad blocks and the local functions are consolidated on the borders of their ranges.

Note that bad blocks are always adjacent only to good blocks. If two bad blocks were adjacent, they would be merged into one longer bad block. Good blocks on the other hand, can be adjacent to both good and bad blocks. Therefore the border between two adjacent blocks, i.e., the last packet of one block and at the same time the first packet of another block, can be either between good or bad block or between two good blocks. Thus each border packet b_m has f defined either only from the block on its left side $f_{left}(b_m)$ or only from the block on its right side $f_{right}(b_m)$ or from both neighboring blocks $f_{left}(b_m)$ and $f_{right}(b_m)$. Note that the left/right nomenclature comes from depicting blocks as segments of the time axis, with *left* representing earlier time and *right* representing later time.

The amended piecewise linear function f' is introduced. First, its values are determined for all border points b_m, $m=[1, M]$, from blocks adjacent to them. For all the possible cases, one of two rules applies, as follows.

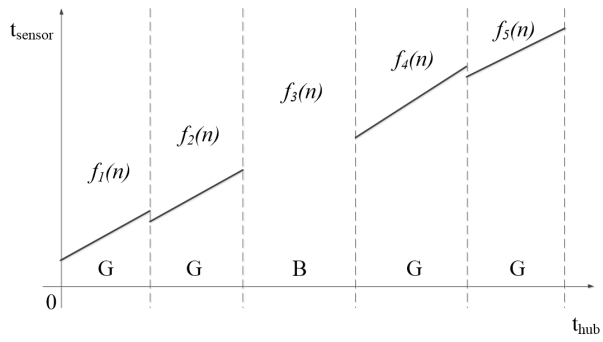

Figure 1. An illustration of 5 consecutive blocks together with designation of their quality (G: good, B: bad) and determined linear regression functions. Note the missing function for the bad block and the discontinous behaviour at the borders of the blocks.

- **Rule 1.** If left side does not have clock estimated, then the last point in its range is assigned the value of the first point of the right range: $f'(b_m) = f_{right}(b_m)$.

- **Rule 2.** If right side does not have clock estimated, then the first point in its range is assigned the value of the last point of the left range: $f'(b_m) = f_{left}(b_m)$.

- If both sides have clocks estimated, the rule 2 applies. The first point in the right range is assigned the value of the last point of the left range: $f'(b_m) = f_{left}(b_m)$.

- The very first and the very last border points border only to a single block. In these two cases the rule 1 and the rule 2 are used, respectively.

The values $f'(b_m)$ are finally connected with linear sections, thus defining f' on all data points. The described procedure is illustrated in Figure 2.

III. EXPERIMENT

A long concurrent measurement on two sensors is performed, where clock drift in expected to be several seconds by the measurement end. The measurement is performed by attaching both sensors to the same artificially generated signal. This enables the evaluation of the synchronization to be performed in a simple and precise manner, by synchronizing both sensor clocks to the hub clock and then observing how well the measurements match.

In the presented case, the generated source emulates an ECG signal with the time period 1 s and the sensors in-use are the ECG sensors with sampling rate 125 Hz, which are connected to an Android device. The configuration is depicted in Figure 3. Even if the experiment is specific, the approach to the problem is generic and thus the findings are applicable to any WSN network.

IV. RESULTS

The measured data obtained by the performed experiment are synchronized in time, following two routines.

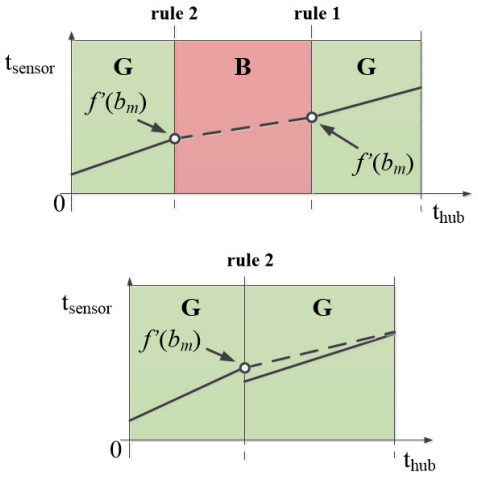

Figure 2. An illustration of function values determination $f'(b_m)$ for border points b_m. The local linear functions f_m are denoted by solid line, while the newly determined parts of piecewise linear function f' are denoted by a dashed line.

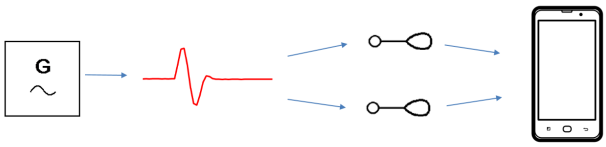

Figure 3. A scheme of concurrent artificial ECG signal measurement with 2 sensors.

The first routine [13] serves as a reference for comparison. It is referred to as the "discontinuous method". The second routine, called the "continuous method" is based on the methodology, which is proposed in this paper.

A short time window is chosen as an example of how the time stamps of the received packets are modified in the process of synchronization, for both of the methods. The example is shown in Figure 4. The actual packets (blue dots) are ascribed with new reference times (magenta dots), based on the determined linear regression lines (black).

The upper graph clearly shows what may happen when linear regression is calculated in a piecewise manner, disregarding transitions between the blocks, especially when unreliable blocks of data are involved. An obvious discontinuity is observed as a jump in the function intercept. With the proposed improvement, the anomaly is eliminated, as shown in the lower graph.

As a result of the observed discontinuity, the two received measurements experience sudden time offsets, as shown in the upper graph of Figure 5. The signals are aligned well in the lower graph of the same Figure, where the proposed continuous method was used.

The results are further compared in terms of the time differences, calculated by finding the peaks of the signals and comparing their timing once per about 100 signal periods, which corresponds to once per 1.8 minute. During the total observation time (18 hours), the synchronism was checked 600 times.

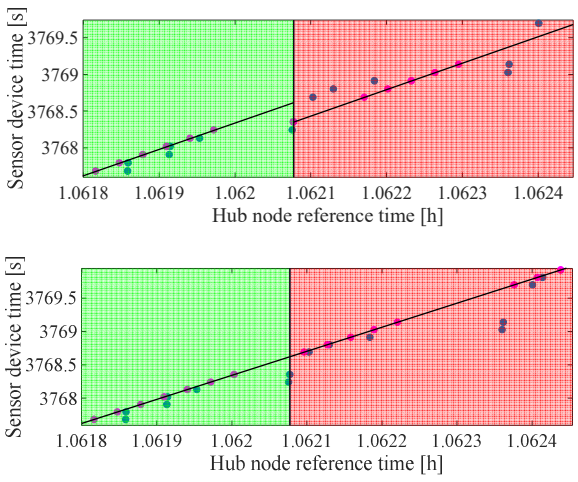

Figure 4. An example of received and synchronized packets. Upper graph: discontinuous method, lower graph: continuous method.

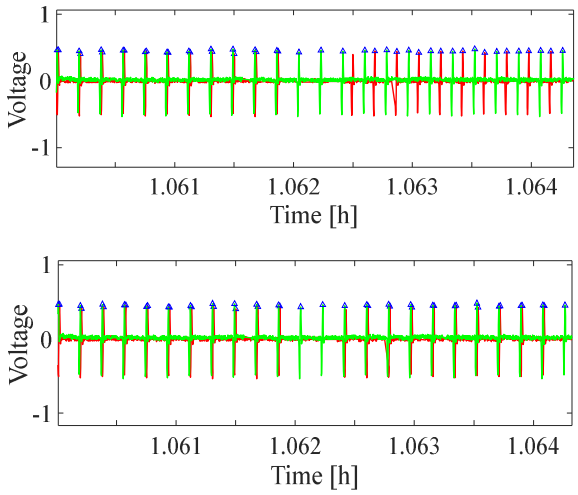

Figure 5. An example of signals, measured by two ECG sensors (green and red signal) and synchronized (blue marked peaks should be aligned) at the hub node. Upper graph: discontinuous method, lower graph: continuous method.

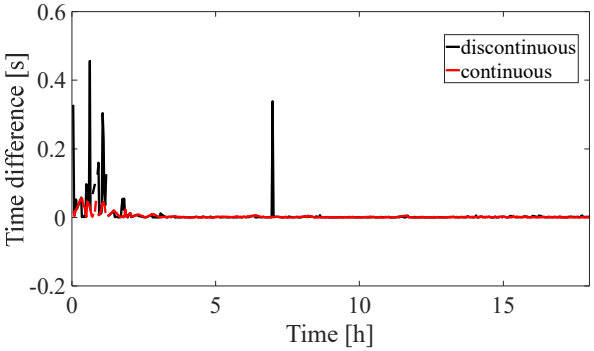

Figure 6. Time difference between the signals, measured by two ECG sensors and synchronized at the hub node by two methods (black: discontinous method, red: continous method).

The peaks of the signals were found by applying the quadratic interpolation, which reduces the error of the peak search algorithm. The results of both applied methods are compared in the graph of Figure 6.

When wireless channel conditions are good, both methods synchronize the signals successfully, as observed in the major part of the experiment. The time difference variations as well as the time drift are mostly negligible. However, at the beginning of the experiment numerous bad blocks occurred, which led to several peak time offsets. With the discontinuous method, a maximum of 456 ms time difference is observed, which corresponds to nearly 57 samples difference at the given sampling rate. The red curve obtained by applying the proposed method shows an improvement: the maximum time difference is reduced to 57 ms, corresponding to about 7 samples.

While the continuous method significantly improves the performance of the discontinuous method in terms of minimization of sudden offsets, their number remains the same. Regardless of the applied method, 50 out of 600 consecutive time difference calculations exceeded 8 ms or 1 sample. The majority of them happened during the bad blocks, where the behavior is in general unstable and thus further accuracy improvements are hardly- or even non-achievable. Nevertheless, it is a matter worth a deeper inspection in the future studies.

V. Conclusion

A simple method is presented for constructing a piecewise linear function, which is used to synchronize two independently kept clocks. Although an example is given from wireless network of ECG sensors, the applicability of the method is not limited to it. Wherever synchronization of clocks is required in post processing, a similar method can be devised.

Experimental results demonstrated that the piecewise linear function should not be constructed in a naïve manner, which leads to discontinuities. The presented method which smooths piecewise function and makes it continuous improves the results by an order of magnitude.

There are many more methods for consolidating the borders between function pieces and there is much work to be done in experimenting with them. In our future work, we will test the use of splines instead of piecewise linear functions.

Acknowledgement

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Evaluation of Cutaneous Microcirculation Patterns by Laser Speckle Imaging

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Abstract - **Atherosclerosis is a chronic systemic process affecting distal circulation, a condition known as Peripheral Artery Disease (PAD). Epidemiological and clinical studies indicate a strong association between PAD and death due to cardiovascular diseases, thus the early detection of DAP by measuring perfusion levels of distal body regions is critical to prevent ischemic events. This work proposes a new methodology for the evaluation of local cutaneous perfusion through laser speckle video processing. The speckle pattern generated by a laser beam projected onto the skin surface after being expanded by an optical setup is captured by a CCD video camera. To evaluate the particular characteristics of the speckle pattern, a video processing algorithm based on an adaptive Local Binary Pattern approach, highlighted by a local Gaussian filtering scheme, the LBPg, was developed. In order to test this new method of video speckle analysis, different patterns of microcirculation were evaluated in skin regions with different textures. The experimental results were compared with others obtained in two clinical conditions associated with PAD (i.e., Deep Vein Thrombosis and Diabetic foot). The results show that the proposed approach is sensitive to the change in perfusion levels (even in cases with reduced perfusion variations), thus indicating that the use of laser speckle technology, jointly with LBPg, is a promising noninvasive, low cost and sensitive method for the early detection of PAD-related diseases.**

Keywords – Laser Speckle; Video Processing; Local Binary Patterns; Skin Microcirculation;

I. INTRODUCTION

Atherosclerosis is a complex chronic and inflammatory systemic process affecting the inner layers of large and medium-sized arteries, (e.g. aorta, carotid, coronaries and peripheral arteries). According to the most recent consensus, the disease physiopathology is the result of a complex interaction between environmental risk factors, genetic component, immune system, hematological and endothelial cells, coagulation factors and inflammatory mediators [1], [2]. Peripheral Artery Disease (PAD) is one of the clinical manifestations of generalized atherosclerosis, whose symptoms range from asymptomatic lower blood pressure in the ankles to intermittent claudication, in which patients need to stop the movement for a few moments until circulation is restored. Although the risk of amputation in PAD patients is low, the correlation of PAD with death of cardiovascular cause is high. Hence, detection of early signs of reduced peripheral[1] perfusion is a key prognostic factor for the early treatment of PAD.

Symptoms related to decreased perfusion are subtle in the initial stages of the disease (e.g., distal pulse reduction, changes in local temperature, …), therefore a quantitative perfusion measurement, sensitive to minor changes in perfusion, is of clinical interest. Currently and according to the guidelines of PAD management, besides the classical Ankle-Brachial Pressure Index (ABPI) defined by the quotient between the systolic pressure measured at ankle and arm, the use of ultrasound imaging techniques may also be useful to characterize the disease. Other imaging modalities (e.g. MRI and CT) are also available to study perfusion in distal arteries, however their use is only requested in advanced stages to establish a PAD treatment (e.g. endovascular therapy). These imaging modalities have some important limitations, such as the cost, time of acquisition and availability in primary care hospital, in the case of CT/MRI, and the user proficiency in the case of ultrasound imaging.

Once the symptomatology appears in advanced phases of the disease, and the clinical signs are difficult to assess in the early stage of the condition, the ability to perform a non-invasive, low cost and high sensitivity evaluation is seen as a challenge of central importance for the diagnosis. Moreover, the aforementioned imaging modalities are mostly used to assess perfusion levels within the vascular system.

In this paper, a new method to evaluate local microcirculation profile is proposed, based on an adaptive Local Binary Pattern methodology highlighted by a Gaussian filtering scheme, performed after Laser Speckle video acquisition. The proposed methodology was tested against controlled perfusion experiments and also tested in patients with PAD relate diseases (e.g. Deep Venous Thrombosis and Type 2 Diabetes).

In the remainder of this paper, in Section II the methodology is presented and in Section III the obtained results are shown. Section IV is dedicated to discussion and finally, in Section V, the conclusions are presented.

[1] This work was supported by Fundação para a Ciência e Tecnologia FCT- Portugal, under the scope of Light Field Laser Speckle project in the scope of R&D Unit 50008, through national funds and where applicable co-funded by FEDER - PT2020 partnership agreement.

II. METHODOLOGY

A. Laser Speckle Imaging Acquisition

Speckle is a physical interference phenomenon obtained by diffused reflections, produced when a rough surface is illuminated by a coherent light source. This multiple reflection of randomly distributed waves with the same frequency, but different phases and amplitudes, thus resulting in varying pattern with specific characteristics. Such patterns can be used to characterize either static (mostly using texture features) or dynamic conditions by using video processing techniques applied on the acquired speckle frame.

For the purpose of this work, an acquisition setup was built, composed by a class III laser beam (633×10^{-9} m wavelength and $5\,mW$ Power), apposite to skin interactions and suitable to access the upper layers of the skin. A beam expander and a CCD Camera (Sony, nxcam AVCHD, 50 fps) were also integrated in the setup, as illustrated in Figure 1.

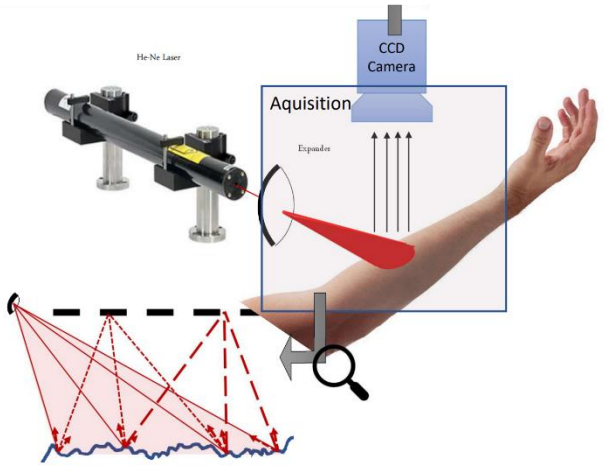

Figure 1: Acquisition Setup.

B. Image Processing Algorithm

When a sequence of speckle video frames is observed, not only the inward spatial, but also the temporal intensity variation across pixels (ranging from white to black) reveal a possible generation of repeating patterns at some underlying frequency [3], [4]. Hence, this characteristics points the LBP as an algorithm having potential to describe speckle activity.

Proposed by Ojala in [5], the LBP methodology was developed to extract 2D surface descriptors, acting as a texture operator, to locally evaluate the variation of intensities of the neighboring pixels (considering a number of points P, and a radius R to the central pixel) [6]. The LBP algorithm labels the pixels of an image by thresholding the neighborhood of each pixel and considering the result as a binary number. Each element of the binary sequence is then multiplied by a power of 2, thus obtaining a grayscale image whose histogram can be used as a texture descriptor. The LBP methodology has being used in several research areas, in particular related to object detection [7], face recognition [8] and image retrrieval [9].

Given the above-described characteristics of the speckle (i.e. spatio-temporal changing patterns, high-frequency content) the local comparison using LBP does not prove to be effective, mostly due to the high variability in the changing patterns and to the uncertainty introduced by the speckle noise. Thus, in the scope of this work, a new methodology to capture high-frequency and local variations is proposed using an algorithm based on LBP, jointly with Gaussian spatial filtering, the LBPg.

The LBP_g code of a given pixel (x_C, y_C) is defined in (1),

$$LBP_g(x_C, y_C) = \sum_{P=0}^{7} s(g[I_P - I_C])2^P , \qquad (1)$$

where I_P and I_C are, respectively, the intensity of the peripheral and central pixels, s is a step function defined in (2) and g the Gaussian function, as defined in (3) by;

$$s(x) = \begin{cases} 1 & if x \in FWHM_{g_{(\mu,\sigma)}} \\ 0, & otherwise \end{cases} \qquad (2)$$

$$g_{(\mu,\sigma)}(x) = e^{-\frac{1}{2}\left(\frac{x-\mu_{\bar{X}}}{\sigma_{\bar{X}}}\right)^2} , \qquad (3)$$

where $\mu_{\bar{X}}$ and $\sigma_{\bar{X}}$ are respectively, the average and standard deviation of the absolute differences to the central pixel in a 3×3 neighborhood, obtained in a reference sequence of frames. The $FWHM_{g_{(\mu,\sigma)}}$ is the full width at half maximum interval of the gaussian function (3).
Next, two measures of speckle activity are proposed. One is defined as a Spatial Index of activity, in which an LBP_g thresholding scheme is settled to determine the level of sensitivity of the method. This dynamic threshold is applied to the LBP_g output using the 1st, 2nd and 3rd Quartil (Q_1, Q_2, and Q_3), thus stablishing a three-level sensitivity Spatial Index, defined in (4)

$$\bar{P}_{Q_j} = \sum_{\substack{i=1 \\ j=\{1,2,3\}}}^{N} P_{i,Q_j} , \qquad (4)$$

where $P_{i,Q_j}\{j = 1,2,3\}$ is the probalility of one pixel in the LBP_g matrix being greater than Q_j. The other method is an evolutive measure of activity, defined as a Temporal Index, which is obtained by selecting two video sequences (basal and in study) and then comparing the normalized histograms of these two LBP_g sequences. For histogram comparison purposes, the chi-squared metric χ^2 defined in (5) was applied,

$$\chi^2 = \frac{(\hat{H}_B - \hat{H}_S)^2}{\hat{H}_B + \hat{H}_S} , \qquad (5)$$

where $\hat{H}_B$ is the normalized histogram of the basal sequence and $\hat{H}_S$ the corresponding histogram for the video sequence under study.
The global conceptual framework is illustrated in Figure 2.

C. Experimental Protocols

As mentioned before, the main objective of this work is to obtain quantitative markers of reduced distal perfusion to act as a measure of awareness to PAD, in the early stage of the disease. Accordingly, to test the ability of the above-proposed methodology detecting changes in cutaneous microcirculation levels, experimental tests were performed involving a partially block of the circulation in the upper limb vessels, simulating occlusion and perfusion conditions (occlusion-hyperemia test – OHT).

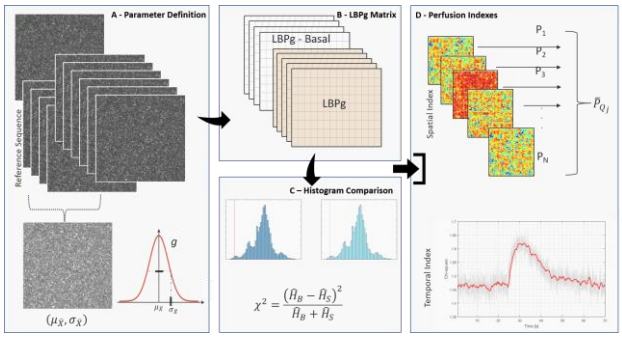

Figure 2: LBPg conceptual framework and derived dynamic indexes.

These experimental tests create distinct profiles of perfusion at the distal level in the arm and were conducted in healthy subjects after a resting period of 5 minutes in a seating position in a controlled temperature room. A distal ROI was selected and a basal speckle video was initially recorded using the acquisition setup shown in Figure 1. Afterwards, a cuff pressure attached to the arm was inflated (pressure level 180 mmHg) and a period of occlusion was accomplished. This occlusion period was followed by a rapid release of cuff pressure to simulate hyperemia, and thus restoring the circulation.

In addition to these experimental pressure-dependent perfusion procedures, two additional tests were also conducted in PAD disease related patients, to confront the results and to assess the sensitivity of the proposed methodology in real word situations. Accordingly, two peripheral regions of two patients diagnosed with Deep Vein Thrombosis (DVP) and type 2 diabetes (DM2) were selected to obtain the temporal and spatial indexes as a measure of microcirculation.

III. Results

The perfusion level as a function of time is shown in Figure 3 for one sample of the OHT test. According to the experimental protocol an inverse relationship between the pressure in the arm-cuff and the tissue perfusion is expected to be observed when the proposed Temporal Index (5) is calculated. In fact, during the acquisition period, this temporal measure of microcirculation shows variations which are correlated with specific time intervals during the test, as observed in Figure 3.

During the occlusion period (**E3** in Figure 3) an initial decrease in the Temporal Index is observed, followed by a constant trend in microcirculation levels (after the physiological adaptation to the acute occlusion). After releasing the pressure in the arm-cuff, a hyperemia period is clearly observed (**E4** in Figure 3), which is followed by a decreasing trend in the perfusion index, achieving the basal level values of the experiment (**E5** in Figure 3).

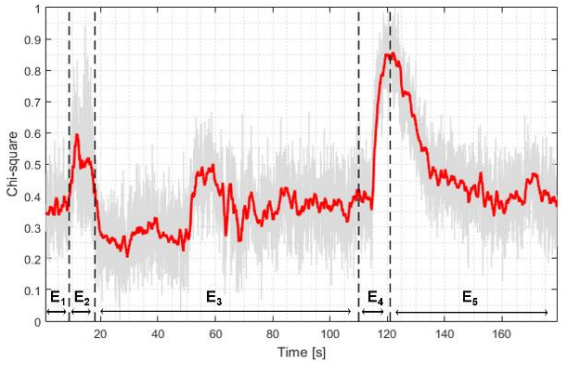

Figure 3: Temporal Index of microcirculation during the occlusion-hyperemia test.

Regarding the Spatial Index, a small interval (i.e. 5 seconds) was selected during three periods associated with changes in the perfusion levels identified in Figure 3 (**E3** during the occlusion, **E4** during hyperemia and **E5** returning to basal conditions). According to the definition in (4), three threshold levels were implemented, being the results of $\bar{P}_{Q_j}$ index for the OHT presented in Table 1.

TABLE I. Spatial Index of Microcirculation in OHT

	$\bar{P}_{Q_1}$	$\bar{P}_{Q_2}$	$\bar{P}_{Q_3}$
E3	0.9473	0.7260	0.1690
E4	0.9933	0.9471	0.5258
E5	0.9639	0.7900	0.2102
Total	**0.9667**	**0.8138**	**0.2891**

The Spatial Index was also used to assess microcirculation profiles in two distal regions (**A** at ankle and **B** shank) in two DVP and DM2 patients. The values of the Spatial Index regarding the two conditions for regions A and B (in each patient) are presented in Table II.

TABLE II. Spatial Index of Microcirculation in DAP Patients

	Region	$\bar{P}_{Q_1}$	$\bar{P}_{Q_2}$	$\bar{P}_{Q_3}$
DVP	**A**	0.8041	0.5647	0.2882
	B	0.8432	0.7581	0.6511
DM2	**A**	0.7989	0.5312	0.2525
	B	0.5252	0.1773	0.0168

To illustrate the output of this methodology in a joint example, one region in the DVP patient is shown in Figure 4, in which it is possible to observe both indexes (temporal variation at left and LBPg matrices before the thresholding at right).

IV. DISCUSSION

The methodology presented in this work to access cutaneous microcirculation profiles was based on two microcirculation indices (Temporal and Spatial), by the identification of the underlying perfusion patterns (simulated by experimental protocols or obtained in patients with known reduced perfusion levels).

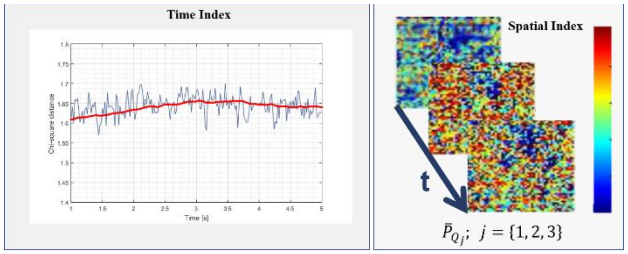

Figure 4: Temporal and Spatial indexes (3) and (4) in one distal region in a DVP patient.

The temporal analysis of the microcirculation profile allows correlating the increase in the pressure levels imposed by the external pressure, with the decrease in microcirculation as measured according to (4). This type of temporal analysis allows us to identify the physiological adaptations of the tissue to hypoxia response, such as the profile change occurring in the E3 period, where after 30 seconds of occlusion there is a muscular contraction response.

The results obtained by the experimental tests also reveal the ability of the temporal index to capture flow variations, thus allowing its use as a dynamic marker. In the cases of DVP, reperfusion time can be measured, so the Temporal Index may be used to quantify the degree of disease by calculating the time to return at baseline levels, or by comparing perfusion time with other regions.

In cases where the degree of cutaneous microcirculation is reduced, the existence of a spatial perfusion marker allows perceiving the flow geometry and its subcutaneous distribution. This index may be of special interest for diabetic foot risk analysis, and for this reason, the definition of three sensitivity levels for the Spatial Index proves to be particularly useful. By analyzing the results in Table 1, is possible to conclude that, for the three levels of sensitivity $(\bar{P}_{Q_i}, i = 1,2,3)$, the highest value presented is that of the E4 region (where de highest variation perfusion levels occur). In cases where the change in perfusion is subtle, it is possible to increase the index sensitivity, by changing the threshold level to $(\bar{P}_{Q_3})$.

Particularly, patients diagnosed with PAD not only have low perfusion levels at distal regions, but they also present a reduced variation of perfusion within these regions. As can be seen from the data in Table 2, by the analysis of $(\bar{P}_{Q_3})$ index, the greatest variation is noted at this level in the DVP patient, who is at an advanced stage of the disease). In the case of the patient with T2DM, who is classified as low level risk of diabetic foot, there is a low perfusion variability between regions A and B (for any of the cut-off levels), whereby the definition of threshold can be in these cases less demanding in terms of sensitivity.

V. CONCLUSION

This work presents a video speckle pattern analysis method to evaluate cutaneous microcirculation profiles. This is an LBP derived image processing methodology, adapted to video speckle characteristics and based on a local filtering scheme using a Gaussian threshold, the LBP_g . Based on the LBP_g output, two metrics were proposed to evaluate the microcirculation profile (a Temporal and a Spatial Index).

The methodology was applied to different perfusion conditions, both in experimental perfusion-occlusion situations and in patients with PAD. The results obtained point to the usefulness of these measures in cases where the diagnosis of PAD is established, with potential practical application in the context of PAD surveillance in primary health care. Additionally, the technique is innocuous, portable and inexpensive imaging modality, that can be easily used for clinical surveillance purposes.

Although based on experimental studies where distinct perfusion profiles were simulated, these results should be analyzed with caution, due to the reduced number of clinical experiments. In the near future, a clinical study will be conducted to reinforce the findings reported in this work, requiring a study enrolling more patients to achieve a greater level of detail in the analysis. Nevertheless, the results are encouraging and promising for potential use of this technique - speckle video analysis - based on the LBPg patterns and the respective Temporal and Spatial Indexes in the surveillance of PAD patients.

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Heartbeat Interval Dynamics in Response to Acute Stress in Human: A Case Study of Real Fear of Snake

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***Abstract* - Heartbeat dynamics changes promptly and substantially in response to acute stress. This is due to direct neural connection of the heart and the central nervous system. An opportunity to analyze a video recording synchronized to a simultaneously recorded ECG arose after preparation of educational TV show about adrenaline. Although the scenario for the experiment in Ljubljana Zoo did not presume to expose a person to acute fear, the unexpected situation of awareness of proximity of the snake's head led to actual sudden acute fear of the snake for the third time in person's life. This case study presents heartbeat dynamics before and during acute fear phase. The response of the heart to acute fear was immediate. Large and fast variations of heartbeat intervals were observed throughout the whole experiment (heartrate decrease by up to 32 beats/min in 5 seconds), indicating upheaval in regulation of cardiovascular parameters.**

Keywords - heart rate variability, acute stress, ophidiophobia

I. INTRODUCTION

Some snakes are venomous, therefore the fear of snakes is effective in a sense that a person reacts quickly to avoid danger. From the evolutionary point of view, it is clear that a quick response is more important than a precise identification of real danger. Even if a person is convinced that there is no real danger, the mechanism of reflex reactions takes priority in human response [1, 2]. It is believed that the fear of snakes occurs in about one third of adults [3]. The exaggerated fear of snakes is called *ophidiophobia* [1]. It is one of the most common specific phobias. Detection of snakes in visual search tasks has been shown to be more rapid than detection of other tested objects [4]. It has been shown that even 6-month old infants reacted with pupillary dilation when presented with pictures of snakes [3]. The non-arbitrariness of the snake fear, in combination with the evolutionary relevance of snakes to human survival, lead to the postulation that humans are evolutionarily "prepared" to fear certain stimuli over others [1, 2, 5]. However, many researchers failed to replicate some of the findings supporting the so-called Preparedness Theory and have criticized the contextual relevance. Furthermore, methodological and interpretative limitations have been addressed [1, 6]. Neither have various cultural differences been studied. Therefore present understanding implicates that fear of snakes is primarily learned through cultural transmission [1, 6].

One of the reactions to acute fear is an accelerated heartbeat. In this case study, we analyze ECG and video recordings from TV cameras, soundtracks included. The recordings were made during preparation of TV show and the experiment was therefore not specifically prepared for the purposes of this case study; only after a thorough examination of the recordings two months later such a possibility was noticed. The acute fear was unmotivated; the response to acute fear was genuine and could not have been achieved in controlled experimental conditions. Such an experiment would have been even unethical.

In this case study, we analyze the heart rate variability at the time when the person was preparing to take a non-venomous snake in her hands, during the time when she held the snake in her arms and at time when the acute fear of snake was triggered due to an unexpected movement of the snake's head. Furthermore, the heart rate variability during the experiment is compared to person's heart rate variability at rest.

II. MATERIALS AND METHODS

A. The person and the snake in the experiment

The experiment in Ljubljana Zoo has been made for the educational television show about adrenaline ("Osvežilna fronta", RTV Slovenia, released on 11th December, 2017). The person involved in the experiment later described that she has had the fear of snakes ever since she remembers. This fear was likely learnt by way of listening to the fairytales and her grandmother's stories about snakes. She saw a snake for the first time in her life when picking up mushrooms in the woods at the age of eight. She got frightened as she nearly stepped on it. The snake was lying still on the ground, and then raised its head when unexpectedly approached. The second experience with a living snake happened 5 years ago, when she got scared again while preparing a contribution for TV Slovenia on overcoming the fear of snakes. The 3rd experience is described in this paper (Fig. 1).

The snake called Greta is a female python (*Python regius*, known as Royal python) that inhabits the Ljubljana Zoo. It is not venomous, and is not endemic in Slovenia. In Slovenian natural habitat, there indeed are snakes but are smaller, and few of them are venomous.

B. ECG, video and audio recordings

The ECG recording was made with Savvy ECG (Saving, Ljubljana), a single-channel ECG with long-term recording capability that communicates via Low Power Bluetooth with

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the mobile phone [7]. We used the MobECG application (version 1.7.5.1, Saving, Ljubljana) on the LG K8 4G smartphone (using Android 6.0). On the day of the experiment the person was self-recording her ECG from 8:27 AM to 6:45 PM. We used an unfiltered recording, which in addition to the ECG included high frequency signals of muscle murmur and other artifacts also. The electrodes were installed at the V1 and V2 positions of the standard 12-channel ECG so that the device measured the voltage difference between the V2 and V1 leads. Ag/AgCl electrodes (Skintact, T60) were used. The ECG recording was then analyzed with the VisECG program (version 1.2.13, Jožef Stefan Institute, Ljubljana).

Fig. 1: The female presenter a fraction of a second before noticing that the snake 'Greta' (*Python regius*) just moved its head closer to her left hand (see No. 9 in Fig. 2). The smartphone in the hands of her colleague shows real-time ECG from the wireless ECG sensor attached to her chest. Picture reproduced with permissions of both subjects

Video and audio were recorded for 5 minutes simultaneously with two professional TV cameras. The resolution of the images was 1920x1080, 25 frames/s, stereo audio channels were sampled with 48 kHz, all coded in MPEG-4 format (picture 8 Mb/s, sound 189 kb/s). Videos were viewed with a program that also displays individual video frames (Vegas Movie Studio Platinum 9.0, Sony Creative Software Inc.). In the analysis of recordings we used only single camera footage, while the footage of the second camera was used only to verify the quality of synchronization between the ECG and the video footage of the first camera.

ECG and video synchronization was accomplished in two steps. Rough synchronization was achieved by comparing the ECG recording with parts of the video, where the camera showed the screen of the phone with a display of telemetric ECG. In this step, we achieved synchronization with an accuracy of about 100 ms, because the ECG display on the phone lags 133-233 ms, which was measured with a test video (30 frames/s). The test clip simultaneously screened the phone with the signal from the ECG sensor and the LED (Light Emitting Diode), which was connected to the ECG sensor and to the pulse generator. This generator (we triggered it manually) was switching the LED on and off. In the next step, the synchronization accuracy was improved by comparing the ECG recording to the video clip. The sudden movements of the person (a clap and a fast up and down hand movement) are clearly identified in the video footage and the reflection of these movements can be identified in the ECG recording also (artifacts). This is how we improved the synchronization between the ECG and the clip to 1-2 video frames that is 40-80 ms. Synchronization was time consuming, which could be avoided if the experiment had been planned for such image processing. The synchronization step could have been optimized by using a test generator and the LED in the same manner as done for the display of the smartphone and the LED.

C. Experiment

As mentioned earlier, during the experiment the test subject (the female reporter pictured on Fig. 1) wore the one-channel ECG sensor, which was wirelessly sending a signal to the phone.

At the beginning the test subject was getting accustomed to the presence of the snake. This phase lasted for almost 4 minutes (Fig. 2, No. 1 - 7); from the time the snake was taken out of the terrarium until the moment when the test subject claimed that she was no longer afraid. Shortly afterwards (15 s), the test subject took the snake into her own hands and again quickly handed it back to the demonstrator due to the unexpected movement of the snake. In her own words, the test subject corroborated that she did not remember precisely whether she either saw the movement of the snake's head or felt the move. The video footage demonstrates that the person was not looking directly at the snake but rather at the phone displaying her ECG. Only her left eye was in such a position that her peripheral vision may detect the movement of the snake's head. To study the effect of adrenaline the TV show also features measurements of the force by which a person can compress a dynamometer, but these measurements are not presented in this case study.

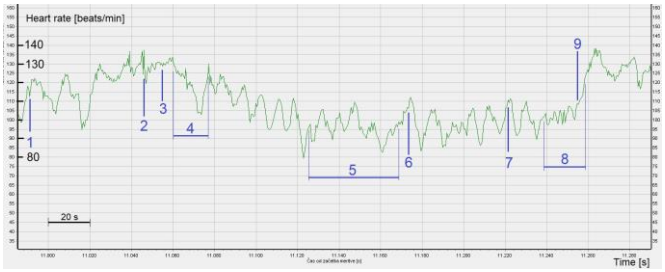

Fig. 2: Heart rate during a 5-minute video recording. Large variations of heart rate in intervals of less than 10 seconds are visible. 1) The snake is taken from the terrarium. 2) The test subject touches the snake for the first time. 3) The test subject touches the snake for the second time. 4) The test subject contracts the dynamometer. 5) The interval during which the test subject is getting used to sensation of touching the snake. 6) The test subject agrees to take the snake into her hands. 7) The test subject proclaims, "I'm not afraid." 8) The interval where the test subject holds the snake in her hands. 9) Acute stress event, when the snake suddenly moves its head, which scares the test subject

III. RESULTS

All of the experimental phases correlated with the heart rate are presented in Fig. 2. From the time they take the snake from the terrarium (1), until the test subject first touches it (2), the

pulse is on average constantly growing. Simultaneously there is a high variability of the heart rate with a maximum range of 95 to 130 beats/min; the ascent occurred in mere 8 seconds. From that moment and up to the start of the interval 5 in Fig. 2, the average heart rate is decreasing. During this time the Zoo staff member is reassuring everyone by chatting about snakes not being slimy and that when showing a snake to a fearful person the snake's head should be hidden. In the interval 5, the test subject constantly keeps her hand on the snake, thus reducing her fear to the point when accepting to hold the snake by herself (6). Fifty seconds later she even said that she was not afraid (7). Just before the beginning of the interval 5 the largest pulse rate drop occurred (from 111 beat/min to 79 beats/min in 5 seconds). From the beginning of the interval 5 to the beginning of the interval 8, the average pulse rate is about 98 beats/min, and high heart rate variability is still present, reaching another large deviation after point 6, when the pulse drops from 112 beats/min to 83 beats/min in 5 seconds only. Such fast changes can be a result of rapid activation of both branches of the autonomic nervous system (sympathetic and parasympathetic) that innervate the sinus node of the heart. In the interval (8) till the moment of acute stress activation (9), the amplitude of the heart rate variability was about 3 times smaller than before.

Acute stress occurred when a person detected an unexpected movement of the snake (Fig. 3). The interval S in the image (the snake moved its head) is located with an accuracy of 40-80 ms with respect to the interval T. The test subject's reaction of shiver has a sharply defined start and end. Myopotentials presented here could be distorted, since the sampling frequency was 125 Hz, the low-pass filter before the A/D converter was 150 Hz (-3 dB), which means that the signal was under sampled. The first heartbeat (QRS complex in ECG) after acute stress event emerges during the interval T when the person felt the shiver. We here quote the test subject's description of the stress event in the Slovenian language: "*Zgrozila sem se, kar pomeni, da me je streslo, kot da bi me zazeblo, tako kot se prestrašiš. Vse je bilo zelo avtomatično, nič premišljenega, kače pa sem se želela rešiti čim prej. Skratka, v mojem spominu je, da sem videla/čutila premik in to me je prestrašilo tako, da sem se stresla in se želela čim prej rešiti kače*". Translation: "I was horrified, meaning I shivered; it felt like getting cold, like when you are scared. Everything was very automatic, nothing rational; I just wanted to get rid of the snake immediately. Basically, as far as I can remember, I saw or felt the snake's movement, which scared me to such an extent that I shuddered and just wanted the snake gone".

After the acute stress event, the heart rate increased, slowly at first and then after the 3th heartbeat, the biggest rise in the heart rate occurs (Fig. 4). At the time of the beat 4, the test subject has already relinquished the snake, and the frequency increased up to 138 beats/min in the 15th beat after the stress event. The effect on the sinus node was therefore the strongest in the time between the third and fourth beat that is from 1.2 to 1.7 seconds after the occurrence of the acute stress cause. It was taken into account that the influence of the autonomic nervous system on the sinus node is possible only before the P wave in ECG.

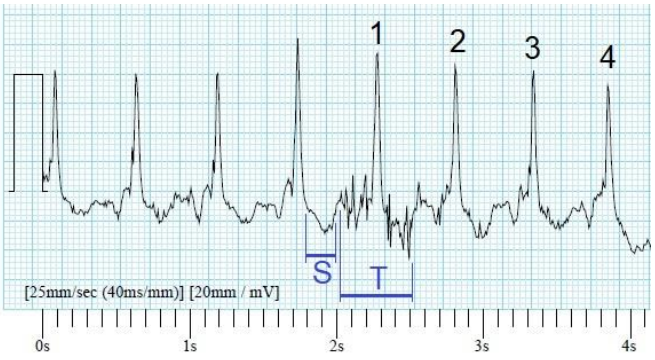

Fig. 3: ECG at the time of acute fear. In the interval S, which lasts about 0.2 seconds, the snake moved its head. This provoked an acute response, which first appears as the test subject's shiver, and is recorded by the ECG as myopotentials in the T interval (480 ms). The center of the S interval is taken as the reference time of the acute stress event

After the 5th beat the acceleration of the heart rate was reduced till the 9th beat, which was the first one after the stress with deceleration, indicating that parasympathetic influence was greater than the sympathetic one. Further to the 9th beat a fine interplay between the two branches of the autonomous nervous system can be seen in Fig. 4.

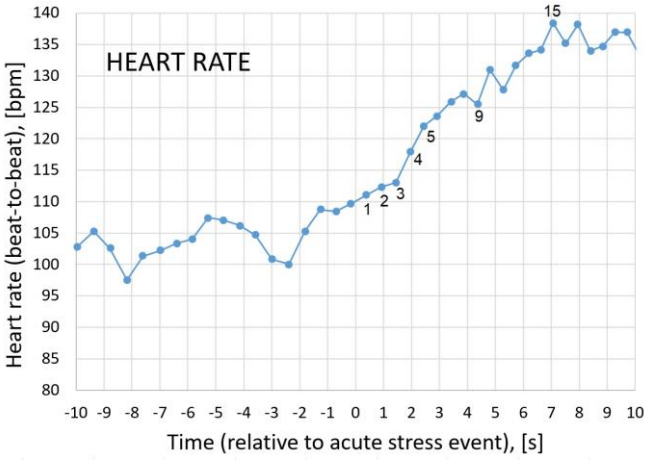

Fig. 4: Heart rate 10 seconds before and after acute stress event (time 0). The first consecutive 5 heartbeats and the heartbeats 9 and 15 after the acute stress event are numbered. The numbers 1–4 correspond to those shown in Fig. 3

In comparison the heart rate variability in the evening of the same day is presented in Fig. 5. The amplitude of heart rate variability in 20 s segments is smaller than during the experiment with the snake (Fig. 2).

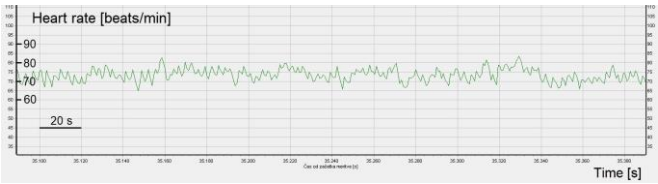

Fig. 5: Heart rate during 5 minutes in the evening (around 6:15 PM)

IV. DISCUSSION

In case of a stressful event like in this case, a part of the brain, the amygdala, sends a distress signal to the hypothalamus, which functions as a command center, communicating with the rest of the body through the nervous system. As expected in threatening situations, speed is significant. Therefore fear-related information reach the amygdala prior to any information from the visual cortex, and a fear response is initiated prior to conscious recognition of the threat [1, 8, 9, 10]. The fast amygdala response explains immediate and rapid increase in heart rate after acute stress event in our case study. Response to sudden threatening stimuli is mainly unconscious and is called startle reflex. It assists to protect vulnerable parts of the body and facilitates escape from sudden threat [11]. Startle reflex is systematically modulated by the organism's ongoing emotional state. Subjects with specific fears show a greater startle potentiation [12]. Anxiety, a negative emotional response to threatening circumstances, is associated with elevated high blood pressure, increased heart rate and an enhanced respiratory rate [13]. Heart rate responses to trauma-related pictures contributed to the identification of individuals with posttraumatic stress disorder [14]. Startle responses are not modulated by ongoing emotional processes alone. The amplitude of the startle response is reduced when a non-startle stimulus is immediately preceding the startle eliciting stimulus [12]. All these and many other mechanisms influence physiological response of an individual. Defensive behaviors in animals and humans vary dynamically with increasing proximity of a threat, and in dependence upon the behavioral repertoire at hand. When the approaching threat was inevitable, attentive freezing was observed as indicated by fear bradycardia and potentiation of startle reflex. In preparation for active avoidance, a switch in defensive behavior was observed, characterized by startle inhibition, heart rate acceleration and a general sympathetic dominance to facilitate fight or flight responses. If the organism was again placed in a context where a threatening event has been experienced, precautionary behavior has been engaged. Response output was characterized by attentive freezing, accompanied by fear bradycardia and potentiation of the startle reflex [15].

It is worth mentioning that in our case person's heart rate was already increased before the acute stress event due to snake's presence. Beside the direct neural connection of the brain and heart there is also a hormonal regulation of the cardiac response to stressful event, which is slower but was in this case already present. After a distress signal is sent from amygdala and/or other parts of the brain, hypothalamus activates sympathetic nervous system and activates adrenal glands that release adrenaline into bloodstream. Circulating adrenaline has a number of physiological effects (faster heart rate, increased cardiac contractility, increased blood pressure, faster breathing, bronchodilation, increased blood glucose, and many more). Additional oxygen increases alertness and sharpens the senses, while increased blood glucose supplies energy to all parts of the body. Since our case study subject would like to overcome the fear of snakes it is reasonable to assume that simultaneous parasympathetically mediated mechanisms persisted and influenced the heart rate. Fear response is initially beyond the conscious control, but conscious control can be quickly involved [16]. To our knowledge there are no studies to understand this interplay between cognitive and automatic responses in the acute fear phase. However, individual differences have been observed in the psychological and physiological reactions to trauma-related stimuli and it has been suggested that this depends on trauma encoding indicating the codependence between cognition and automaticity [17]. Fear bradycardia and freezing response are commonly reported in animals in the face of overwhelming threats [18, 19]. For fear bradycardia in humans an alternative explanation, increased orienting, is also proposed [17].

Heart rate variability, a physiological phenomenon of variation in time intervals between consecutive beats, may be a marker of cardiovascular health or an indicator of autonomic nervous system activity. Heart rate variability of healthy cardiovascular system is associated with its own chaotic nature due to a beat-to-beat regulation by opposite sympathetic and parasympathetic modulatory influences [13]. Furthermore, hormones also influence the heart rate variability. It is accepted that in case of increased heart rate, the heart rate variability decreases [13, 19]. This has, however, not occurred in our case; the amplitude of heart rate variability was higher the whole time of the experiment when compared to the heart rate variability in the evening when the heart rate was lower. As expected, the highest rise in heart rate emerged immediately after the acute stress event. Heart rate increased from 110 to 138 beats/min (difference of 28 beats/min). In comparison, in studies where only fear relevant pictures were presented to fearful subjects, a statistically significant difference of only 4 beats/min has been reported [12]. In our case fear bradycardia was not apparent. However, it might have been hidden in the slow increase of the first 3 heartbeats after the acute stress event. Only after the 3th heartbeat large rise in heart rate occurs.

It is important to notice that in order to remain within the ethical standards, the acute fear phase achieved in this experiment was not planned and therefore could not have been accomplished in a controlled experiment. Acute stress induces the release of stress hormones, which have various detrimental effects on the organism like suppressing immune system [20]. Furthermore, chronic stress has been linked to pathogenesis of numerous diseases and disorders like insomnia, depression, anxiety, rheumatoid arthritis, cardiomyopathy, gastric ulcers, ulcerative colitis, infections, diabetes, cancer, and other. However, our findings may be studied further within the existing workshops designed to overcome stressful situations.

V. CONCLUSIONS

We have demonstrated that a small wireless ECG device combined with video recording could be efficiently used in behavioral experiments. To the best of our knowledge, this is

the first example where the heart rate variability was measured during a real life response to the fear of snakes. The heart rate variability was shown to have been higher during the periods of high heart rate (stress) than during the period of low heart rate (relaxation), which was contrary to expectations and may be due to fast activation and deactivation (modulation) of the sympathetic and parasympathetic branches of the autonomic nervous system that innervate the sinus node of the heart. This predicament may fall into category of individual differences. Further studies are needed to explain either variations of individual differences or to adjust the explanatory model.

ACKNOWLEDGMENT

The authors of this study acknowledge the assistance of Neža Prah Seničar, who described her experience in detail and also provided the TV footage. Also, we thankfully acknowledge RTV Slovenia for giving the permission to use their recordings. Last but not least we are thankful to Eva and Luka to help us with translation of a part of the manuscript.

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A web-based virtual reality environment for medical visualization

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***Abstract*—In this paper, we present a novel approach to integrating virtual reality (VR) into a web-based medical visualization framework. The framework supports visualization of volumetric data, such as 3D scalar fields acquired by a CT, MRI or PET scanners. To improve users' perception, understanding and manipulation of 3D volumes, we adapted the traditional 2D screen representation with support for visualization of data in a VR environment. By providing complete visual immersion, VR can help users to gain better insights and understanding of the visualized data. Our main goal was to allow users to view the medical data in VR and interact with it with hand-held controllers for better immersion and spatial perception.**

In the paper, we present a novel approach to implementation of VR for medical imaging, which combines WebGL-based hardware accelerated web visualization with VR. This allows users to use the visualization framework with or without a VR headset by switching between "standard" and "VR" modes. Since visualization runs in a web browser, it is portable, easy to use on different devices and therefore accessible to a broad number of users. The visualization system was tested with real medical scans to assess its performance and usability.

I. Introduction

With the development of 3D scanners for medical purposes [1]–[3], physicians are getting large sets of radiological data about their patients. The data provides support for physicians with diagnosis, planning surgeries and even during surgeries. With better visualization, we could make their decisions easier and more confident.

Modern scanners usually give us data in form of 3D scalar fields. This data needs to be processed and displayed in a way that can be easily viewed by physicians. Usually, images are rendered on traditional 2D screens, but viewing 3D images on 2D screens can cause some problems with perception and display of the details, because these screens lack the depth perception, which is crucial for better spatial perception of volumetric data. It is harder to see specific details and it took longer to put them in the perspective, which is very important in medical domain.

There are existing applications, that can display data in 3D with pre-installed software and specific headsets [4], [5]. Very good example of a software that uses volume rendering and virtual reality combined is SpectroVive[1]. It was developed at the University of Basel as part of the MIRACLE project[2]. There are also many commercial products in field of VR in medicine: Immersive Touch[3], Medical Realities[4], Osso VR[5], Surgical Theater[6].

Apart from actual products, there are also many articles researching possibilities of using computer graphics and VR in medicine.

Virtual reality is becoming very important in medicine. An article [6] explains current and future use cases in this field. We have seen a big rise in popularity in recent years due to reductions in the cost of VR headsets and commercialization. An article also addresses a history of VR use in medicine.

In article [7] researchers presented benefits of using three-dimensional ultrasound imaging in the diagnosis of rental-onset skeletal dysplasia. Results clearly showed that physicians were able to score better in finding skeletal dysplasia when using 3D ultrasound, compared to using 2D ultrasound. We believe that with VR physicians will be able to get better results compared to viewing 3D ultrasound images on 2D displays.

Study about the user acceptance of the web-based distribution of radiology services was made in Western Australia [8]. There were many different opinions about the system, but on average they were satisfied with the approach.

Many applications and frameworks were developed for visualization of volumetric data. A good example is Exposure renderer [9], which is used for local visualization but lacks support for web and VR.

Researchers have also investigated the benefits of immersion in virtual reality for volume data visualization [10]. They concluded that VR platforms have untapped potential for exploring visualizations of volumetric data. They pointed out that the VR community needs empirical results to validate the claims of benefits of immersion for VR.

An article [11] named "Applications of Virtual Environments in medicine" shows us many possibilities of using VR in medicine. First health care applications of VR started in the 90's. In past decades there were huge advancements in both software and hardware, making VR experience more accurate and affordable. There is a huge interest in medicine for VR because it can be used in many situations such as medical

[1]https://www.unibas.ch/en/News-Events/News/Uni-Research/Virtual-Reality-in-Medicine.html
[2]http://dbe.unibas.ch/public/dbe/research/FlagshipProject.html
[3]http://www.immersivetouch.com/
[4]https://www.medicalrealities.com/
[5]http://ossovr.com/
[6]http://www.surgicaltheater.net/

education, surgical simulation and planning, virtual endoscopy, neuro-psychological assessment, rehabilitation and many other situations.

In contrast to approaches presented above, we present a novel web-based framework for medical imaging in VR. Our framework uses WebGL 2.0 for hardware accelerated web visualization with support for the VR. This allows users to use our visualization framework with or without the VR headset. It is also not limited to the specific headset and uses the same code base for all visualization purposes. Best of all, it runs in modern browsers, even on mobile devices. Currently supported browsers and platform are held in an updated list[7].

The remainder of the paper is organized as follows: In Section II we present the developed system and its properties, in Section III we present the evaluation and results of the developed system and in Section IV we present the conclusions and give pointers for the possible future work.

II. The Developed System

The developed system presents an extension of Med3D framework with support for VR through use of WebVR application programming interface and integration of volumetric ray casting rendering technique for volumetric data visualization.

A. Med3D

Med3D [12] is an open-source web-based 3D medical data visualization framework (see Figure 1) based on NeckVeins Java framework [13]. It was developed as a platform independent tool for visualization of medical volumetric data. WebGL 2.0 library is used for exploiting the hardware accelerated graphics rendering in the browsers. The application enables remote collaboration between users [14], who can share data, view data annotations and can also communicate via integrated chat. The framework runs in all modern browsers and supports standard input devices such as mouse and keyboard. On top of that the framework also supports the 3D mouse and Leap Motion for navigation. The application is capable of displaying 3D mesh models (in form of .obj files) as well as mesh representation of 3D volumetric data (such as CT or MRI scans in form of .mhd files).

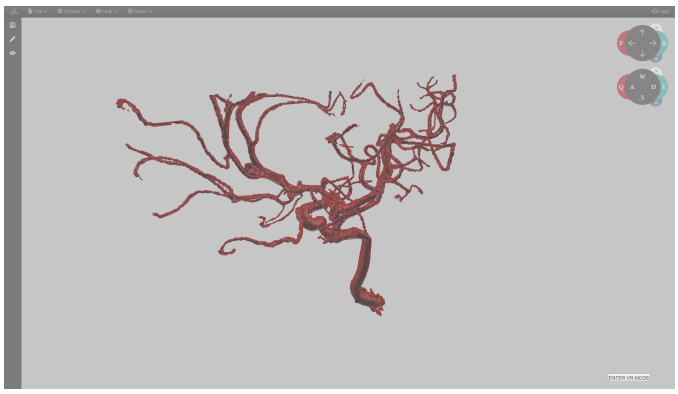

Figure 1. Med3D visaulization framework.

[7]https://webvr.rocks/

B. Integration of VR

Since we want to display data in virtual reality and also make the application available through web browser we decided to use WebVR application programming interface [15]. The WebVR application programming interface provides support for exposing virtual reality devices (usually a head-mounted display) to web applications. We used this application programming interface inside Med3D in a way that is displayed in Figure 2.

1) Using the WebVR application programming interface: In the first step we query the application programming interface for available VR devices. In response we get list of references to available VR displays. We have to select a display on which we want to present the visualization to user. If we successfully obtained at least one VR display we can advertise VR functionality to the user in form of button for entering VR mode (see Figure 1 - bottom right of the screen). When the user clicks the button, the application requests presentation on the selected display. In the next step the application makes a method call `VRDisplay.requestAnimationFrame()`, to run the rendering loop at the correct refresh rate for the display.

Inside this loop, method call `getFrameData()` returns required data needed for rendering the current frame. Afterwards, the displayed scene is draw twice (first with parameters for left eye, second with parameters for right eye). When rendering the scene for both eyes is finished the result image has to be submitted to display in the headset. Because WebVR application programming interface is responsible for communication with VR devices (headsets) our framework does not have to deal with calls for specific headset.

2) Additional modifications required in Med3D application: Because we wanted to use existing rendering pipeline, we had to adapt the Med3D framework in order for the application to work in the desired manner. When the user requires rendering in VR, we obtain VR display parameters (e.g. rendering width, height, etc.). In each iteration of render loop we have to render the scene separately for left and right half of the display. Because each rendered image is narrower, we have to set correct aspect ratio. We also have to compute correct FOV, far and near plane from projection matrix and pass them to existing method calls. The application with enabled VR display is presented in Figure 3.

3) Implementing VR controllers support: For implementation of controllers we used Gamepad application programming interface[8]. It gives developers a way to access and respond to signals from controllers. Benefit of using this application programming interface is that it works with multiple controllers. Since it is still only experimental technology it might have some drawbacks. Currently there is also limited support in browsers, but it has broader support than WebVR. We used experimental game-pad extension GamepadPose to give users better experience in VR mode. The GamepadPose interface is very useful in our application, since it represents

[8]https://developer.mozilla.org/en-US/docs/Web/API/Gamepad_API

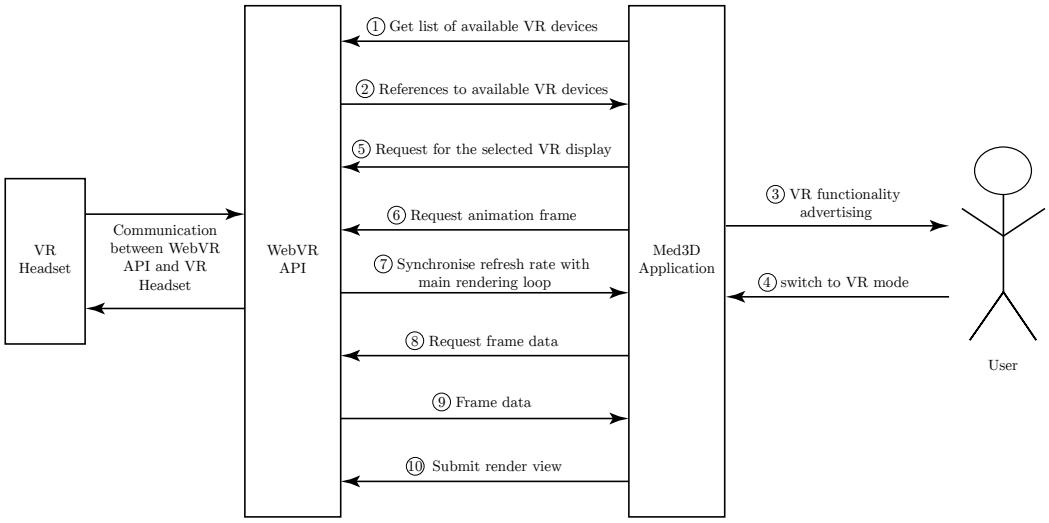

Figure 2. Diagram of WebVR integration in Med3D framework.

a pose of WebVR controller. It has many properties including orientation, position, acceleration, etc. Firstly we have to check if game-pad is connected to the computer. Afterwards, we make sure that game-pad is available and we query the game-pad object to obtain interaction data. We use controllers for the scene navigation.

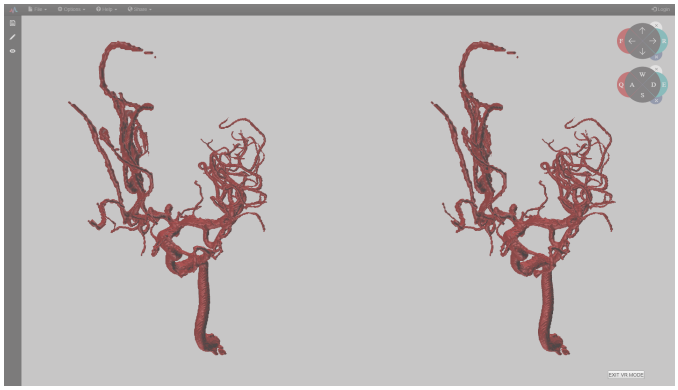

Figure 3. Visualization of data in VR mode.

C. Integration of volumetric ray casting

Volume ray casting [16] is an image based volume rendering technique which allows direct rendering of 3D scalar data without converting it to the mesh object. The implementation was developed as GLSL shader used in the standard Med3D framework rendering pipeline. The framework was adapted with support for sending larger 3D scalar data directly to GPU, setting the volumetric ray casting parameters and executing the rendering on the data in fragment shader as done in deferred rendering approach. The implementation also supports different ray casting techniques such as: maximum intensity projection, ISO surface rendering and alpha compositing.

All other Med3D functionalities were kept, such as scene navigation and other user interaction. The scheme of the individual system components and their relationship is presented in Figure 4.

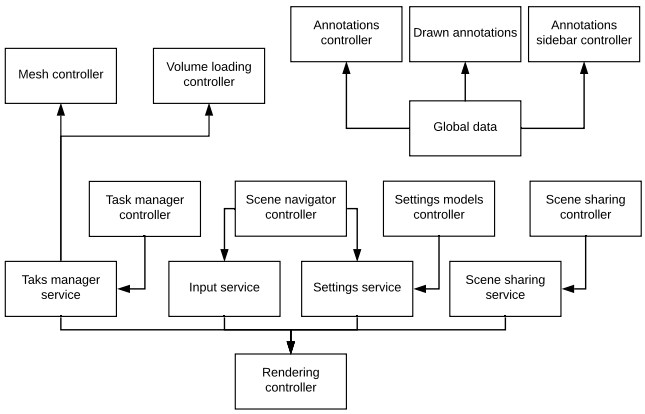

Figure 4. The system architecture and it's individual components.

III. Evaluation and Results

For quantitative evaluation we tested frame rates of ordinary rendering to the screen and rendering in VR mode. To eliminate dependency on specific headset we tested it with special plug-in[9] for Google Chrome that emulates HTC Vive headset.

The application was tested on two computers. First was a HP laptop with Intel i7 (2.2 GHz) processor, 8GB RAM and AMD Radeon HD 8750M graphics cars. Average fps (frames per second) for ordinary rendering on screen is 26.860 frames per second. Average fps for rendering in emulated VR mode is 46.992 frames per second.

We tested application with the same model on another computer: Intel i7 (3.6 GHz), 16GB RAM and NVIDIA TITAN Xp graphics card. Average result here was for both

[9]https://github.com/spite/WebVR-Extension

normal and VR mode was approximately 60 fps. Reason for this is the browser limitation, which is 60 frames per second.

Frame rate is higher in VR mode for first system, but it is still to slow for high-quality VR experience. The goal of VR is to target 90 frames per second at all times to ensure good user experience of virtual reality. The hard limit of 60 fps is the downside of rendering graphics in web browsers.

IV. Conclusions and Future Work

We developed a web application that allows visualization of mesh data and volumetric data in virtual reality. It's main purpose is to provide physicians with the better insight in the volumetric data obtained from 3D medical scanning (such as MRI, CT etc.). The main advantage of our such application is its accessibility. While most of the other applications (mentioned in the article) require specific software and hardware for displaying the data to users in virtual reality the presented application runs in the web browser and does not require any specific software (apart of the browser and software from your VR headset manufacturer). It also gives users freedom of choice, because they can use a headset of their choice or even use the application without the VR capabilities. Since this technology is quite new, there are certain limitations and weaknesses. Applications that run in the web browser usually cannot be as fast and responsive as native applications. There is also limited support for different web browsers as well as web browser limit of rendering 60 fps. All browsers do not support WebVR application programming interface yet and some headsets are limited to certain operating systems. With the development of the technology and predicted growth in the next years these limitations will gradually vanish.

In the future we will try to optimize implementation of VR functionality to make it faster and more user friendly. We believe that VR will play important role in the future of medicine and our improved application can be a good example. In addition to optimizing currently supported options for rendering there are still many techniques that we could implement in the future to make our application better and more user friendly.

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Optimal DSP Bandpass Filtering for QRS detection

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***Abstract*—An electrocardiogram refers to the process of recording the electrical activity of the heart over a certain time interval. ECG signal holds vital information for the current health condition of the patient. Detection of cardiac disorders is based on detection of sudden deviations from the mean line. Detection of heartbeat functions is based on extracting ECG characteristic features, especially the R-peak. Although in this paper we address a general approach, we focus on using wearable ECG sensors and developing an efficient QRS detector to determine the heartbeat function. The real problem in detection and ECG signal analysis is processing the noise contaminated ECG signal and the way one can reduce the feature space to extract the relevant features. In this paper, we set a research question to investigate how the filter affects the accuracy, sensitivity and precision values on QRS detectors. We report our findings on optimal filter design with a central frequency of 8.33 Hz and -3db cutoff frequencies at 4 Hz and 20 Hz. The analysis addresses development of an efficient filter with small computing complexity intended to be used for wearable ECG sensors.**

***Index Terms*—ECG, Heart Signal, FIR, IIR, Discrete Wavelet Transformation, R-peak, QRS Detection, Filter Length.**

I. Introduction

ECG signal follows a typical waveform with P, Q, R, S and T features as presented in Fig.1. Algorithms for detecting ECG disorders are based on correctly detecting these features. In each QRS detection algorithm, the basic step is to detect an R peak.

Software QRS detection has been a research topic for more than 40 years. Whereas in the early years the computational load determined the complexity and therefore the performance of the algorithms, nowadays the detection performance is the major development objective. Although with advances in computer technology, the computational load becomes less and less important, the development of small wearable sensors revitalizes the research on fast and efficient QRS detection algorithms.

Usually, the ECG signal is contaminated with noise, that can stem from different internal and external sources, such as environmental noise or internal body muscle movement. The next step is to reduce the search space and extract only the QRS complexes as much as possible in order to construct a good QRS detector. Analyzing the QRS structure and the properties of a typical ECG signal, one can conclude that a bandpass filter can successfully be used for these purposes. Some authors suggest using only a high-pass filter to extract the QRS complexes. This can be realized based on the knowledge that the intensity of QRS is larger than the intensity of high frequencies noise.

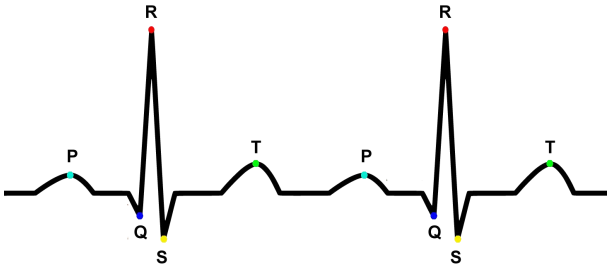

Fig. 1. A typical PQRST waveform of an ECG.

To avoid misinterpretations due to the baseline drift and other potential noise and obstacles generated by other internal waves, we continue with an analysis based on bandpass filters. Our goal in this paper is to determine the optimal values of the bandpass filter that can successfully eliminate the noise and extract the QRS waves only.

Therefore, the research question will be to investigate the effect of the filter length in case of FIR filtering, or other characteristics relevant for IIR filters or wavelet filters, trying to find the optimal values of the central frequency, bandwidth and -3 db cutoff frequencies of the filter. The influence of the bandpass filter will be evaluated by the accuracy, sensitivity, and precision. We use the standard MIT-BIH database while evaluating the algorithm.

The organization of the paper follows the next structure. The dispersion of the signal energy of ECG features, such as QRS complexes, P, and T waves and related work is presented in Section II. In Section III we analyze the QRS spectra theoretically. The methodology to test the filters and validate the QRS dispersion and QRS detection is given in Section IV. Section V presents the results of obtained measurements and discusses the optimal filter values. Finally, Section VI summarizes the obtained results and gives directions for future work.

II. Related Work

A good QRS detector needs a well-designed bandpass filter. Gusev et al. [2] present challenges to develop an efficient mobile solution for wearable ECG sensor and elaborate the need for the development of an efficient solution due to smaller

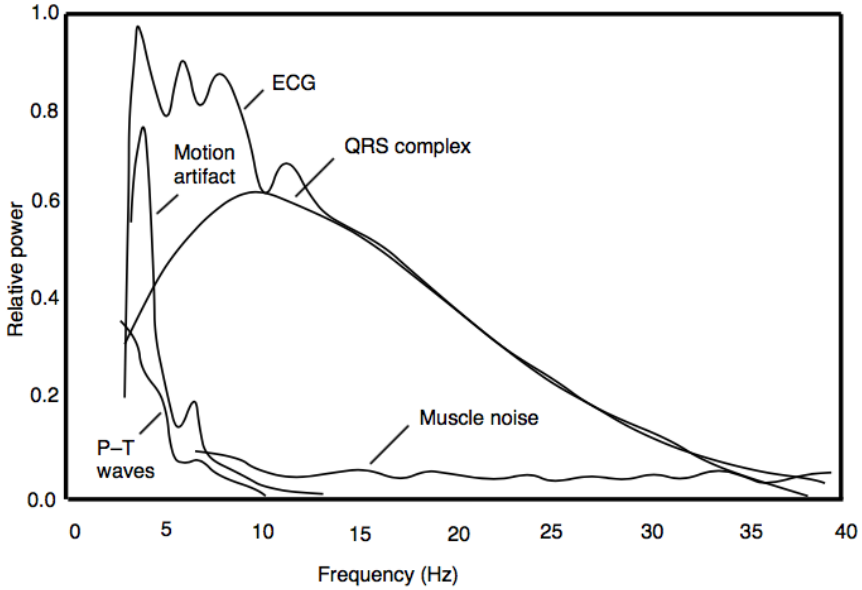

Fig. 2. Relative power spectra of an ECG signal [1].

resources found in wireless mobile devices and dew computing solutions [3]. Further on, we overview the filters and their characteristics, as a background for the experiments that will help to find the optimal values for the noise elimination and feature space reduction.

Filters can be defined by one of the following forms impulse, step, and frequency response, while the input and output of a digital signal are usually analyzed in the time domain [4], [5]. In *finite impulse response (FIR)* filters, the output data samples can be computed by a convolution of the input data samples and the filter coefficients that represent the impulse response of the filter, while in *infinite impulse response (IIR)* filters, the output is using already calculated output values besides the input samples by a set of recursion coefficients. Wavelet filter is based on wavelet transform that decomposes the signal into a mutually orthogonal set of wavelets useful in compression/decompression algorithms.

In this section, we present related work about the feature space reduction in order to extract the QRS features. Particularly, we analyze the spectral dispersion of QRS complexes.

Tompkins [6] discusses the genesis of the ECG by analyzing the physics of the heart muscle movements. The slow-moving depolarization of the atria which begins at the sinoatrial (SA) node produces the P wave. Then, the signal is delayed in the atrioventricular (AV) node resulting in an isoelectric region after the P wave, then as the Purkinje system starts delivering the stimulus to the ventricular muscle, the onset of the Q wave occurs. Rapid depolarization of the ventricular muscle begins producing the R wave and reaching an R peak when most of the cells are depolarized. The final phase of ventricular depolarization occurs as the excitation spreads toward the base of the ventricles giving rise to the S wave. This is followed by a T-wave ventricular repolarization.

In addition to the QRS complex, P, and T waves, the ECG waveform contains noise from external factors, including environmental high-frequency noise or noise from other electrical equipment, noise from internal factors, such as, electromyography (EMG) electrical activity from muscles, motion artifacts from the electrode and skin interface, etc. One has to eliminate noise prior to feature space reduction to enable a quality analysis of ECG signals, and especially in the case when they are weak. So the typical procedure starts with elimination of the noise and then continues with feature space extraction eliminating the other signals such as P and T waves.

A lot of researchers have tried to measure the power spectra and conclude a typical spectral dispersion. Thakor et al. [1] have analyzed the ECG spectra and summarized the relative power of the ECG, QRS complexes, P and T waves, motion artifact, and muscle noise, as presented in Fig. 2.

Kohler et al. [7] declare that those typical frequency components of a QRS complex range from about 10 Hz to about 25 Hz without giving any experimental proof. This is why, in this paper, we have intended to research the QRS dispersion and the effect of bandpass filtering on QRS detection.

Many different approaches to QRS detection have been proposed; such as, differential methods (signal derivates) including the Pan Tompkins [8] based methods, using mathematical morphology, and recent developments including, for example, algorithms from the field of artificial neural networks, genetic algorithms, wavelet transforms, filter banks as well as heuristic methods mostly based on nonlinear transforms. A good overview of various approaches for QRS detection can be found in [7] and for wearable devices in [9]. A nice overview of the state-of-the-art wearable ECG sensors and cloud-based solutions can be found in [10].

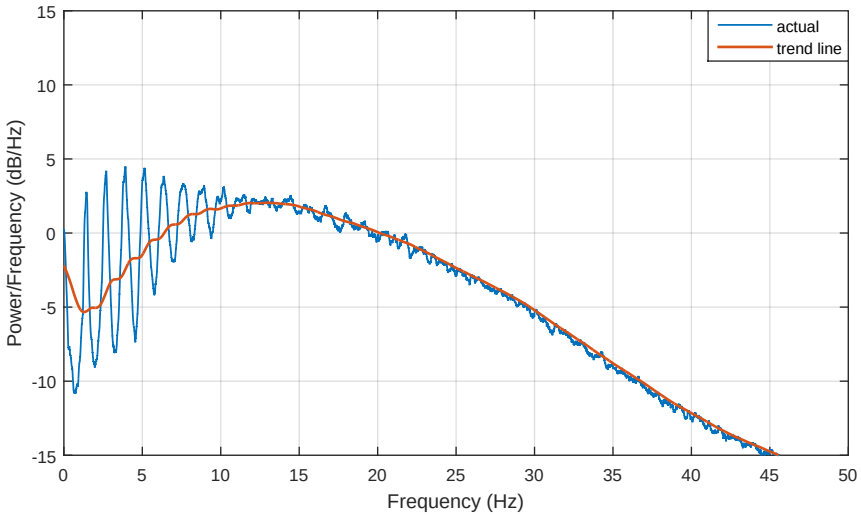

Fig. 3. Relative power spectra of QRS complexes (MIT-BIH 100).

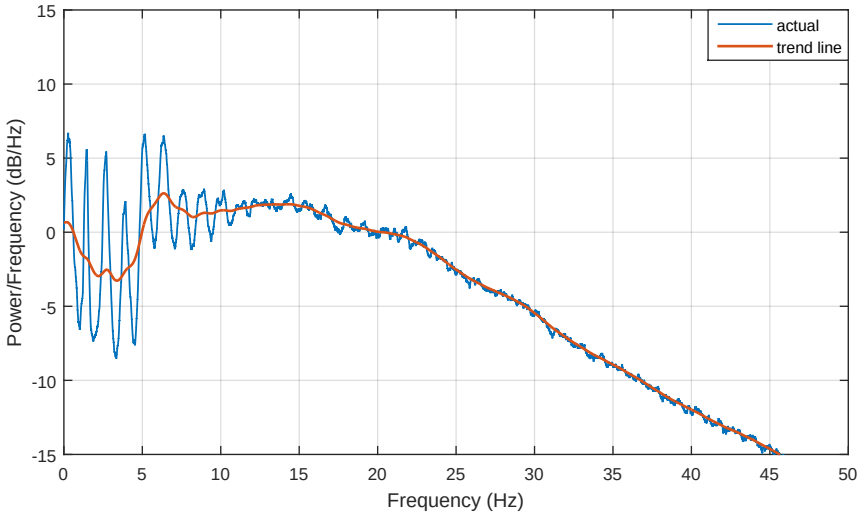

Fig. 4. Relative power spectra of noise, P and T waves (MIT-BIH 100).

Note, that the filters used in various QRS detection approaches include different precisions and frequency bands, starting from filters that use integer-only arithmetics to reduce the computational complexity and filters realized by sophisticated analysis technology with increased computational complexity.

III. Analysis of the ECG and QRS spectra

We have analyzed experimentally the power spectra of QRS complexes and other signals including the noise of the MIT-BIH dataset of 48 records. Here we present, a typical spectrum for patient ID=100 in Fig.3 for QRS signals only, and in Fig.4, the determined noise spectra and the spectra of the P and T waves.

Although the measured values mostly correspond to the earlier findings and conclusions, we can determine that there is no clear distinction of the exact QRS band. Note that the patients with pacemakers have a slightly different spectrum, mostly due to the fact that the QRS is shorter.

One can observe oscillations in the range of 0 and 10 Hz in the spectra of the QRS complexes and a typical answer is that they happen due to respiration and muscle movements. However, the respiration rate and muscle movement affect only the spectra from 0 to 1 Hz.

Oscillations in the region from 1 to 10 Hz represent a typical situation of a frequency modulation between the QRS complex waves and heart rate waves. Suppose that a typical QRS wave is a part of an ideal sine wave with a frequency of f_{QRS}. Then this wave is repeated at regular time intervals determined by the heartbeat rate with frequency f_{HR}. A composition of these two signals results in a frequency modulation of the signal with a higher frequency (f_{QRS}), also known as carrier frequency, with a signal with a smaller frequency (f_{HR}) or signal frequency. The power spectra of this composed

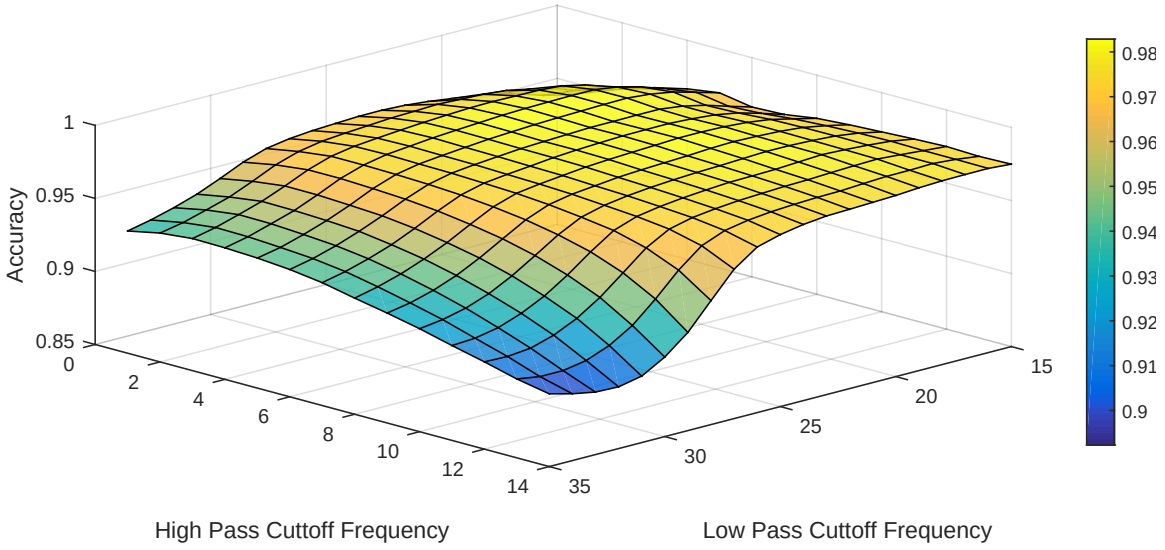

Fig. 5. Accuracy for different bandpass filter values for FIR filters.

signal will consist of these two frequencies presenting the corresponding intensities.

However, in reality, the QRS wave is not an ideal sine wave and it is a composition of several frequencies. This also applies to the heartbeat since a typical heart changes its frequency almost in each heartbeat. This is reflected as a variation of the carrier frequency. The oscillations in the observed spectra, actually represent the effects of frequency modulation of these signals.

The following analysis addresses the power spectra of the QRS complexes (Fig. 3) in the band 0 to 10 Hz. The regular peaks that repeat each 1.25 Hz are noticeable and they represent the heart rate frequency f_{HR}, which corresponds to the average heartbeat rate of $1.25 * 60 = 75BPM$. The variations in the sine wave shape present the heart rate variations, and in higher harmonics, they are less expressed. One can notice that a low pass filter will determine the heart rate frequency (f_{HR}) and the high-pass filter, the carrier frequency (f_{QRS}).

The same frequency modulation phenomenon can be observed also for T (and P waves although they are smaller in intensity) in Fig. 4. One can notice the first harmonic with a value of about 3.8 Hz, and its harmonics.

In this paper, we desire to determine the spectra of the carrier frequency and detect the QRS complexes, by a theoretical interpretation of the experimental results about spectral analysis at higher frequencies.

The literature [11] points time duration typical values of a normal heartbeat QRS complex to be between 60 and 120 ms. The inner part of the signal that mostly looks like a half sine wave occupies approximately most of this interval. So, one can expect that the distribution is mainly around a frequency that corresponds to a full sine wave of 120 ms, which in fact is 8.33 Hz. A larger and smoother QRS complexes last 120 ms correspond to 4.17 Hz, and smaller sharper QRS complexes might last at least 30 ms, which correspond to 16.7 Hz.

So far, our analysis leads to a conclusion that filtering the signal within 4 and 20 Hz will reduce the feature space to mostly the values of those in the QRS complexes. Note that in the case of paced beats, the QRS complexes might look even sharper and last less than 30 ms, which will need filtering with frequencies higher than 33 Hz. On the other hand, in the case of premature ventricular beats, the morphology of the QRS complex is prolonged and might last more than 250 ms, which leads to frequencies lower than 4 Hz.

The problems in detection might arise from the onset of P and T waves. The typical values of P waves (half sine wave) are 110 ms, so its power spectral energy will be around 4.5 Hz. T waves are even larger than 200 ms that corresponds to frequencies below 2.5 Hz.

This analysis shows that a bandpass filter with a central frequency of approximately 8.33 Hz and cut off frequencies at 4 Hz and 20 Hz will enable feature space reduction to extract QRS complexes. However, a good QRS detector has to be implemented also on experimental results and analyze also the other sources of the power spectra, including the environmental noise, P and T waves and muscle and motion artifacts.

IV. Testing Methodology

There is no ideal filter design, so this is why we analyze several filters to estimate their performance not just from the feature space reduction and noise elimination aspects but also from the aspects of their computational complexity, and their implementation in a real environment with real wearable sensors, such as the long-term Savvy ECG sensor [12].

For the experiments, we have used a differential approach to detect a QRS complex, based on applying filtering with DWT reconstruction db3 low and high pass filters, which actually constructs a bandpass filter. The output of this filter

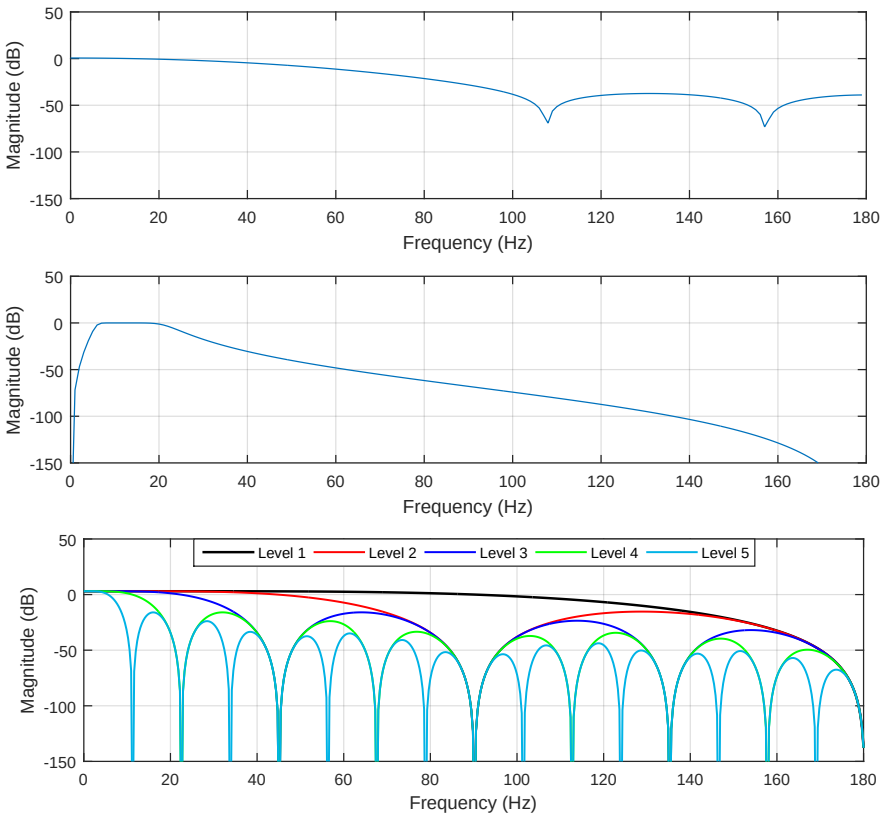

Fig. 6. Frequency response characteristics of used FIR, IIR and DWT filters.

is compared to a threshold value, which is calculated as one-third of the average value of all output items. The experimental environment was a computer with a high-frequency Intel Core i7-3632QM CPU @ 2.2 GHz processor with 8 cores, and 12GB memory.

The dataset used was the MIT-BIH database [13]. We have conducted test cases on all 48 records with 650000 samples each corresponding to 30 minutes ECG records with a 360 Hz sampling frequency.

The test cases included high-pass cutoff frequency ranges from 1 to 14 Hz with incremental steps of 1Hz and low pass cutoff frequency from 15 up to 35Hz, with incremental steps of 1Hz.

The test range of the bandpass FIR filter length ranges from 11 to 201 with incremental steps of 10. In the last case, the best parameters will be combined and tested. We have used FIR filters with lengths of 5 up to 201 and IIR filters with a length of 5, 7, 9, 11, 13 and 15.

The signal filtered by DWT was reconstructed by using the approximation of A3 (0-22.5Hz) and deducting the A5 (0-5.625Hz) which leads to a bandpass filter with a close approximation of the desired band between 5.625 - 22.5Hz.

The test goal is to measure and optimize the *sensitivity (SEN)*, *accuracy (ACC)* and *positive predictivity rate (PR)* values, as defined by (1).

$$\begin{aligned} SEN &= \frac{TP}{TP+FN} \\ ACC &= \frac{TN+TP}{TN+TP+FN+FP} \\ PR &= \frac{TP}{TP+FP} \end{aligned} \tag{1}$$

To calculate these performance measures we used the count of those beat annotations that appear to be correct by *true positive* and denoted by TP, and samples that were correctly annotated that are not peaks *true negative* denoted by TN. Annotations that were generated as a QRS peak, but are not real heartbeats as *false positive* by FP, and those that were missed by the algorithm are *false negative* as FN. Our testing QRS detection algorithm is based on a wavelet filter using a simple algorithm based on differential approach testing the slope of the ECG curve. The performance of the algorithm is 99.63% QRS sensitivity, without using extra filters prior to applying the QRS detector algorithm.

V. Evaluation and Discussion

Fig. 5 presents the accuracy values for an FIR bandpass filter with different values on the lower and higher cutoff frequencies. Note that the maximal values are obtained in the band with cutoff frequencies of 4 to 20, which proves the theoretical analysis.

TABLE I
COMPARISON OF VARIOUS FILTERS ON QRS DETECTION SENSITIVITY (SENS.), ACCURACY (ACC.) AND POSITIVE PREDICTIVTY RATE (PR).

Filter Type	TP	TN	FP	FN	Sensitivity	Accuracy	PR
No Filter	105443	0	2874	4051	0.963	0.938	0.973
FIR (9)	106683	0	2888	2811	0.974	0.949	0.973
IIR (9)	108486	0	1141	1008	0.991	0.981	0.989
DWT (db2)	108668	0	1165	826	0.992	0.982	0.985

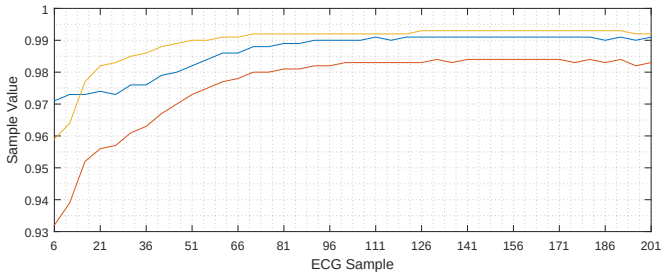

Fig. 7. Sensitivity, Accuracy and Precision dependency on FIR filter length.

We do not present the measured sensitivity and precision diagrams since their diagrams are quite similar.

The frequency response of used FIR, IIR and DWT filters is presented in Fig. 6. To obtain a higher bandpass filtering one can use a smaller IIR length and needs a higher filter length of the FIR filter to obtain a better performance. The performance of the wavelet filter is even better.

The FIR filter is designed to reach the $-3db$ cut off value at the desired frequency. The design of the IIR filter follows the same principles. While designing we have used different filter lengths of FIR and IIR filters. Filter length impacts the algorithm performance. For example, Fig. 7 presents the impact of FIR filter length on performance expressed by sensitivity, accuracy, and positive precision rate. One can notice that after a length of 100 the trend line stabilizes and reaches the maximal performance.

Table I compares different filter approaches for using the filter between 5.625 and 22.5 Hz. The default configuration labeled as 'No filter' is the result of executing our QRS detector algorithm without extra filter prior to the QRS detection. The values compared in the table are presented for FIR and IIR filters with a length of 9 and DWT filter using db2.

Our algorithm is based on differential wavelet filter and the additional preprocessing bandpass filter just gives the advantage in achieved performance. The sensitivity, accuracy, and positive predictivity rate obtained in the best case for measuring overall 48 patients in the MIT-BIH database reached 0.992, 0.983 and 0.990 correspondingly. The implemented preprocessing filter actually improved the sensitivity by 3.1% and accuracy by 4.5% and reached performance values where the mistakes are less than 1.65%.

Note that some might think that wavelet transformation needs more processing power and is not as fast as the other filters. However, a recent study [14] shows that there are improved pipelined implementations that make the wavelet filtering fast.

VI. CONCLUSION

We have concluded that QRS complexes are dispersed mostly in the range between 4 and 20 Hz. This was elaborated theoretically and proven experimentally. Therefore, adding a bandpass filter in this range will improve the QRS detection performance and reach values where the mistakes are less than 1%. Our research shows that choosing an FIR filter with a length of 101 gives sufficient performance, although IIR outperforms this filter for much smaller lengths. The wavelet-based filters are the best and the difference in obtained results is very small (less than 0.5%).

We recommend the intended implementors of ECG wearable and mobile devices to use the technique that allows stability of the filter and uses less complex operations that will enable faster processing with fewer resources.

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Evaluation of peripheral arterial occlusive disease with arterial oscillograph prototype

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Abstract – Arterial oscillography (AO) is a non-invasive pneumatic technique for measurement of blood volume changes inside an organ or body part. In presented study, a peripheral arterial disease (PAD) of 19 individuals (35 legs) was measured using AO prototype instruments. The results of AO evaluation were compared to results of computed tomography angiography (CTA), which is the gold standard for diagnosis of PAD. The sensitivity and specificity of AO prototype instrument in amount of 79% and 81%, respectively was calculated.

Keywords **– leg pain, plethysmography, diagnostics**

I. INTRODUCTION

Peripheral arterial disease (PAD) can be defined as a range of noncoronary arterial syndromes that are caused by the altered structure and function of the arteries that supply the brain, visceral organs, and the limbs [1,2]. Based on objective testing, reported in several epidemiologic studies [2-5], an overall prevalence of PAD in value of 3% to 10% has been found. These values are even higher (15% to 20%) in persons older then 70 years. The majority of patients with PAD are asymptomatic. The ratio of patients with symptomatic and asymptomatic [2,3,5,6] PAD is in the region of 1:2 to 1:4. Patients with symptomatic PAD have a significantly higher risk of death from cardiovascular disease [1,2,7].

In this study, an evaluation of PAD using arterial oscillograph prototype was performed. Arterial oscillography (AO) is based on measurement of change in volume of the extremity caused by the cyclic nature of arterial inflow. Early instruments used a mercury strain gauge placed around the extremity. Change in volume causes a change in circumference, and therefore, in the electrical resistance of the strain gauge. The resistance is easily measured and plotted on a strip chart, which results in a waveform that has the same basic contour as the pressure wave [8]. Impedance plethysmography works on similar principles; it monitors electrical impedance, which is inversely proportional to volume of the limb.

These devices have been largely replaced by arterial oscillography (arterial air plethysmography), which monitors pressure in a cuff placed around the extremity and inflated to 65 mmHg. Raines [9] and Raines et al, [10] who developed these instruments, called them pulse volume recorders; the term still used today. These devices are more rugged and easier to use than the strain gauges that they have replaced.

Like segmental pressure measurements, waveforms obtained with pulse volume recording (PVR) at various levels of the lower extremity can be used to infer the presence and location of arterial occlusive disease. The normal pulse contour has a rapid upslope, a sharp systolic peak, a dicrotic notch, and a downslope that bows toward the baseline (Fig. 1).

Downstream from stenotic segments, the waveform becomes dampened. Thus, a decrease in pulsatility (either the amplitude or upstroke) from one segment to the next indicates the presence of stenosis upstream. The extent of the changes in the waveform is related to the severity and extent of the proximal disease.

The upstroke becomes less steep, the dicrotic notch is lost, and the overall amplitude is decreased. The test is confounded by similar waveform changes that may be caused by downstream disease.

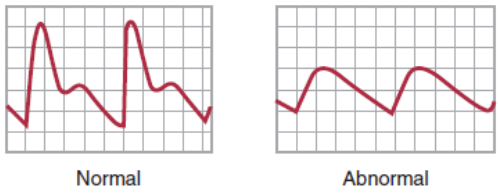

Figure 1. Normal and abnormal pulse volume contours recorded at the ankle level. The normal form shows a prominent dicrotic wave on the downslope. Cuff pressure, 65 mm Hg; cuff volume, 75 mL.

II. METHOD

Thirty-five legs in 19 patients with evidence of PAD were studied prospectively by physical examination, AO and CTA in Vascular laboratory of General Hospital Novo mesto during a 12-month period from October 2016 to September 2017. After a single examination by one senior vascular surgeon, measuring data were recorded. The patients were currently seeking care by a vascular surgeon for worsening of PAD symptoms.

A prototype instrument for PAD was designed, fabricated and characterized together with readout electronics. Prototype instrument presented in Figure 2 consists of Riester's 24-32 cm standard reusable manual inflation blood pressure cuff (www.riester.de), silicon piezoresistive pressure sensor and readout electronics. Silicon piezoresistive pressure sensor FER-PS111 (Fig.2) was designed and fabricated in Laboratory of Microsensors Structures and electronics (LMSE). The details of fabrication process and temperature compensation were described elsewhere [11,12]. Measurements in this clinical test were performed with National Instruments 16-Bit USB multifunction I/O device USB-6212 connected to personal computer, which acts as readout electronics and serves as pressure sensors voltage source (5V).

Changes in leg volume were measured by wrapping a cuff around the lover extremity as shown in Fig.3. The cuff was placed 5 cm above the medial malleolus (ankle) and inflated to 65 mm Hg. During the measurement, patient was in supine position (lying horizontally with the face and torso facing up) with elevated measured leg.

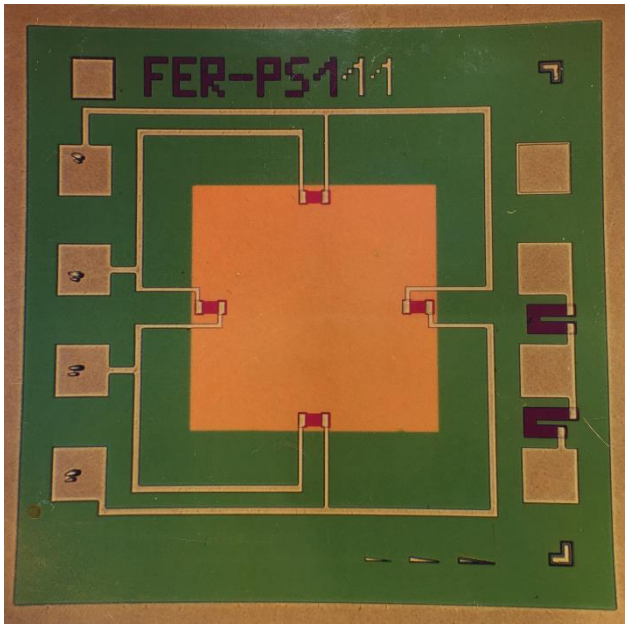

Figure 2. Micrograph of Silicon piezoresistive pressure sensor FER-PS111 used in prototype. Diffused resistors are placed on edge of 25µm thin silicon diaphragm and connected to Wheatstone bridge.

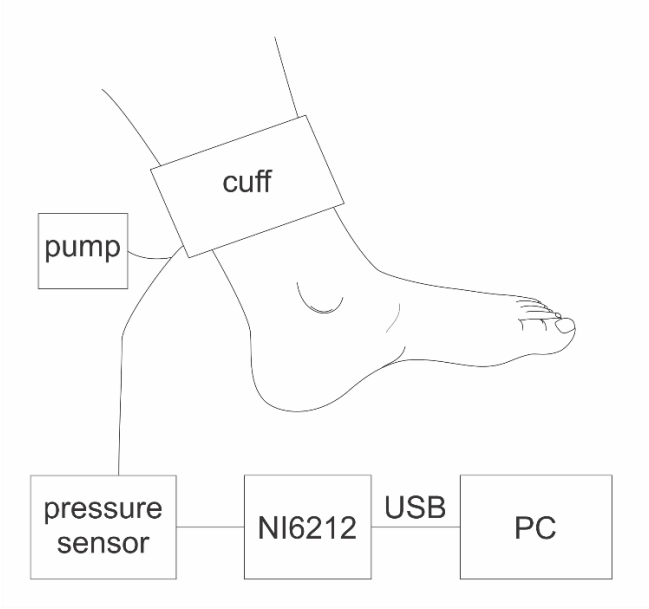

Figure 2. Measurement setup during clinical test

Measuring results obtained from prototype instrument were used to calculate AO rise times, which were further compared with the results obtained with computed tomography angiography (CTA). Based on comparison of measuring results a sensitivity, specificity and efficiency of AO method was calculated from Equations (1). The rise time longer than 220 ms was considered pathologic [13], shorter than 200 ms normal, 200-220 ms uncertain (Fig.4).

III. RESULTS

The patient group consisted of 12 men and 7 women with age range from 59 to 83 years (a mean of 73.4 years). Clinical examination was performed at initial presentation with the standard criteria.

sensitivity or true positive rate (TPR)

$$TPR = TP / (TP+FN)$$

specificity (SPC) or true negative rate

$$SPC = TN / (TN+FP)$$

efficiency (EFF) or diagnostic accuracy

$$EFF = (TP+TN) / (TP+FN+FP+FN)$$

TP - true positive, TN - true negative
FP - false positive, FN - false negative

(1)

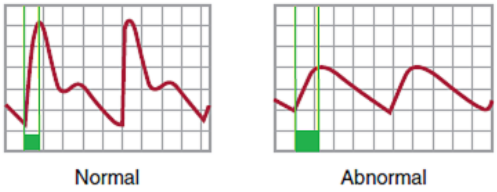

Figure 4. Normal raise time is less than 200 ms

The analysed results of AO show the PAD in 15 limbs and missed the disease in 4 limbs. In addition, AO results show 13 normal limbs, but missed 3 limbs (Table I).

From measuring results, presented in Table I, and Equations (1) sensitivity, specificity and efficiency of the AO method was determined in amount of 79 %, 81 %, and 80%, respectively.

IV. Discussion

As early detection and early intervention of PAD is becoming more important in community health care, the need for a sensitive test is becoming more important.

TABLE I. Comparison of AO rise times and CTA results (P).

P	[ms] right AO	pathologic right CTA	[ms] left AO	pathologic left CTA
1	205	NO	193	NO
2	223	YES	229	YES
3	182	NO	208	YES
4	185	NO	188	NO
5	178	NO	175	NO
6	239	YES	237	YES
7	192	NO	202	NO
8	215	YES	222	YES
9	amputated limb		215	YES
10	198	NO	187	NO
11	185	NO	185	YES
12	234	YES	221	YES
13	227	YES	109	NO
14	192	YES	amputated limb	
15	172	NO	185	NO
16	243	YES	212	YES
17	ulcus cruris		192	NO
18	206	YES	225	YES
19	193	YES	183	YES

This study demonstrated that the sensitivity and specificity of AO for detecting PAD was comparable with other studies [14]. AO is less affected than segmental pressure measurements (ankle-brachial index) by arterial calcification. So the AO is more accurate in diabetic patients, which have usually calcified vessels. The combination of segmental pressure measurements and AO is more accurate than either method alone for detecting PAD. AO has the same limitations as most other indirect tests, including segmental pressure measurements. Like the other indirect tests, AO is used less often in most laboratories that have access to duplex scanning, which provides more accurate and detailed information.

Traditionally, clinical symptoms are considered to be important in diagnosing PAD. However, the presence of intermittent claudication largely depends on the activity level of patients. In chronic debilitating condition such as diabetes mellitus and chronic renal failure, PAD may manifest as a critical limb ischemia even in patients without claudication. As PAD is closely associated with ischemic cardiovascular disease, early detection and early intervention (such as risk reduction medication and exercise programs) for PAD have become more important. And with rapid progression in the technology of interventional endovascular procedures, timely intervention in selected patients could decrease amputation, procedural morbidity, and mortality.

V. Conclusion

Although AO can provide an assessment of the overall physiologic function of the arterial system, it is most useful as a relatively simple and non-invasive measurement to detect the presence of PAD. CTA is usually used in patients with symptomatic PAD to check the anatomic location of disease before any interventional procedure. It is considered as accurate as digital subtraction angiography, a gold standard diagnostic method in PAD. However, as CTA needs a bolus injection (usually >100 mL) of iodine-contained contrast agent, and potential serious complication such as nephrotoxicity and anaphylaxis limits its usage as a primary diagnostic method, especially in patients with decreased renal function.

AO is an optimal measuring method of the presence or absence of PAD when no further information concerning the arterial hemodynamic situation is desired. If information on the severity of PAD or evaluation of improvement after arterial surgery is required, a quantitative test will be more useful.

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Parallelization in biomedical time series analysis web platform: the MULTISAB project experience

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Abstract - **Parallel execution of operations required for biomedical time series (BTS) analysis is an important issue in optimization of medical software efficiency. We investigate the applicability of several parallelization approaches to BTS analysis in the context of feature extraction from multiple heterogeneous BTS on a Java-based web platform called MULTISAB, designed for medical diagnostics. Considering only the calculation parallelization of many different BTS features, our research suggests that parallelization based on simple Java multithreading works the best. The threads are assigned based on the data and analysis parameters provided, where feature extraction parallelization is performed on the following levels: 1) multiple segments; 2) multiple signal trails; 3) multiple patient records. The synchronization mechanism should be simple: the analysis continues once all threads terminate their work and record the extracted feature vectors. A special case, when features from two signal trails (bivariate features) are extracted, includes multithreading on signal pairs for multiple signal trails level parallelization. We also provide an overview of the web platform architecture to put the parallelized parts into the overall perspective.**

Keywords - biomedical time series analysis, feature extraction, web platform, parallelization, multithreading

I. INTRODUCTION

Biomedical time series (BTS) analysis software usually possesses a significant amount of computational complexity, due to the fact that the implemented algorithms need to efficiently manage noisy and non-stationary properties of the considered time series [1]. The degree of complexity depends largely on the goal of the analysis and the features used in reaching that goal. For example, extracting linear statistical features such as mean and standard deviation from an already preprocessed BTS in order to determine if an analyzed segment significantly deviates from an expected behavior does not require intensive calculations. However, performing empirical mode decomposition based Hilbert-Huang transform and extracting many potentially relevant time-frequency features on a broader scale of learning a model for a disease, based on many patient records, is highly resource-demanding [2].

In our earlier investigations, we approached the problem of designing the architecture for a BTS analysis web platform called MULTISAB[1] [3]. The platform is intended to provide ubiquitous web access to interested researchers and medical personnel that want to analyze BTS. The platform is based on specification and execution of analysis scenarios. We have also previously shown the feature implementation details regarding heart rate variability, electrocardiogram, and electroencephalogram analysis, also including a definition of expert recommendation system for features that need to be extracted, depending on the analysis goal and data type [4]. Data mining methods, including feature selection and classification algorithms are also implemented in the platform, which is a topic of another, currently submitted conference paper [5]. At the moment, the platform is in integration and testing phase and is planned to be open for users soon.

In this work, we focus on the details regarding computational complexity amelioration that has been achieved in the platform. In particular, we address the complexity problem by examining the applicability of different parallelization approaches to the feature extraction step of the analysis. As feature extraction is the crucial part of BTS analysis, accelerating this step brings big difference to the web platform user experience.

The work is organized as follows. In Section 2, we provide a brief overview of the current state of MULTISAB platform implementation and highlight the spots where parallelization may be beneficiary. Section 3 first discusses some related work and then describes our attempt at directly parallelizing individual feature calculations. Section 4 provides the details of parallelization implemented in the platform, including some experimental validation. Section 5 concludes the paper and provides future guidelines.

II. PLATFORM STRUCTURE AND PARALLELIZATION LOCATION

A. MULTISAB Platform Structure

The MULTISAB web platform is organized in three separate subprojects: *frontend*, *backend* and *processing*.

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The main technologies and intended tasks of each subproject are briefly explained here.

The *frontend* subproject is designed using several recognizable contemporary web frontend technologies, including Angular, HTML5, CSS3, and Node.js. The web site is organized as a single-page web application written using Angular components in TypeScript language, where a TypeScript compiler is used to produce JavaScript code.

The majority of web application's content is focused on conducting an analysis scenario. The user starts the analysis scenario by logging into the platform and opening a new session (or continuing the last existing one). BTS analysis process is divided into 8 steps, some of which may be skipped, depending on the user: 1) analysis type selection, 2) scenario selection, 3) input data selection, 4) records inspection, 5) records preprocessing, 6) feature extraction, 7) model construction, and 8) reporting [4].

The analysis on *frontend* proceeds from a starting step to an allowed set of next steps, which is continued until the final step, reporting, is reached. The possible transitions between steps are governed through a finite state machine (FSM), where a step may correspond to one or a few FSM states. Using this approach, we managed to provide a clearly defined BTS analysis workflow, which would not be possible using standard web site navigation, where any (or most) transitions between steps would be legal. An example of possible step transitions in the platform are shown in Fig. 1, where the user is currently in step "4. Data plot" (records inspection) and may move to the earlier step "3. Select input data" or to steps "5. Preprocessing" and "6. Feature extraction". OpenAPI [6] is used to create the documentation for the MULTISAB's RESTful API that is used for testing the communication between backend and frontend subprojects.

The *backend* subproject is designed using Java 9 and Spring Boot. Java Persistence API (JPA) is used for communication with the database, which is also a part of the backend project. H2 database management system was chosen primarily because it stores all data in a single file. As we store the uploaded BTS files into the *backend* server file system, the H2 database is used only to store registered users and sessions data. The *backend* subproject is built using Maven build tool in order to easily integrate all the required libraries. We use stateful session control by tokens. After logging in, the user is given a token for accessing protected resources on backend, which expires after a timeout if no action is made. For security insurance, we use HTTP/2 protocol. *Backend* currently includes the *processing* subproject as a library. *Backend* calls the methods of relevant classes in *processing* in order to enable the execution of analysis steps. For example, a call from `analysis.RecordsInspectionController` class on *backend* to `signalVisualization.ImageCreating` class on *processing* enables the construction of an image file for visualization of a patient record segment.

The *processing* subproject is designed in Java 9, and is intended to cover all the details regarding BTS analysis. It is implemented as a stand-alone library with potential to be distributed on several hosts. Currently, it is located on the same server as the *backend* subproject. The structure of the *processing* subproject is the most complex one, consisting of several frameworks for handling most of the analysis steps as well as additional platform functionalities. The frameworks with some of the most important packages (small first letter) and classes (capital first letter) are depicted in Table I.

TABLE I. MULTISAB PROCESSING SUBPROJECT FRAMEWORKS WITH IMPORTANT PACKAGES OR CLASSES

Framework	Package or class
Record input handling	`AnnFile`
	`CsvFile`
	`EdfFile`
	`InputData`
	`Metadata`
	`SignalParameterData`
	`TxtFile`
Preprocessing	`filtering`
	`iirj`
	`morphologicalOperations`
Signal visualization	`ImageCreating`
General time series features extraction	`frequencyDomain`
	`nonlinear`
	`timeDomain`
	`timeFrequencyDomain`
Specific (domain) time series features extraction	`eegAnalysis`
	`ecgAnalysis`
	`hrvAnalysis`
Feature extraction	`FeatureExtraction`
	`Parallelization`
Expert system recommendations	`DroolsExpertSystem`
	`ExpertSystem`
Data mining	`discretization`
	`featureSelection`
	`normalization`
	`Classification`
Reporting	`ReportingMain`

More details regarding *processing* functionalities are available in [5]. It is important to stress out that a large number of general BTS features (e.g. approximate entropy, mutual information) as well as specific BTS (i.e. HRV, ECG, EEG) features are implemented in the platform. Also, preprocessing steps, including filtering methods and ECG characteristic points detection using state-of-the-art algorithms such as the one from Elgendi et al. [7] are also supported. Data mining methods currently implemented include several filter-based feature selection algorithms (e.g. symmetrical uncertainty, Chi-square) and several classifiers: SVM [8], MLP, RBF, PNN and NEAT [9]. Aside from our own implementations, permissive licenses (Apache, MIT, BSD, or LGPL) only external libraries are included in MULTISAB.

B. Parallelization Candidate Locations

We carefully examined the potential spots in the platform that would benefit from parallelization. We concluded that efficient speed up of BTS analysis may be beneficiary in the preprocessing, feature extraction and data mining steps, as these are the computationally most demanding steps.

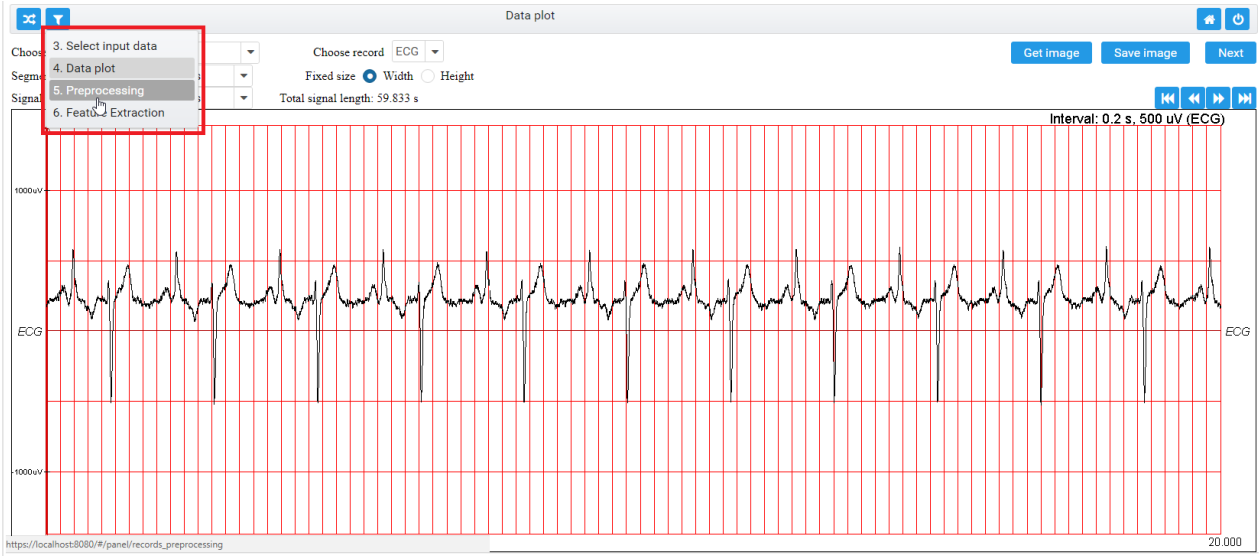

Figure 1. Moving through the analysis steps on frontend: an example where the user is currently in "4. Data plot" (records inspection) step, the relevant part is highlighted with the red rectangle

Our initial considerations indicated that input data preprocessing (such as applying various filters) parallelization may be achieved only for a subset of preprocessing methods. Also, heavy use of preprocessing methods is something that is not the primary focus of the platform. Therefore, currently, if any computationally demanding preprocessing is required, it is expected that the platform would take some extra time. Our decision was to focus first on parallelization of feature extraction, on which we report in detail in Section 3.

It is known that data mining algorithms, in particular, various ANN and SVM algorithms, greatly benefit from parallelization when training with sufficiently large datasets. Generally, parallelizing such algorithms is not trivial, as the internal steps are dependent on the previous calculations. Nevertheless, some efficient parallelization implementations are known, mostly based on OpenMP and GPU [10,11]. This is something that we may consider in the next phase of MULTISAB implementation, but probably not using OpenMP, as its support for Java is limited. We also plan to implement some naturally parallelizable data mining algorithms soon, such as random forest [12].

III. Parallelization Approaches

A. Related Work

The work of Wilson and Williams [13] reported achieving significant performance increase (up to 100x) using GPU parallelization in the case of many-channel (more than 100 channels) for EEG spatial filtering, because matrix multiplications, easily processed by GPU, are used for that purpose. The same work also reported success for parallelizing autoregressive Burg algorithm for power spectral density estimate. However, specific Burg algorithm code optimizations were needed, which prohibits a more general solution for various BTS preprocessing methods implemented in our platform. Chen et al. [14] managed to parallelize ensemble empirical mode decomposition algorithm for many-channel EEG on a CUDA GPU and thus enable faster calculation of Hilbert-Huang spectral entropy, which was used to detect epileptic seizures. Signal preprocessing parallelization may also be realized in a specialized hardware, as was shown by Ahn et al. [15].

The work of Sahoo et al. [16] focused on a web based cloud solution for ECG records preprocessing and visualization. The platform called Cloudware relies on Hadoop 'big data' infrastructure and enables fast preprocessing of ECGs. Parallelization is achieved on patient record and segment levels through the use of MapReduce jobs. By translating EDF format patient data to WFDB format and utilizing PhysioNet preprocessing algorithms (e.g. for R peak detection), which were not parallelized, resulted in faster preprocessing and inspection of large amounts of data available to the medical multicenter in which the system was installed.

B. Attempting BTS Feature Calculation Parallelization

Regarding feature extraction from BTS, we analyzed several possible approaches to parallelization. The first idea was to parallelize feature calculation algorithms themselves. Specifically, we considered GPU-based as well as CPU-based parallelization using Java OpenCL library called aparapi [17]. Aparapi is designed to translate native Java bytecode into OpenCL kernels dynamically at runtime, thus dispatching the tasks either to a multi-core CPU or to GPU, depending on the settings. OpenCL CPU uses processor drivers that need to be installed on the computer and the most advanced instruction set that we have available (e.g. AVX2 for an Intel processor). OpenCL GPU uses GPU's shader processors and, by default for large data sets, global GPU RAM. Initial experiments with aparapi GPU and CPU parallelization indicated more than an order of magnitude acceleration compared to Java Thread Pool. However, the test data included millions of signal samples and non-conditional simple calculations. When faced with a real-world feature

calculation algorithm (e.g. approximate entropy), taking only several thousand samples, conditional next-step execution and non-trivial mathematical operations (e.g. square root), the results were far less impressive. More precisely, the overhead needed to transfer data to CPU or GPU, as well as inability to parallelize most of the feature calculation steps, resulted in parallelization execution time that was significantly longer than the traditional sequential algorithm. The most important problems seemed to be the nature of the feature calculation algorithm itself and dynamic translation of OpenCL kernel. Having multiple interdependent sequential steps, some conditional branching and non-trivial mathematical operations (which prevents parallel reduction technique [18]) resulted in significant performance drop. This was the conclusion for all the inspected feature calculation algorithms.

IV. Parallelization Implementation in MULTISAB

A. Parallelization Context

The *backend* subproject calls the methods of the *processing* subproject when a user's request from *frontend* arrives. Parallelization is handled as one of such requests, currently supported during feature extraction step. The assumptions for starting feature extraction are, as follows:

- There may be multiple patient records uploaded and preprocessed in the earlier steps of the analysis session in the platform.
- Patient records may contain heterogeneous signals (signal trails), e.g. 10 EEG trails, 2 ECG trails and 1 skin conductivity trail.
- The number of feature extraction iterations is equal to the number of different signal types (i.e. ECG, EEG...) in the records.
- All uploaded and preprocessed patient records contain the same types and numbers of signal trails.
- Each iteration of feature extraction is performed on one signal type in all records, because each signal type uses different features and feature parameters.
- All signals in all uploaded and preprocessed records are of equal duration, and if this condition is not satisfied, the analysis may be performed only until the end of the shortest signal trail in all records.

Prior to execution of parallelization for a feature extraction iteration, all the feature extraction parameters need to be set:

- The list of features that need to be extracted in the iteration.
- The list of feature parameters with values for each feature that needs to be extracted in the iteration (in the case where a feature has some parameters).
- The starting time in the record from which the feature extraction process starts (the same for all iterations).
- The analyzed segment width (the same for all iterations).
- The final time in the record until which the analysis is performed (the same for all iterations).

All of these feature extraction parameters are sent from the *backend* subproject after the user specified them via browser GUI on *frontend*. The user may choose not to use parallelization. In such a case, classical sequential feature extract would ensue.

B. Parallelization Progression

Parallelization starts by a call from *backend* to class `Parallelization` within the package called `analysis` in the *processing* subproject. The `Parallelization` class is designed to take as input the paths to patient records that were uploaded and which may have been preprocessed in the earlier steps of an analysis session. The file paths are stored in the database on `backend`. During object instantiation of the `Parallelization` class, all the selected data records are loaded into the working memory to enable faster calculations. Input record size as well as total upload size may be limited by the platform to prevent out-of-memory errors. The data structure in memory is somewhat dependent on the input file format, but it nevertheless allows the use of the same methods for parallelization of execution.

We achieved parallelization through the use of Java multithreading, without aparapi library. We limit the degree of parallelization to the number of available logical cores on the server computer at the moment of parallelization starting minus one (let the number of parallel threads in each such parallelization chunk be k). Parallelization is achieved on several levels: for multiple patient records, within a record for multiple signals of the same type, and for multiple segments within a signal trail. The procedure for parallelization of feature extraction is implemented, as follows:

1. If there is more than one segment present within a signal, then the features in these segments are extracted in parallel, where the parallelization proceeds until all the segments are analyzed.
2. Else, if there is only one segment per signal and there are multiple signals of the same type, then the signals are processed in parallel, where the parallelization proceeds until all the signals are analyzed; a special case for the implemented bivariate features is that all signal pairs (e.g. for calculation of the mutual information feature) are analyzed in parallel.
3. Else, if there is only one segment and one signal of the same type per record, and there is more than one record, then the parallelization is run so that multiple records are analyzed concurrently, which proceeds until all of them are analyzed.
4. Else, when there is only a single record with a single signal type and a single segment, then the parallelization is not performed and the record is analyzed in the original thread.

It is important to note that the extraction of the list of features in a single segment, signal, or record always proceeds sequentially. The reason for this is because the complexity of individual features calculation differs significantly from one feature to another. Therefore, due to easier synchronization, we decided not to create new threads for each feature calculation.

The parallelization synchronization is, as follows: all k threads need to finish with the current feature extraction before moving on to the next chunk of parallelization. This may slow down the possibly achievable runtime of parallelization, but the synchronization is simpler and thus less error-prone. After all k threads finish, the results of feature extraction (feature vectors) are appended to two output files, one in .csv format and the other one in a more informative, .arff file format [19]. The process is repeated for each parallelization chunk, until all the records are analyzed in the iteration.

After all the iterations are completed, the model construction step (data mining) may begin. Therein, complex models may consider features from different signal types stored in several output files, and also other patient metadata, while simple models may use feature vectors extracted from a single type of BTS.

In Table II, we state the most important classes in the *processing* subproject that directly or indirectly (through object references) take part in the feature extraction parallelization process. All of these classes may be found in the `analysis` package of the subproject.

C. Parallelization Validation

As demonstration, we conduct a validation experiment of the implemented feature extraction parallelization to establish its efficiency compared to sequential execution. For that purpose, we proceed with a rather complex feature extraction scenario for extracting multiple features (27 in total) from cardiac rhythm annotation records from PhysioNet MIT-BIH Arrhythmia database [20], which is the standard database for testing algorithms to detect various types of arrhythmias based on heart rate variability (HRV).

We include the following general time series features: four approximate entropies (for $m = 2$, $r = \{0.1, 0.15, 0.2, 0.25\}*\sigma$), four sample entropies (for m = 2, $r = \{0.1, 0.15, 0.2, 0.25\}*\sigma$), corrected conditional Shannon entropy, spatial filling index, Allan factor, and five recurrence plot features (rec. rate, Lmean, DET, rec. Shannon entropy, and rec. laminarity). We also include: 1) standard time domain HRV features – AVNN, SDNN, RMSSD, SDSD, pNN50, HRV triangular index, TINN; 2) standard frequency domain features calculated using Lomb-Scargle periodogram – low frequency PSD, high frequency PSD, and low/high frequency PSD ratio; and 3) standard deviation ratio of Poincaré plot feature. Some details about the features may be found in [21].

The experiments were conducted on an Intel Core i7-4790 CPU @3.6 GHz with 16 GB RAM and 8 logical cores, of which 7 were used for parallelization. We used three settings: 1) only a single record, "100.ann"; 2) first 12 records of the MIT-BIH Arrhythmia Database; and 3) all 48 records of the MIT-BIH Arrhythmia Database.

The results are shown in Table III. The experiments were run five times, with mean ± stddev reported. We can see that, with the exception of single record with the largest number of segments and shortest segment length, parallel execution outperforms sequential execution. We can observe that few longer segments take more time to analyze than many shorter segments. This is because most of the features calculations complexities are more than linearly dependent on the size of the segments. Based on the results for 7 segments, we can expect that the largest positive effect of parallelization takes place when the number of segments is the multiple of the number of used logical cores. Also, as we can see from the results of analyzing only 2 longest segments, better positive effect can be achieved by analyzing longer segments (the effect is almost the theoretical double for 48 records). The reason for this is because threads spend most of the time calculating the features, and less time preparing data for the next chunk or waiting on other threads to finish the current chunk. Based on these results, we may conclude that the maximum effect of multithreading for a general BTS analysis may be achieved for long segments and for the number of segments given as multiple of the number of used logical cores.

V. CONCLUSION

In this work, we have shown the organization of the MULTISAB platform and highlighted the steps that may

TABLE II. *PROCESSING* CLASSES THAT IMPLEMENT PARALLEL (AND SEQUENTIAL) FEATURE EXTRACTION

Class	Purpose
`Parallelization`	The main class intended for starting parallelization. It supports loading data from preprocessed files, adjusting parameters and job scheduling among threads
`ParallelExtraction Thread`	A single thread that deals with the analysis of a single data section (commonly, a file segment, rarely the whole file)
`Features`	The class intended for storing and transferring features that need to be analyzed
`FeatureParameters`	The class intended for storing and transferring parameter values for individual features that need to be analyzed
`FeatureExtraction`	The class intended for feature extraction from data. As input, it takes signal data needed to be processed. As output, extracted feature vectors are sent as results to the `ExtractedFeatures` class
`ExtractedFeatures`	The class intended to save the extraction results to two output files. Feature vectors are stored line by line in the output files, with the values that correspond to the extracted features and feature parameters specified by the user and available in the files' headers

TABLE III. PARALLELIZATION VALIDATION RESULTS ON MIT-BIH ARRHYTHMIA DATABASE RECORDS, RESULTS ARE IN MILLISECONDS

No. of analyzed record segments, with their length	Parallel / sequential execution	Number of included records		
		1	12	48
85 segments, each 20 s	parallel	116±30	357±14	1135±79
	sequential	103±14	393±15	1304±66
18 segments, each 90 s	parallel	145±13	447±9	1506±23
	sequential	178±8	962±29	3372±13
7 segments, each 240 s	parallel	200±17	890±43	2519±12
	sequential	266±16	1973±20	8002±42
3 segments, each 560 s	parallel	315±7	1966±23	7858±204
	sequential	531±16	4268±117	17672±115
2 segments, each 840 s	parallel	466±7	3556±49	14781±244
	sequential	766±29	6181±55	26395±223

benefit from parallelization. The specifics of the platform mandated a practical solution to accelerate feature extraction. We have learned that, due to the nature of feature calculations, it is impractical to perform OpenCL based CPU and GPU parallelization on the level of individual feature calculation algorithms. In our experience, the best solution was to use Java multithreading and parallelize feature extraction based on available data, by examining multiple segments, signals and records at the same time.

In the future, we plan to consider several venues for improvements. First, as mentioned, we would like to add the option to the *backend* subproject to communicate with multiple computers, each host containing an instance of the *processing* subproject, thus increasing the degree of parallelization. For some specific preprocessing algorithms for which parallelization was shown to be beneficial in literature [13], we also plan to add parallelization support using GPU. Another venue is to explore parallelization for some specific, yet unimplemented complex multivariate features, such as the one measuring synchronization between brain regions in an EEG [22].

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Interoperability of ECG standards

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***Abstract*—The increased demand for interoperability of electronic health records leads to the need for establishing reliable standards for storing and retrieving electrocardiogram data. Multiple medical record data standards were created in response to medical organization initiatives, based on binary and XML formats. These standards raise the need to maximize interoperability between systems that share ECG datasets. HL7 aECG, SCP-ECG, DICOM, and ISHNE are among the most popular ECG standards, which are compared within this paper. We have implemented an adapter system - ECGConvert, which provides interoperability on raw ECG to HL7 aECG and SCP-ECG, while also supporting ISHNE format to HL7 aECG conversion. We provide a discussion for the interoperability of these standards in the healthcare, the problems we have faced and solution to improve the process of sharing ECG datasets between organizations.**

Our interoperability platform can support the wearable ECG devices that provide single-channel ECG streaming data. The metadata raw ECG record can be converted to any of currently used ECG standards by the built prototype.

***Index Terms*—Interoperability, ECG standards, ECG adapter system, Digital electrocardiography**

I. Introduction

Establishing reliable methods for storing and retrieving electrocardiogram data for a patient is an important area of research in health informatics industry [1], [2]. The increased demand for interoperability of clinical documents between heterogeneous electronic health records and various Hospital Information Systems (HIS) leads to the need of establishing ECG standards. The interoperability of ECG records would improve patient care, reduce costs and allow for rapid data analysis.

Medical organizations created initiatives for developing digital ECG standards, and each standard has its own characteristics based on the needs of a particular organization. These requirements lead to different ECG standards, making the interoperability between the standards almost impossible. Most of these standards support 12 ECG channels, for a maximum length of the recorded channel being 30 seconds. The newest wearable ECG devices provide data for a single channel only, thus being capable in terms of storage and capacity to record this data for a much longer time than 30 seconds. This represents a huge problem for the current ECG standards, since there is no standard able to record long periods of a single channel ECG data.

In this paper, we will present a design of the adapter system "ECGConvert", which provides interoperability on raw ECG to HL7 aECG and SCP-ECG, and supports the conversion of ISHNE format to HL7 aECG. The design of the current state of the system introduces many challenges introduced by the ECG standards.

The paper structure is as follows. The related work is presented in Section II. The data standards for storing ECG medical records that are topic of interest in this paper are presented in Section III. Section IV provides a comparison of these standards, while also providing an overview of the interoperability problems of these standards and a possible solution. The practical implementation of the ECGConvert is provided in Section V. Section VI provides the conclusion of our work.

II. Related work

A Schloegl et al. [3] provide a two-way converter between SCP-ECG and HL7 aECG. They introduce BioSig, an open source library for biomedical signal processing, written in the programming language C++. The library provides an internal data structure, which is used as a middle layer in the process of conversion from one standard to another. They also provide two types of readers/writers for each of the standards in the conversion. The General Data Format (GDF) for biomedical signals is introduced, which stores the raw ECG data in the process of conversion. The tests done on the converter are based on a sequence of conversions, for example: SCP-ECG $>$ GDF $>$ HL7 aECG $>$ GDF $>$ SCP-ECG $>$ GDF $>$ HL7 aECG. The authors also point on some issues with the standards, including the inability of SCP-ECG to support multiple ECG recordings in one file and the extra annotations in HL7 aECG which cannot be found in SCP-ECG.

V Sakkalis et al. [4] introduce a gateway in form of a web service, which offers digital ECG conversion between SCP-ECG and DICOM. The main focus of the gateway is on the conversion of ECG signals between both standards. Diagnosis statements, beat references and global measurements are not available in their system.

Marcheschi et al. [5] identify lots of proprietary ECG devices with software solutions that are only effective in the medical organization for which they are created, but they introduce even more interoperability problems. An XML based system is suggested, having the core as a web service, which provides conversion between different ECG digital formats into the HL7 aECG standard. The authors identify a large

number of digital standards as the greatest problem and challenge to any interoperability system.

Our interoperability platform can support the wearable ECG devices that provide single-channel ECG streaming data. The metadata raw ECG record can be converted to any of currently used ECG standards by the built prototype.

III. Data standards for storing ECG medical records

This section gives an overview of existing ECG standards.

A. HL7 aECG

HL7 aECG [6], [7] is a medical record data format for storing and retrieving electrocardiogram data for a patient. This standard is XML based, which is a self-descriptive markup language, designed to store and transport data over the Internet. The aECG (which stands for "annotated ECG") XML file contains one or more series of ECG waveforms related to given time point and a set of derived ECG findings for that particular time point.

The standard is created in response to the digital ECG initiative of the US Food and Drug Administration (FDA) introduced in 2001. Created by the HL7's Regulated Clinical Research Information Management (RCRIM) in response to the FDA's need, accepted by ANSI in 2004. The main concerns of the initiative are based on the evaluation of non-cardiac drugs for negative cardiac effects. Before the initiative, the organization could not systematically evaluate the ECG waveforms and measurements, because most of them were collected with paper and not electronically retained. Even though the aECG standard was created in response to the FDA's need to have ECG waveforms and annotations, it doesn't mean that the standard should be used for those purposes only. It is quite a flexible standard, and as such is capable of accommodating for additional uses.

This standard is based on the Object Oriented (OO) approach, using Unified Modeling Language (UML). The message models are derived from HL7's Reference Information Model (HL7 RIM). A Refined Message Information Model (R-MIM) is the source for defining messages and XML schemas; the complex model aECG R-MIM is a fundamental basis for developing the XML structure for ECG recordings in this standard. Each ECG file has a unique identifier (UID), containing a 'root' object identifier (OID) and an 'extension'. The OID is defined by ITU-T recommendation X.208 (ASN.1) and is comparable to the DNS namespace. Organizations can obtain OIDs from IANA [8]. Each medical organization owns an OID prefix to manage OIDs for Organizations, People, Places, and Things.

The organization is responsible for defining a namespace hierarchy of Universally Unique Identifiers (UUIDs) for computer-generated elements. The ECG waveform contains annotations for a particular relative time point called a Region of Interest (RoI). A series will contain all the waveforms and annotations for a single ECG. If multiple ECGs are contained within a single aECG file, a different series is used for each waveform.

B. SCP-ECG

SCP-ECG [2] is a binary format for storing and retrieving electrocardiogram data for a patient, implemented in 1993. It is the official European standard for the storage and transmission of ECGs since 2005. In July 2002, the SCP-ECG format became part of the European funded consortium called OpenECG [9].

Every SCP-ECG file must start with a two-byte checksum to ensure that the file is not corrupted during transmission. Four unsigned bytes describe the actual file size followed by 11 independent sections to store data relevant to a particular ECG waveform. Only two sections are mandatory. and the manufacturers can store custom information in additional sections by assigning a section number is between 128 and 1023.

Each section starts with a structured header. Section 0 is the pointer section that describes the length (in bytes) of each of the other sections, along with their starting byte position within the file. Section 1 refers to patient demographic data about the particular ECG recording. Section 2 defines details on actual ECG data encoding, for example, it may contain Huffman tables for achieving lossless compression of data. Section 3 identifies the stored ECG leads along with the start and end sample numbers of all the leads.

Section 4 presents the annotations of the QRS beat locations and Section 5 the actual reference beat data, starting from the P wave location and ending with the T wave. Section 6 stores the residual data that cannot be used by referenced beats and has been left over in the compressing technique. Alternatively, the full raw signal data can be stored limited to 10 seconds. Section 7 further gives details on the QRS axis, P onset, P offset etc. Section 8 retains the textual diagnosis that has been produced by a diagnostic classification algorithm. Vendor-specific diagnostic information is given in Section 9 and Section 10 stores various durations, intervals and amplitudes for each of the leads, i.e. QRS duration, Q wave peak value. Finally, Section 11 stores universal statement codes and over-reading data.

C. DICOM

The National Electrical Manufacturers Association (NEMA) and the American College of Radiology (ACR) formed a coalition to develop an image standard called ACR-NEMA in 1985. This format evolved to become version three DICOM [2] in 1993, while finally becoming a European standard in 1995. This standard was originally created to store and transmit radiographic images. Since then, it has grown to support all diagnostic modalities. DICOM-WS 30 was introduced to support the storage of raw medical waveforms, which stores actual sample values instead of raster images. That allowed the DICOM standard to store various waveform datasets, including blood pressure, ECG, and audio. The overall ECG community refers to the DICOM-WS 30 as DICOM-ECG [10].

The standard specifies data in a binary format, structured in various information objects defined using Information Object Definitions (IOD). The IOD is a kind of a schema, since

it defines mandatory attributes in the object, along with the optional and conditional attributes. Once these attributes have been assigned with values, they become information object instances uniquely identified using UIDs. Entity Relationship (E-R) diagrams are used to guarantee that information objects are normalized and have been designed using object orientated principles. DICOM supports functions for 12-lead ECG recordings and long time series from Holter monitors [7].

D. ISHNE

ISHNE [11] is built to support digital Holter data. A header is followed by a large data block containing all stored ECG digital samples, in order to maximize the ratio between simplicity and flexibility. The file starts off with a "magic number" which consists of a predefined string of characters to allow a quick verification. The "magic number" consists of the name of the standard, followed by the ISHNE version. The next two bytes are a CRC checksum calculated over the complete header (fixed-length and variable-length). The header consists of a fixed-length block (512 bytes) and a variable-length block. The fixed-length block comes first and one of its fields indicates the size and offset of the variable-length block. The variable-length block consists of a stream of ASCII (extended set of 256 characters) characters that any user or manufacturer will use according to their needs.

The main goal of the header is to provide all necessary information on the associated ECG file. The total size of the ECG binary file will depend on the number of leads and on the sampling rate. Maximum of 12 ECG leads are stored in this format.

IV. Comparison between standards

In the healthcare, standard interoperability represents the ability of different information systems to communicate and exchange data. The existence of many Electronic Medical Records (EMR), which compose Electronic Health Record (EHR) systems, raises the need to maximize interoperability between systems that share ECG datasets.

We should note that the available standards do not solve all the problems in ECG interoperability, nor any of these standards are widely used. Generally speaking, each organization created a standard based on the needs of the organization [5]. Perfect example for this is the DICOM standard, which was initially created to solve the problems of transmitting radiographic images. Lots of proprietary ECG devices are available to the healthcare institutions, with each device having its own solution for transmitting ECG datasets. This is effective only within an organization that is using the particular device, but when we talk about interoperability, it's almost impossible to share data between systems due to the wide range of standards. These proprietary standards discourage the data export between systems of different organization, nationwide.

To solve these problems with interoperability, a new standard needs to be created. That means that the standard in the initial stage should cover the most general problems that the institutions are facing and then to go into details and customize it to meet their requirements. From the currently available standards, two options are available in terms of the format of the standard: XML or binary. The XML format is readable by humans, making it easier to understand and doesn't require additional processing. On the other hand, the binary file cannot be read by humans, making it harder to process.

TABLE I
Comparison analysis of ECG standards

	HL7 aECG	SCP-ECG	DICOM	ISHNE
QRS marking	Yes	Yes	Yes	No
Beat classification	Yes	Yes	Yes	No
Rhythm identification	Yes	Yes	Yes	No
Number of channels	12	12	12	6
Streaming ECG	No	No	No	No
Duration period	30 sec	10 sec	30 sec	24h

These standards do not support long-term storage or data streaming of a single ECG channel. Most of them support up to 12 channels; for example: HL7 aECG supports 12 ECG channels, each with a duration of 30 seconds. ISHNE supports continuous data up to 24 hours per channel. Table I provides a tabular overview of the comparative analysis in this section.

The problem with all standards is in the inability to support a single ECG channel for long-term measurements, such as data for one or two weeks, or even longer. The newest wearable ECG sensors stream data for a single channel only. The HL7 aECG standard supports QRS data that is generated by any device, along with all the ECG beats and the representative beat data. SCP-ECG supports the same data as HL7 aECG, having the QRS data in section 4, and the beat data in section 6 of the standard [12]. DICOM also provides complete support for both QRS and beat data. Only the ISHNE standard does not support streaming of QRS data, nor ECG beats and representative data.

V. Practical implementation of an interoperability platform

We have designed and developed an interoperability platform ECGconvert to support single channel streaming wearable ECG sensors.

The application is build using ASP.NET MVC framework. The prototype supports multiple ECG conversions:

- raw ECG to HL7 aECG
- raw ECG to SCP-ECG
- ECG data in ISHNE format to HL7 aECG

For the SCP-ECG conversion, we have been using the open-source toolkit "C# ECG Toolkit" [13].

A. Design considerations

Our interoperability platform was designed to support the latest wearable ECG devices according to the following requirements:

- single-channel ECGs,
- streaming ECGs, and
- long-term measurements.

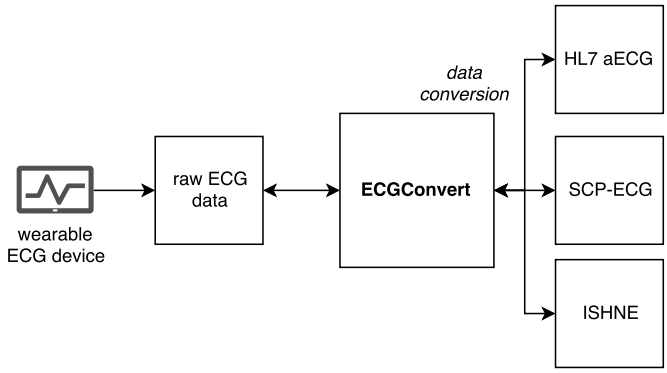

Fig. 1. Overview of an interoperability platform between raw ECG data and any available digital ECG standard

Raw ECG data from wearable devices is streamed into the system, resulting in metadata being created by the new interoperability framework. It is much easier to achieve interoperability when we consider using the raw ECG file data in the process of conversion to any digital standard. This enables the use of a single interoperability platform for achieving conversion to any digital ECG standard (presented in Figure 1).

B. Raw ECG to HL7 aECG conversion

The system supports file upload, which contains raw ECG data only. Data can contain all the leads from the patients' recordings, along with the raw ECG digits. The file is read by the application, and the leads are determined manually. Then, the process of creating of HL7 aECG starts by generating the basic XML file elements, which are needed to meet the minimum standard requirements. 'AnnotatedECG' XML element is the root element in this standard. The root element contains required UID that identifies the specific ECG recording with the code system number that describes the number of the leads used in the HL7 aECG file. The element 'effectiveTime' is following up, which represents physiologically relevant time range assigned to the ECG findings.

The next important section in the XML file is the 'componentOf' element. It consists of 'timepointEvent' element, which represents time point or study event during which the ECG waveforms were collected. In the 'timepointEvent' we have the child element 'subjectAssignment', which represents the act of associating a subject to a trial. This element consists of the 'subject' and 'clinicalTrial' elements. The 'subject' element identifies the subject from which the ECG waveforms were obtained. This element defines the 'trialSubject' which defines the unique identifier for the subject. It is composed of a root and optional extension. The root must be included, and is a UID. The optional extension may be anything. The combination of the root and extension must be universally unique and are provided by the sponsor. In addition to the 'trialSubject' element, in the 'subject' element is defined the 'clinicalTrial' XML element, containing the identifying information about the trial. The rules from the 'trialSubject' also apply to this XML element.

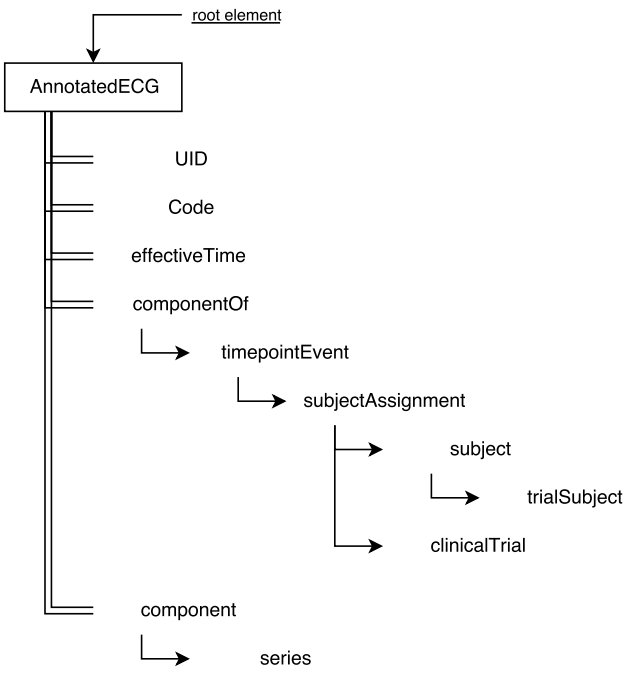

Fig. 2. Basic HL7 aECG XML structure

The main ECG leads data is stored in the 'component' section of the HL7 aECG XML, which holds the 'series' element. This tag contains all the sequences and annotations sharing a common frame of reference. The 'series' element contains all the waveforms and annotations for a single ECG. If multiple ECGs are stored in the same HL7 aECG XML, then new 'series' element is used for each ECG (not a common scenario). In this element, we describe if the series is "RHYTM" or "REPRESENTATIVE_BEAT". Follow up the leads data, starting from MDC_ECG_LEAD_CONFIG (unspecified lead), MDC_ECG_LEAD_I and MDC_ECG_LEAD_II to chest, precordial, auxiliary bipolar and derived leads. Figure 2 gives overview of the basic HL7 aECG XML structure.

C. Raw ECG in ISHNE format to HL7 aECG conversion

In addition to the initial raw ECG format we have been using, the ISHNE format contains data about the ECG's subject: name, ID, sex, race and date of birth of the subject. Because of this reason, the HL7 aECG implementation explained in section V-B is extended to contain the data about the particular subject. The element 'trialSubject' is extended with new XML element - 'subjectDemographicPerson'. This element defines the 'name' element, which contains the name of the subject. The 'administrativeGenderCode' contains the subject's gender. The element 'birthTime' defines the subject's date of birth. The 'raceCode' element is also used to store the data about the subject's race. Figure 3 gives an overview of the HL7 aECG XML structure for the ISHNE format.

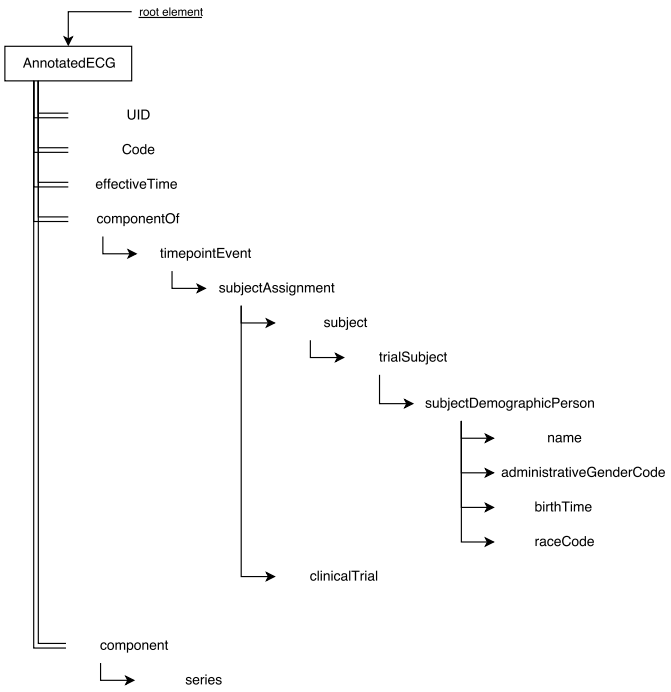

Fig. 3. HL7 aECG XML structure for the ISHNE format

D. Raw ECG to SCP-ECG conversion

To support SCP-ECG conversion in our application, we have been using part of the code of the open-source toolkit "C# ECG Toolkit" [13] to convert, view and print electrocardiograms on a desktop. The SCP-ECG conversion supports all the sections that are specified in the standard. First, the pointer section is extracted, which gives us the starting and ending bytes of the other sections in the file. Then, the patient demographic data is extracted, followed by Huffman tables, lead definitions, QRS locations, beat data and rhythm, global measurements, diagnosis and manufacturer specific diagnosis information.

VI. Conclusion

We have given an overview of the most popular standards for storing ECG medical records: HL7 aECG, SCP-ECG, DICOM and ISHNE. The characteristics of each standard were provided, along with their history and the process of development, based on the increased demand for requirements. We have presented ECGConvert and its practical implementation, representing an interoperability platform of these standards. Raw ECG to HL7 aECG and SCP-ECG, ISHNE format to HL7 aECG represent the interoperability options that are implemented in the ECGConvert system. We have also discussed the interoperability of these standards in the healthcare, providing the problems we have faced and solution to facilitate the process of sharing ECG datasets between organizations.

Our interoperability platform can support the wearable ECG devices that provide single-channel ECG streaming data. The metadata raw ECG record can be converted to any of currently used ECG standards by the built prototype.

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Scalability Performance Evaluation of the E-Ambulance Software Service

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***Abstract*—E-Ambulance is a Software as a Service (SaaS) solution for computer assisted diagnoses of ECG recordings. It is an expert system, providing doctors and their patients a cloud solution for computer assisted diagnoses of ECG recordings and means of collaborative monitoring and treatment. In this paper, we aim at evaluating the scalability performance of the E-Ambulance SaaS solution by presenting the architecture of the SaaS application and annotation REST service for diagnoses/anamneses, followed by the testing methodology. The overall goal is to evaluate the scalability performance and find the optimal architecture that will offer highest performance for the user.**

We have developed a prototype of the main SaaS application and a prototype of one web service to be used within the SaaS application for management of annotations. Both were developed in different technologies to find out if there is any influence on the performance.

***Index Terms*—Architectural performance, Cloud Computing, ECG Visualization, Load testing, REST, Service Oriented Architecture, Software As A Service**

I. Introduction

Cloud computing is the technology that offers a long-held dream of computing as a utility, which has recently emerged as a commercial reality [1]. Developers with innovative ideas for new services can use all of the advantages of cloud computing and significantly lower all of the risks accounted to developing new services. With cloud computing, developers do not need to be concerned with over-provisioning, thus, wasting costly resources, or under-provisioning and missing potential customers and revenue.

E-Ambulance is an expert system, providing doctors and their patients a SaaS solution for computer assisted diagnoses of ECG recordings and means of collaborative monitoring and treatment. Each patient is given a limited cloud storage that the patient will use to upload and organize the personal ECG recordings obtained by wearable ECG sensors. As soon as the ECG recording is uploaded onto the cloud, it is processed by the diagnoses framework and the findings from the parametrization phase are saved along with the recording. After the ECG recording has been processed, the patient is given an access to a visualized perspective of the imported data and is able to submit anamnesis for a particular and flexible time frame regarding the personal perceptions that concern the cardiac condition for the corresponding time frame. Each doctor can access the own patient's records, along with any anamnesis on the momentary condition, and is able to add information for a particular and flexible time frame regarding the diagnosis and the treatment of the interpreted condition.

E-Ambulance enables different system roles, such as various level of administrators (system, ambulance administrator, officers), doctors and patients. It is a unique system that interconnects a service for setting diagnoses and anamnesis for each ECG in the system and also, a service for ECG data visualization. Based on the amount of users that may use the system, we will evaluate scalability performance with tests to find out how the performance scales with scaling of the architecture and users. This evaluation will help us find the optimal performance metrics of the system. The provided data is captured with Apache JMeter [2], a load testing tool to analyze and measure the performance of web applications and services.

The paper structure is as follows. Related work is presented in Section II. Section III describes the E-Ambulance application and Section IV the methodology to test the scalability of the solution. The results are presented in Section V, while Section VI describes the evaluation and comparison of the results. Finally, the conclusion and future work is presented in Section VII.

II. Related Work

Almadani et al. [3] propose an E-Ambulance framework as a smart ambulance system model that provides health monitoring of patients for remote medical professionals. The main objective of the system is to provide health monitoring and auto response in terms of alerts and suggestions to paramedic stuff that work in the ambulances. Their E-Ambulance system architecture consists of multiple units where DDS middleware will take place in most of the units to hide heterogeneity of these units and control QoSs needed for the proposed system.

Ristovski et al. [4] present an ECG experts system developed as a SaaS application. They address a challenge to deal with streaming ECG data in a SaaS solution by an architecture composed of an ECG sensor used for recording, a phone used to connect to the sensor via Bluetooth to reroute the data from the ECG sensor towards a streaming unit, a data processing unit used for storing the ECG data in a database and, finally,

the architecture contains a main unit used for storing the user personal data.

Pandey et al. [5] propose a Cloud based system for monitoring of patients who suffer from cardiac arrhythmias, requiring continuous episode detection where the ECG data is obtained in real-time from commodity wearable sensors. The authors describe the ECG data analyses process and how they model the problem as a workflow. The prototype system is composed of a web service which is responsible for handling the client requests, a Container Scaling Manager used for instantiating and turning off containers, Workflow Engine which is hosted in a container and it is used for managing the execution of tasks from the ECG workflow and Aneka [6] which is a workload distribution and management platform.

Two approaches are identified in [5] when testing the scalability of the application: horizontal and geographic scalability. The horizontal scalability provides the ability of a system to easily expand its resource pool to accommodate heavier load, while the geographic scalability provides better performance and usability over a given geographical area. The goal of the architecture is to seamlessly handle the changes in request patterns. The authors provide different setups of the architecture, based on which the scalability will be tested. These setups range from fixed number of Amazon EC2 resources for 25 virtual machines, to dynamic resource allocation policies and containers. In all these setups, the user requests range from 80 to 2000, gradually increasing over time. From the results of the conducted experiments they conclude that dynamical scaling results gradually increase in response time as the number of user requests increased instead of the sharp rise in response time at the beginning for all the tasks in the case when there are fixed number of worker nodes.

Vecchiola et al. [6] consider multiple cloud models when determining the scalability of their system, including Platform as a Service (PaaS) and Infrastructure/Hardware as a Service (IaaS/HaaS). When testing the scalability of the system, they consider the existing cloud platforms: Google AppEngine, Microsoft Azure and Amazon EC2. Their system provides support for distributed execution of evolutionary optimizers and learning classifiers, while yielding significant speed up on distributed environment, compared to a single machine. The results also show that for a small number of requests there is no advantage in leveraging the execution of a distributed environment.

III. System Architecture

This section describes the overall architecture of the two system modules. The first one is the *front-end Software as a Service (SaaS) application* used for initial communication with users, and the second one with a *distributed processing unit* to allow monitoring access of the ECGs. Due to large storage and processing demands, a distribution unit can provide services only for a limited number of users. The main system is scalable so that if there are more users, then another distributed processing unit can be added.

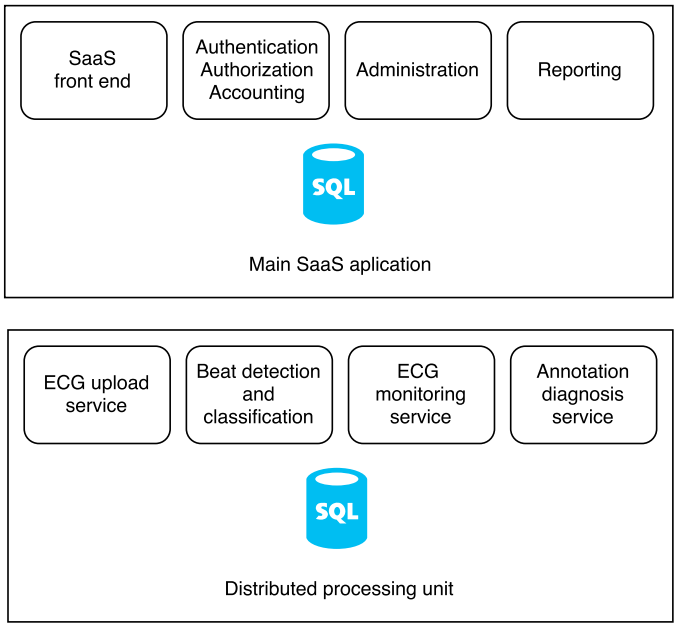

Fig. 1. Overview of the E-Ambulance system architecture

This separation of the main application and distributed processing unit was done in order to enable a common entry point for the main SaaS application, and to distribute the processing of a very large quantities of ECG data. To illustrate the operation of the distributed processing unit we have implemented a web service for submitting and updating diagnoses, therapies and anamneses.

Figure 1 presents a logical framework of the main SaaS eAmbulance application and one distributed processing unit with various web services for ECG processing and monitoring.

In case of a small number of users one virtual machine instance can host the main SaaS application unit, and another one can host the distributed processing unit.

A. Software as a Service system architecture

The Software as a Service (SaaS) software distribution model is used in the development of the E-Ambulance application, in which all of the components are designed to be services [7]. The core of the architecture is an ASP.NET web application, implemented with Model-View-Controller (MVC) pattern. The nature of the project defines strict rules realized by corresponding MVC patterns.

The system is personalized for any ambulance that is registered at the system, thus requiring full control over the rendered HTML, ease of integration of different frameworks and following the nature of the stateless web principles.

The SaaS application uses a separate Microsoft SQL Server database for controlling user access, ambulance personalization and overall work flow of the system. Relational database is chosen as a primary database of the system, because of the strict rules and personalization for each ambulance and user.

External services interconnect with the SaaS application, which provide utilities for visualizing ECG data, beat detection

and classification and also, service for saving diagnoses and anamnesis. These services are part of the distributed processing unit.

B. Annotation service for diagnoses, therapy and anamnesis

A REST service is used for creating anamnesis information by the patients and also for creating diagnoses and therapies by the doctors for a given time span. Patients can access ECG recordings and browse diagnoses and recommended therapies based on query parameters.

The service is a web application written in the programming language Python [8] using the Django Web Framework [9]. Additionally, we were using the Django Rest Framework [10] for easier definition of the REST APIs for the service.

The service is composed of two models, *Diagnoses* used for storing the diagnoses and *Comments* used for storing anamnesis. As a database for the models we were using the MySQL database [11] and the models were stored in two separate tables.

The *Diagnoses* model is composed of *id*, *created_timestamp*, *from_timestamp*, *to_timestamp*, *diagnoses*, *patient* and *doctor* fields. The *id* field is the unique identifier for the resource. The *created_timestamp* field is a time stamp that marks when the resource was created. The *from_timestamp* and *to_timestamp* fields are used to mark the time span of the diagnoses. The *diagnosis* field is the actual text of the diagnosis. The *patient* and *doctor* fields are the ids of the patient and doctor accordingly. Listing, creating, updating and deleting of resources (diagnoses) is done in a RESTful fashion.

The *Comments* model is composed of *id*, *created_timestamp*, *from_timestamp*, *to_timestamp*, *comment* and *patient*. The *id*, *created_timestamp*, *from_timestamp*, *to_timestamp* and *patient* fields are same as in the *Diagnoses* model. The *comment* field is the actual text of the anamnesis. Same as in the *Diagnoses* model, listing, creating, updating and deleting of resources (comments) is done in a RESTful fashion.

IV. Testing Methodology

The testing methodology contains description of the experiments, testing environment, test cases and test data for defining the load testing of the E-Ambulance application and its services.

For this testing we have measured data over two instances, the first one is the response of the SaaS application, and the second one to the annotation web service.

The goal of this testing is to find out how many concurrent users can simultaneously use the SaaS application and web service. This is based on the most common scenario in the system, where each doctor and patient will constantly provide details about the health condition, based on the analyzed ECG parameters. In such scenario, we want to keep the performance of the system optimal, no matter the number of the users actively using the system.

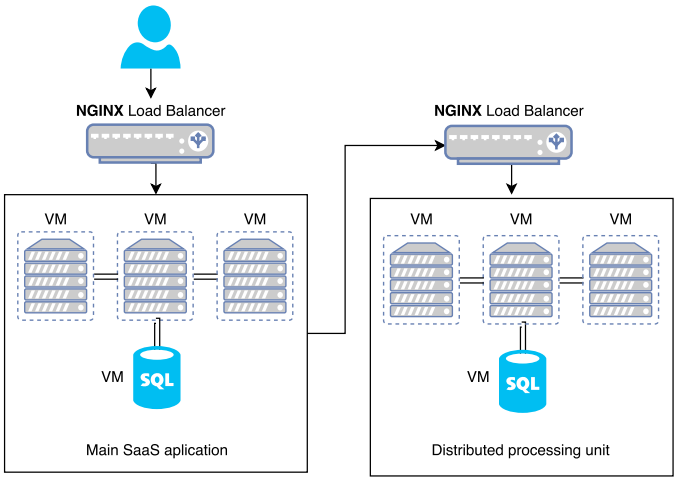

Fig. 2. Testing environment: Hosting of the E-Ambulance software modules

A. Testing environment

Figure 2 provides a visual presentation of the testing scenario. Each part of the architecture requires at least one virtual machine to be running; more virtual machines are added as the service demand increases by the users. Additionally, we have set the database server to be hosted on a separate virtual machine.

The database of the application was hosted on a single dedicated (virtual) server, while the application itself was hosted on 3 dedicated (virtual) servers. The overall architecture of the application included NGINX [12] load balancer, with three testing scenarios being simulated, where each application server used the same database server:

- *Scenario 1* using 1 application server and 1 database server;
- *Scenario 2* using 2 application servers and 1 database server;
- *Scenario 3* using 3 application servers and 1 database server.

All of the servers have 1 CPU, 1 vCPU with 2GB RAM. Windows Server 2012 was used as the main operating system for hosting both the application and the database.

The load testing experiments conducted on the main SaaS application were based on a standard user sign in scenario, based on both *GET* and *POST* methods (the former retrieves the sign in page from the server, while the latter posts the users' specific data to the server; an exact simulation of the real behavior of an user).

The experiments for load testing of the distribution processing unit were using only the service for diagnoses and anamnesis. Testing was composed of making *GET* request to either retrieve an anamnesis resource or a diagnoses resource and *POST* request to either create an anamnesis resource or a diagnoses resource by variable number of users.

The service architecture consists of a load balancer (reversed proxy) for routing the requests, (virtual) servers which were hosting the application service and serving the requests and

one (virtual) server which hosted the MySQL database server. The architecture of the service for diagnoses and anamnesis is shown in Figure 2. As a load balancer we were using the NGINX reverse proxy server and it was running on a (virtual) server with 2 CPUs, 4 vCPUs and 2GB RAM (same configuration is used for the SaaS architecture). As a routing logic, we were using *least-connected* logic, which means that the next request will be routed to the server with the least number of active connections.

The application service was running on a (virtual) server with 1 CPU, 1 vCPU and 2GB RAM. Finally, the MySQL database server was running on a (virtual) server with 1 CPU, 2 vCPUs and 2GB RAM. The service architecture experiments are based on the same scenario (setup) as the SaaS architecture.

Experiments were conducted using the Apache JMeter software. The testing environment was created and is being hosted on the cloud at the Faculty of Computer Science and Engineering, Ss. Cyril and Methodius University in Skopje, Republic of Macedonia.

B. Test cases

The load testing simulation of the SaaS application was done based on different number of users trying to sign in, sending requests (both *GET* and *POST*) for one minute, for each architectural scenario. And the load testing simulation of the service for diagnoses and anamnesis was done based on different number of users making both *GET* and *POST* requests for five minutes, for each architectural scenario.

We started the test off with 10 users, then increased to 50 (the service for diagnoses and anamnesis directly started from 50 users) and 100, 200, and so on until 1000 users (increasing by 100 users each time). All the requests that were created by these users were sent simultaneously.

C. Test metrics

In order to figure out how the architecture will scale based on the different test scenarios and to be able to compare the results, we were measuring the minimum, maximum and average response time in each of the given scenarios for both the SaaS application and web service. In addition, we were measuring the throughput expressed in requests per second.

We have completed at least 5 measurements for each test case and calculated the average values. Differences in the measured values are expected due to various behavior and current state of the overall cloud where our testing environment was hosted.

The measurements included the response time T in seconds and server throughput V in requests per second. Values for each scenario are determined by its index 1, 2 and 3. The overall speedup of scenarios 2 and 3 against scenario 1 is given by (1) when response time is analyzed and in (2) for throughput (velocity). The normalized speedup is given by the equation (3), where m and t are the indexes of the scenarios, for both the response time and velocity. Equations in (4) provide the normalized speedup of scenario 2 and 3 against scenario 1, measured by the response time. The equations in (5) provide the normalized velocity speedup, accordingly.

$$S_{12}(T) = \frac{T_1}{T_2} \qquad S_{13}(T) = \frac{T_1}{T_3} \tag{1}$$

$$S_{12}(V) = \frac{V_2}{V_1} \qquad S_{13}(V) = \frac{V_3}{V_1} \tag{2}$$

$$NS_{mt} = \frac{S_{mt}(T)}{t} \qquad NS_{mt} = \frac{S_{mt}(V)}{t} \tag{3}$$

$$NS_{12} = \frac{S_{12}(T)}{2} \qquad NS_{13} = \frac{S_{13}(T)}{3} \tag{4}$$

$$NS_{12} = \frac{S_{12}(V)}{2} \qquad NS_{13} = \frac{S_{13}(V)}{3} \tag{5}$$

The higher the speedup, the better the performance is.

V. Results

The results will be presented in charts where the blue line with circle markers corresponds to Scenario 1 (1 application server), the orange line with square markers to Scenario 2 (2 application servers) and finally the gray line with triangle markers to Scenario 3 (3 application servers).

A. Performance of the SaaS application

Figure 3 provides a visual representation of the average response time of the three testing scenarios, and Figure 4 for the test scenarios based on requests per second.

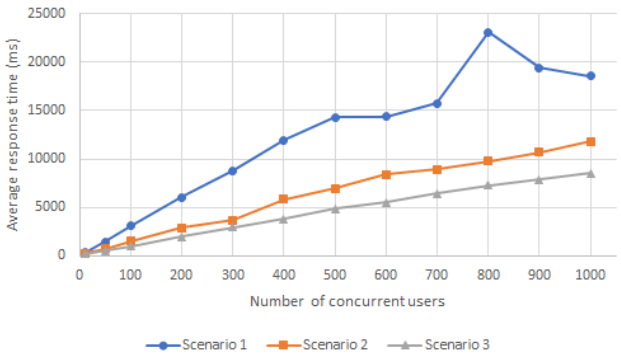

Fig. 3. Average response time of the front-end main SaaS application.

From the results presented in Figure 3, we observe that the number of application servers impacted the response time of the SaaS application. The response times when using only one application server are obviously larger than the response times when using two application servers which are also larger than the response times when using three application servers.

Next, we can observe similar improvements in the Figure 4 where the requests per second are presented for the different test cases. The lowest number of requests per second is observable when there is only one application server (blue line in the figure). When using two application servers (orange line in the figure) there is clearly improvement over using one

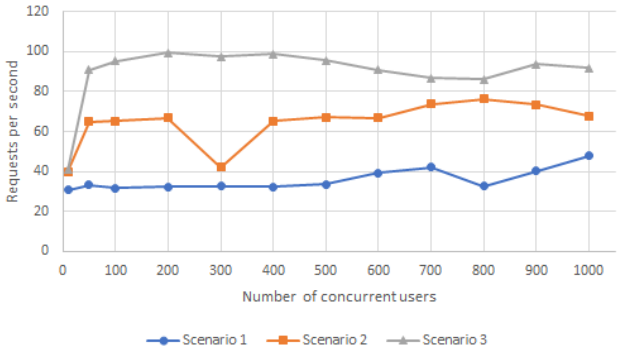

Fig. 4. Requests per second of the front-end main SaaS application.

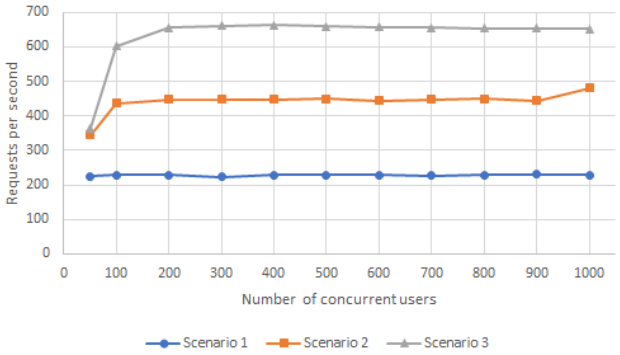

Fig. 6. Requests per second of the distributed processing unit.

application server and also we can see the same when using three application servers (gray line in the figure). For example, when there are 1000 concurrent users, there are 48 requests per second when using only one application server, there are 68 requests per second when using two application server which is 1.42 times improvement over one application server, and there are 92 requests per second when using three application servers which yields an improvement of 1.92 times over one application server.

B. Performance of the services

Figures 5 and 6 provide visual representation of the average response time of the service and the requests per second respectively for the three testing scenarios.

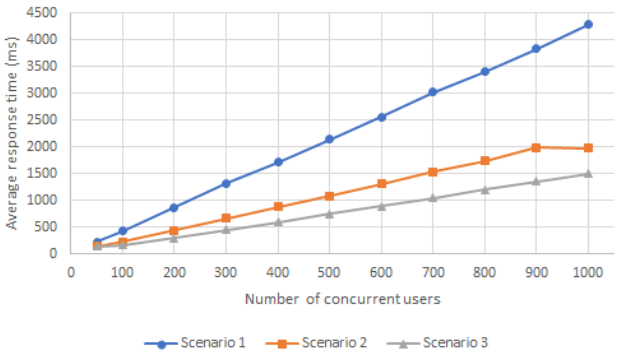

Fig. 5. Average response time of the distributed processing unit.

Improvements similar to the main SaaS application are observed for the web service, as presented in the figures (Figure 5 and Figure 6) when load testing was performed on the service for diagnoses and anamnesis.

Figure 5 presents the average response times of the service for the different test cases. It is obvious that the lowest response time is for scenario three.

A similar behavior is observed in Figure 6 that presents the requests per second of the service for the different test cases. The highest number of requests per second are achieved when there are three application servers (gray line in the figure) and the lowest number of requests per second are achieved when there is only one application server (blue line in the figure). For example, when there are 1000 concurrent users, one application server can process 228 requests per second, two application servers can process 481 requests per second which is 2.1 times higher than one application server and finally, three application servers can process 652 requests per second which is 2.86 times higher than one application server.

VI. Discussion

In this section we will present and analyze the normalized speedups we observed from the experiments that we have conducted. Additionally, we will give brief discussion of the results presented in Section V.

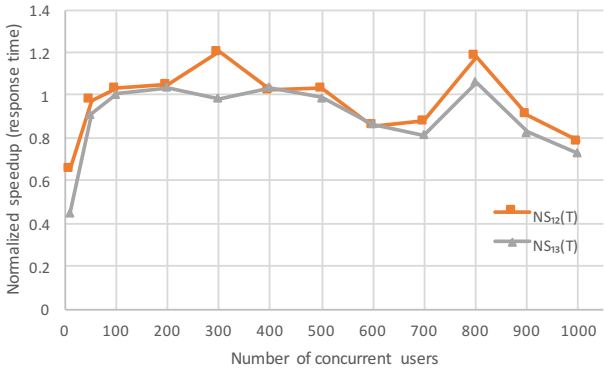

Fig. 7. Normalized speedups $NS_{12}(T)$ and $NS_{13}(T)$ of the front-end SaaS application (comparison of scenarios 2 and 3 against scenario 1).

The normalized average response time speedup for the SaaS application is presented in Figure 7 and Figure 8 gives visual representation of the normalized requests per second speedup. From the figures can be observed that the speedup is same for both of the scenarios until 500 concurrent users. When there are 500 or more concurrent users, Scenario 3 has worse speedup than Scenario 2. This is expected behavior, because all of the application servers are using the same database.

Similar behavior can be observed for the service as well. Figure 9 gives visual representation of the normalized average

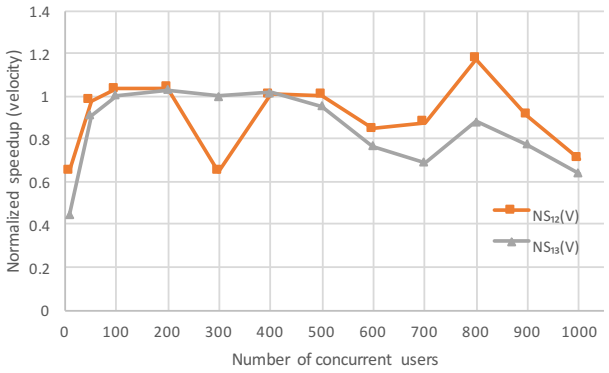

Fig. 8. Normalized speedups $NS_{12}(V)$ and $NS_{13}(V)$ of the front-end SaaS application (comparison of scenarios 2 and 3 against scenario 1).

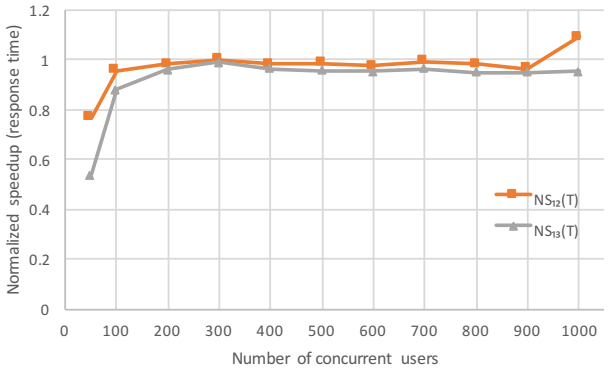

Fig. 9. Normalized speedups $NS_{12}(T)$ and $NS_{13}(T)$ of the distributed processing unit (comparison of scenarios 2 and 3 against scenario 1).

response time speedup for the service, and Figure 10 gives visual representation of the normalized requests per second speed up of the service. As we can see from the figures, the speedup is same for both of the scenarios until 900 concurrent users, and after that, Scenario 3 has worse speedup than Scenario 2.

From the results presented in Section V we can also conclude when a new application server can be added so we would get better response times and better requests per second. From Figure 3 and Figure 4 we can figure out that when there is only one application server, a new application server should be added when there are 50 concurrent users, and when there are two applications servers, a new application server should be added when there are 200 concurrent users. From Figure 5 and Figure 6 we can see that when there is only one application server, a new application server should be added when there are 50 concurrent users, and when there are two application servers, a new application server should be added when there are 100 concurrent users.

VII. Conclusion and Future Work

In this paper, we have presented the scalability performance evaluation of the E-Ambulance application as a system for

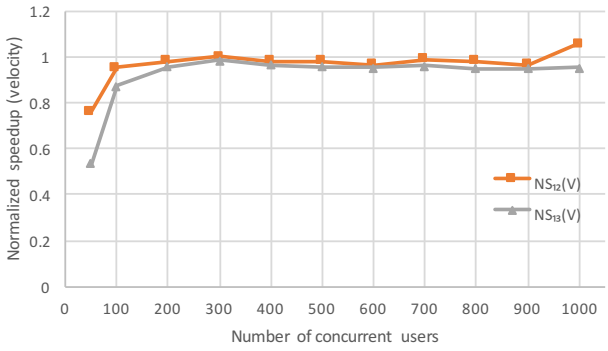

Fig. 10. Normalized speedups $NS_{12}(V)$ and $NS_{13}(V)$ of the distributed processing unit (comparison of scenarios 2 and 3 against scenario 1).

computer assisted diagnoses of ECG recordings, by describing the software application architecture, methodology for conducting experiments, presenting the testing results and their evaluation. The testing tool for conducting load tests was Apache JMeter. From the discussion in Section VI, we can clearly conclude that the overall architecture scales well, while preserving the optimal performance for the users.

As our future work, we would like to test how different storage technologies for preserving the ECG data can impact on the overall performance of the system. We will conduct experiments in order to find out the scaling of different storage architectures, based on different number of concurrent users.

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Enabling IoT based monitoring of patients' environmental parameters: experiences from using OpenMote with OpenWSN and Contiki-NG

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Abstract – **Remote health monitoring can be leveraged by the IoT paradigm. We tested OpenMotes, state-of-the-art IoT devices featuring IEEE 802.15.4 protocol, with Contiki-NG and OpenWSN, two of the most popular IoT operating systems, for the purpose of obtaining data from the OpenMote's sensors. The procedure is not strait forward and requires additional programing of the operating systems. All the steps necessary to make the OpenMote work with Contiki-NG are presented in detail. We also describe how to use Copper Firefox add-on to access the sensors data over CoAP, as well as how to design a functional web interface in Node-RED for the sensors data.**

Keywords - Internet of Things, IoT, remote health monitoring, remote patient monitoring, telehealthcare, eHealth, WSN, IEEE 802.15.4e, TSCH, 6TiSCH, OpenMote, OpenWSN, Contiki-NG.

I. INTRODUCTION

Remote health monitoring (RHM) has a potential to provide better care and reduce healthcare costs. The RHM should be continuous, real-time, enabling decision support and prediction, and improve quality of life through smart environments, controlled medication and wellbeing services [1]. The Internet of things (IoT), combined with Cloud and Fog, is one of the key technologies enabling RHM. Within the IoT paradigm each sensor is assigned a unique IPv6 address, which makes it uniquely identifiable on the internet, so that the readings from it can be transferred to whatever IP end-devices as well as to the Cloud.

Two key issues with the IoT enabled sensors are the energy consumption, which corresponds to the independent standalone time, and the robustness of the wireless technology used. Recently, the IEEE 802.15.4e standard has been proposed, which introduces a specific medium access control (MAC) behavior model called Time-Slotted Channel Hopping (TSCH). It combines time-slotted access and channel hopping, thus providing predictable latency, energy efficiency, and increased communication reliability in terms of robustness against external interference and multipath fading. TSCH is particularly efficient in providing ultra-low-power operation. Defining IPv6 over the TSCH mode of IEEE 802.15.4e (6TiSCH) is a key to enable further adoption of IPv6 in industrial and healthcare IoT domains [2]. Since OpenMote hardware devices, as well as OpenWSN and Contiki IoT operating system (OS), are all rooted in the new 6TiSCH standard, we investigate their applicability for constructing RHM systems.

The IEEE 802.15.4 was used in various investigations of RHM, e.g. PlaIMoS platform [3], HealthMate system [4], and GPMSwLF system [5], as well as for transmitting fitness exercise related variables [6]. In particular the Zigbee (an IEEE 802.15.4-based specification for communication protocols used to create personal area networks) was used to transmit heat rate and body temperature [7], [8], [9].

Even though IEEE 802.15.4 was primarily designed to operate in low traffic load scenarios it has been shown that it can handle electrocardiogram (ECG) data [10], [11] which is sampled with at least 125 Hz.

In previous attempts to apply the OpenWSN or Contiki for RHM, Archip et al. [12] have investigated the integration of physiological sensors with Zolertia Z1 [13] board featuring IEEE 802.15.4. and running OpenWSN. Zolertia Z1 and Contiki tandem was used by Ruiling et al for the motion detection and classification. [14]. Mathur et al. [15] employed OpenMote with Contiki in their proposed IoT RHM solution. In our recent work [16] we have investigated the inclusion of relational databases in the RHM system's architecture which assumed only Bluetooth connection to sensors. In the follow-up work we have extended our proposed RHM architecture by including IEEE 802.15.4 based networking with OpenMote devices running OpenWSN [17]. In our experience with OpenMotes and OSs for IoT, setting up the system has not been a strait forward task as we faced many obstacles. Documentation on the OSs and OpenMotes is not existing so users have to rely on what is available on the OSs' wiki pages which also contain limited information. Therefore we present the details of coupling OpenMotes with OpenWSN and Contiki, as well as the Node-RED, our preferred way of acquiring and presenting the sensors data. In our example we will use two OpenMotes connected to /dev/ttyUSB0 and /dev/ttyUSB1 of a computer running Ubuntu OS.

II. USING OPENMOTES WITH OPENWSN AND CONTIKI-NG OPERATING SYSTEMS

A. *OpenMotes*

The OpenMote device is a representative of new generation open-hardware platforms [18] which include among others also Zolerita [13], and TI CC2538DK [19]. The OpenMote-CC2538 is based on Texas Instrument's CC2538 system on chip, featuring an ARM Cortex-M3 running at 16/32 MHz and with 32 kB of RAM and 256/512 kB of flash memory. It has IEEE 802.15.4 transceiver and supports several peripherals, such as USB, NVIC, SCB, SysTick, I2C, SPI, UART, and various crypto processors. The OpenMote has three digital sensors (temperature/humidity, light, and accelerometer). It has a battery supply with a battery level sensor, so it can be displaced easily within the monitored area. The OpenMote indoor transmission range is around 50 m, and in outdoor environments is around 200 m.

B. *OpenWSN*

The OpenWSN is a fully standard-based open-source implementation of a protocol stack for IoT networks [20] (see Figure 2.). The IEEE 802.15.4e TSCH standard replaces the traditional MAC protocol without changing the underlying IEEE 802.15.4 physical layer. The logical link layer (uRES) is the partial implementation of the IETF 6TiSCH standard. The 6LoWPAN layer enables the integration of IPv6 protocol in low data rate wireless personal area networks (WPANs). The RPL is the routing protocol responsible for packet forwarding between nodes in multi-hop networks. At the transport layer, UDP protocol is used due to its lightweight implementation. The CoAP application layer is designed to be a simpler alternative to HTTP, but can translate to HTTP for simplified integration with the web, while also meeting IoT requirements such as multicast support, very low overhead, and simplicity.

Additionally, the OpenWSN features also the OpenVisualizer, a Python-based debugging and visualization program which enables the communication with the motes over the USB interface.

OpenWSN can be downloaded from its GitHub page and installed by using the install.sh script that comes with the OS. The installation instructions are provided on the OS's wiki page [20]. To make the OS work the following is required to be executed:

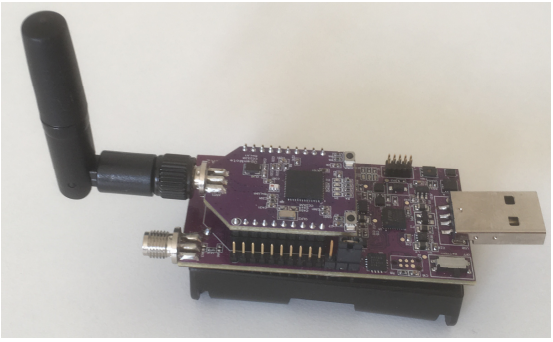

Figure 1. OpenMote.

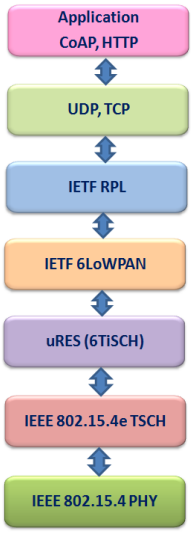

Figure 2. OpenWSN protocol stack.

```
sudo scons board=openmote-cc2538 toolchain=armgcc
apps=cinfo,csensors,cleds bootload=/dev/ttyUSB0 revision=A1
oos_openwsn
```

which will compile and upload the OpenWSN to the mote at USB0 in this case. To get the data from the sensors the csensor application should be specified, whereas "revision" specifies the OpenMote board revision. To compile the other board just the bootload parameter needs to be changed to /dev/ttyUSB1. Once the motes are programmed, one can start the OpenVisualiser:

```
sudo scons runweb
```

In addition to enabling communication with motes over the USB, it also starts a webserver with an interface at 127.0.0.1:8080. After opening that webpage in a browser, it is possible, among other functionalities, to designate one mote of the two as the directed acyclic graph (DAG) root, after which the motes will synchronize between themselves, and it becomes possible to ping each mote. The IPv6 addresses of the motes are displayed in the same interface.

C. *Contiki-ng*

Contiki-NG [21] is a fork of the Contiki OS and therefore retains some of its original features. We have chosen the Contiki-NG mostly because we liked the documentation provided with it. It is in fact on of the focuses of Contiki-NG to improve the documentation of Contiki. Additionally, Contiki-NG focuses on dependable (secure and reliable) low-power communication and on standard protocols: IPv6/6LoWPAN, 6TiSCH, RPL, and CoAP.

To make the motes work on Contiki-NG the following needs to be executed after following the instructions of installing the contiki-ng available on the project's wiki page [21]. We followed the preferred installation way which uses a Docker image.

```
sudo make TARGET=openmote-cc2538
BOARD_REVISION=REV_A1 PORT=/dev/ttyUSB0
border-router.upload

sudo make TARGET=openmote-cc2538
BOARD_REVISION=REV_A1 PORT=/dev/ttyUSB0
connect-router

sudo make TARGET=openmote-cc2538
BOARD_REVISION=REV_A1 PORT=/dev/ttyUSB1
coap-example-server.upload
```

The first line compiles and upload the Contiki core to the mote at USB0 together with the RPL boarder router. In that way the mote becomes the DAG root but also an Internet access point for all nodes in the network. The second line runs the program tools/tunslip6, which bridges the Contiki-NG border router to the host (in our case an Ubuntu machine) via a tun interface. The RPL border router running on the mote, has an auto-configured address which can be read on the terminal after having started the tun interface.

The first two lines need to be executed in the /examples/rpl-boarder-router folder, whereas the third line should be executed in /examples/coap/ folder of Contiki-NG. The third line makes the mote on USB1 a CoAP server.

To get the addresses of the other nodes in the network which are not boarder routers (in our case there is only one):

```
wget -6 "http://[fd00::212:4b00:430:5465]/"
```

where fd00::212:4b00:430:5465 is the address of the boarder router. In our case the address of the node at USB1, i.e. the CoAP server, is fd00::212:4b00:430:5415. It can be pinged, but also since the CoAP server is running on it, we can access data from it over CoAP as described in the next section.

By default Contiki-NG did not support directly the sensor data over CoAP, at least not for the OpenMotes. Therefore before compiling the CoAP server we had to do the following changes in the Contiki-NG code.

In the coap-example server.c:

```
replace SENSOR_ACTIVATE(temperature_sensor);
with: SENSOR_ACTIVATE(sht21);

replace SENSOR_ACTIVATE(light_sensor);
with: SENSOR_ACTIVATE(max44009);
```

In res-temperature.c:

```
replace int temperature = temperature_sensor.value(0);
with: int temperature = sht21.value(SHT21_READ_TEMP);

at the beggining of the file add:
#include ”dev/sht21.h”
```

In res-light.c:

```
replace both:
light_sensor.value(LIGHT_SENSOR_PHOTOSYNTHETIC)
light_sensor.value(LIGHT_SENSOR_TOTAL_SOLAR)
with: max44009.value(MAX44009_READ_LIGHT)

At the beginning of the file add:
#include ”dev/max44009.h”
```

In /arch/openmote-cc2538/board.h add:

```
#define PLATFORM_HAS_TEMPERATURE 1
#define PLATFORM_HAS_LIGHT 1
```

In that way we enabled temperature and illumination measurement from the OpenMote running CoAP server. In the continuation we will describe the CoAP interface for the Contiki-NG but the same applies for OpenWSN with just the names of the sensors being different.

D. The CoAP interface

To access the CoAP-based IoT devices one can just enter the device’s IPv6 address in Firefox, with the help of the Copper add-on. Note that Copper is compatible with Firefox versions up to 55, so one needs to downgrade Firefox to version 55 to be able to install Copper. Figure 3. shows the Copper output in our case with two sensors: temperature and light.

To develop a functional web interface for the data available over CoAP, we have used Node-RED as described in the following section.

E. Node-RED

Node-RED is a flow-based development tool, built on Node.js, which can be used for wiring together hardware devices, and online services as part of the IoT paradigm [22]. It provides a browser-based editor that makes it easy to make flows using the wide range of nodes. Each flow can be deployed to its runtime.

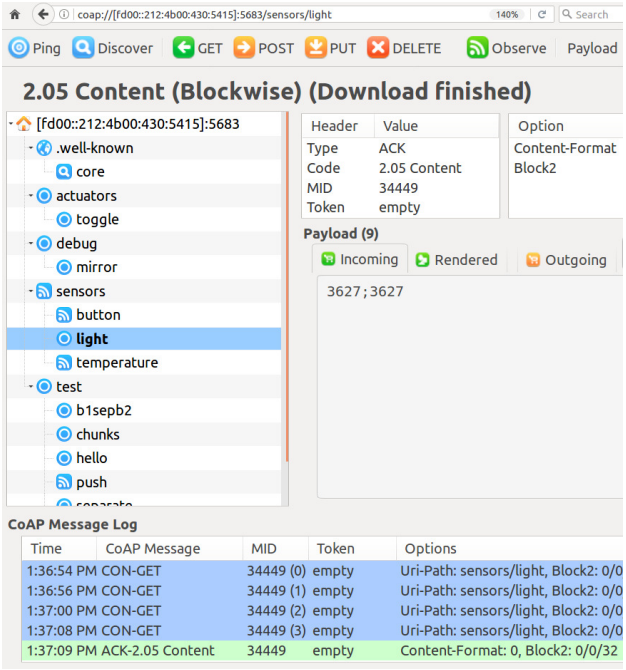

Figure 3. Copper add-on for Firefox. The current light reading of 3627 [lux] is displayed twice in the middle of the screen.

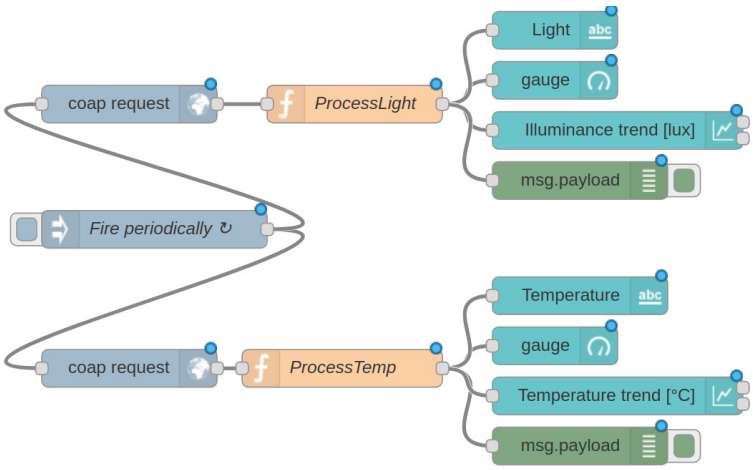

Figure 4. Node-RED flow for processing temperature and light data from CoAP server on an OpenMote.

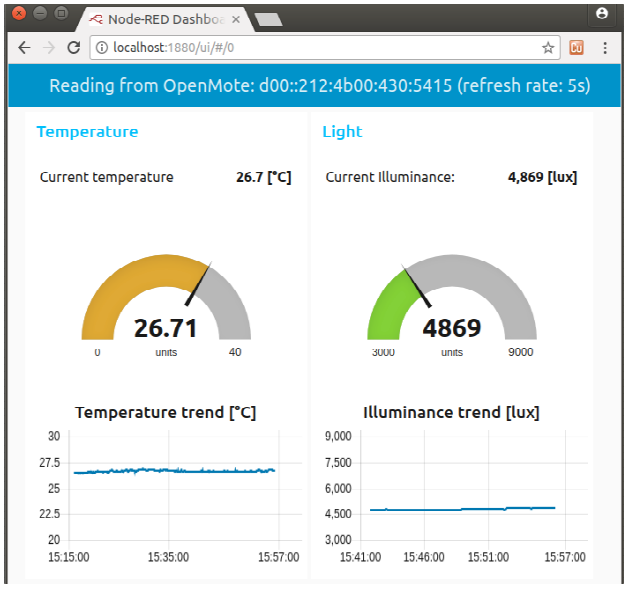

Figure 5. Node-RED dashboard webpage which results from the flow on Figure 4.

Figure 4. shows a Node-RED flow for processing the data from the CoAP server on the OpenMote. Periodically (in our case every 5 s) two CoAP requests are fired, one for the temperature:

```
coap://[fd00::212:4b00:430:5465]:5683/sensors/temperature
```

and one for the light:

```
coap://[fd00::212:4b00:430:5465]:5683/sensors/light
```

The returned data is than processed by two function blocks. In the case of light just one of the two numbers is extracted (see Figure 3), whereas in the case of the temperature the number, since it is integer, just needs to be divide by 100, to get the temperature reading with two decimal points. The results of processing are forwarded to text, gauge, and trend dashboard outputs, the results of which can be seen on Figure 5. The debug nodes designated with msg.payload just display the payload of the message in the Debug sidebar.

III. Conclusion

Our general impression is that Contiki-NG is a more robust OS with much better community support and documentation. In fact, the support we got in the Contiki-NG wiki page was decisive to make the system work with OpenMotes. The community provided us with the information about which code segments to analyze and alter, which greatly reduced the time for analyzing the code. On the other hand, we were not even successful in making the OpenMotes work over the CoAP in OpenWSN, even though that functioned in our previous experiments [17] (the only difference between the two trials being the version of OpenMotes).

One of the differences in the organization of the two OS is that in the OpenWSN the CoAP server and the border router are included in the default compile, whereas in Contiki-NG they are examples that need to be build and flashed to the motes separately. Another difference is that for the direct communication with the motes over the USB OpenWSN uses OpenVisualiser whereas Contiki uses Login program. The Login program however will not work with the OpenMotes before applying the changes available at:
https://github.com/contiki-os/contiki/pull/2302/files .

Node-RED has proved to be a very smooth tool for building a web interface for the sensory data coming over CoAP. It takes only a few minutes to build a functional flow with an attractive web interface.

We spent most of the time on understanding and altering the OpenWSN and Contiki-NG. It came as a surprise to us that such a basic functionality, like getting the data from sensors over CoAP, is not existing by default without a need for additional programming. This programing work can be tedious and futile for potential users who just want to use IoT OSs for the remote monitoring and are perhaps not interested in the depths of the protocols implementations. Our experiences presented here eliminate a need for exploring what needs to be additionally programed in Contiki-NG for the purpose of getting the sensors data over CoAP.

ACKNOWLEDGMENT

I. Tomasic acknowledges the funding by the Swedish Knowledge Foundation (KKS) project CCOPD (reference number: 20160029), as well as the support by the Embedded Sensor System for Health (ESS-H) research profile also funded by the KKS.

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INVITED PAPERS

Internet of Things: Today and Tomorrow

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***Abstract*— Internet of Things (IoT) is buzzword that is widely used in different domains. This paper is explaining current notion of IoT and status in the technological and research point of view, mostly in Europe. Future of IoT is bright and trends in number of devices and money involved are showing significant growth. There are still challenges in technical, business and social domains and some of them are tackled in the paper.**

Keywords*— *Internet of Things (IoT), Machine to Machine (M2M) Communication, Smart Home, Smart City, Security

I. INTRODUCTION

The term Internet of Things (IoT) was coined by Kevin Ashton in presentation to Procter & Gamble (P&G) in 1999 [1]. Ten years later this term was widely spread and used in public communication and scientific community. There is no one unique definition of IoT but general idea is the same. Thing in IoT is everyday object than has embedded computing device with possibility of communication (send and receive data). And IoT is when such devices are connected to the Internet. In recent years virtual things can also be part of IoT.

In 2010 Ericsson CEO in the presentation to the shareholders give estimation that 50 billion devices will be connected in 2020. After that other companies like Gartner, Cisco give predictions on how many devices will be connected in 2020. Their predictions were more conservative but not far behind Ericsson. That was the sign for everybody to change focus to Machine-to-Machine (M2M) Communication which was shifted to term IoT.

II. APPLICATIONS

IoT application uses convergence of various technologies, such as TCP/IP, RFID, sensor networks, home networks, smart metering, mobile network, embedded computing, etc. Some of the most prominent application areas are [3]:

- security – surveillance, alarms, object/human tracking, etc.;
- transportation – fleet management, toll payment, road safety, smart transport in the city;
- e-Health – remote patient monitoring, Mobile Health, telecare;
- manufacturing (Industry 4.0) – production monitoring and automation;
- utilities – metering oil, water, electricity or heat, garbage tracking;
- industrial supply and provisioning – supply and distribution monitoring (storage management), vending machines;
- facility management – informatisation and automation of various home, building, or part of city resource management;
- precision agriculture – sensing air, soil or plant, smart irrigation systems, disease detection.

Different applications have different requirements for network and processing. For example, in the surveillance area you need to have enough bandwidth to stream video when you have security breach in house. In other case like smart metering bandwidth is not crucial. Here is important low power consumption, long-distance communication and low bandwidth. In transportation for road safety it is critical low latency communication between vehicles in order to prevent chain of accidents on the road.

III. ARCHITECTURE AND COMMUNICATION

The basic IoT architecture is depicted in Figure 1. In the smart space are things that can be connected either through gateway or directly to the IoT platform. It depends on the ability of a thing. If the thing has sensor data readings are sent to the IoT platform which is usually located in cloud. If the thing has actuator the IoT platform need to have a way to send a command for actuating. In the cloud are IoT applications that can use collected data for data analytics or to provide application to the end user. End user can use system either by using phone or computer or physically by using physical device in smart space.

IoT platform is software that integrates things. Its purpose is to continually collects data, consolidate data, do data analytics. For IoT application developers, IoT platform provides services such as: searching for resources (sensors/actuators/services), access to sensor data, to actuate or invoke service.

Technologies that are used for sensors/actuators are different microcontrollers with electronics that reads physical values or can actuate something in the environment. An example of such microcontrollers are: Libelium Waspmote, Arduino, Espressif, Gallileo etc. The price of such electronics is now very cheap. Those devices can be connected to the gateway by using:

- Wired communication – Ethernet, Power Line Communication (PLC)
- Wireless communication

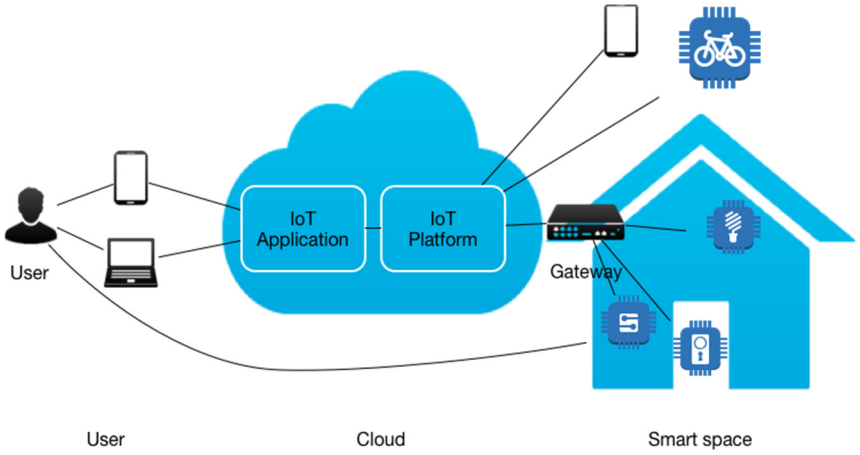

Figure 1 – IoT Architecture

- mobile network (2G/3G/4G/LTE/LTE-M/NB-IOT),
- to gateway in near space – Wifi, IEEE 802.15.4, ZigBee, 6LoWPAN, Bluetooth, Bluetooth Low Energy (BLE),
- to gateway in wide area – LoRaWAN, Sigfox

For special applications Near field communication (NFC) or RFID can be used in smart space.

Gateway is usually connected to the cloud by using standard Internet connection (broadband access).

If a thing is directly to the IP network, then it needs to use some application protocol to connect to gateway or IoT platform. Mostly used protocols are:

- TCP – HTTP and MQTT (Message Queue Telemetry Transport);
- UDP – CoAP (Constrained Application Protocol), MQTT-SN (MQTT for Sensor Network).

IV. STANDARDIZATION

Standardization is crucial in order to have different devices to communicate. Devices need to understand each other. Some of the most important standardization bodies and their standards are:

- IETF – Internet protocols (TCP, UDP, HTTP, CoAP, …);
- 3GPP – Mobile network (2G, 3G, 4G, LTE, …);
- IEEE – wireless communication (WiFi, 802.15.4, …);
- OMA – managing software on devices (OTA);
- oneM2M – platform standardization;
- OGC – SensorThings API;
- W3C – Web of Things.

The future work in the standardization is needed in the area of IoT platforms and their interoperability on different levels. Currently there are more then 400 platforms in the world [4] and most of them are not interoperable in the syntactic level. Semantic level is even more challenging area for the future [5].

V. EU PROJECTS

In 2015 there was call for project proposals for HORIZON 2020 program in the area of interoperability between IoT platforms. On that call 7 project were started funding at the beginning of 2016 for 3 years. They are [6]:

- symbIoTe (symbiosis of smart objects across IoT environments) – interoperability framework across existing and future IoT platforms that will enable the discovery and sharing of resources for rapid cross-platform application development and will facilitate the blending of next generation of smart objects with surrounding environments;
- bIoTope – to easily create new IoT systems and to rapidly harness available information using advanced Systems-of-Systems (SoS) capabilities for Connected Smart Objects – with minimal investment;
- BIG IoT – address the interoperability gap by defining a generic, unified Web API for smart object platforms, called the BIG IoT API;
- AGILE – modular and adaptive gateway for Internet of Things devices. Modularity at the hardware level provides support for various wireless and wired IoT networking technologies (KNX, ZWave, ZigBee, Bluetooth Low Energy, etc.). It allows fast prototyping of IoT Solutions for various domains (eg. home automation, environment monitoring, wearables, etc.);

- VICINITY – will build and demonstrate a platform and ecosystem that provides "interoperability as a service" for infrastructures in the Internet of Things.;
- TagItSmart! – printable QR code called FunCodes when attached to a product such as a milk carton, beer crate, temperature sensitive medical supplies etc, the tags are able to convey vital information along the life-cycle of the product. The context sensitive tags along with widely available smart-phones enable the capturing, recording and transmission of these codes and the information they contain. Context information monitored includes but not limited to temperature and oxygen exposure;
- Inter-IoT – aims at the design, implementation and experimentation of an open cross-layer framework, an associated methodology and tools to enable voluntary interoperability among heterogeneous Internet of Things (IoT) platforms. The proposal will allow effective and efficient development of adaptive, smart IoT applications and services, atop different heterogeneous IoT platforms, spanning single and/or multiple application domains. The project will be tested in two application domains: port transportation and logistics and mobile health; additionally, it will be validated in a cross-domain use case.

They were organized under IoT European Platforms Initiative [6]. The main purpose is to investigate possibility to interoperate between different platforms. In 2016 there was another call for HORIZON 2020 projects regarding large pilots. Selected projects were:

- U4IoT (User Engagement for Large Scale Pilots in the Internet of Things);
- CREATE-IoT (CRoss fErtilisation through AlignmenT, synchronisation and Exchanges for IoT);
- SynchroniCity (SynchroniCity: Delivering an IoT enabled Digital Single Market for Europe and Beyond);
- MONICA (Management Of Networked IoT Wearables – Very Large Scale Demonstration of Cultural Societal);
- IoF2020 (Internet of Food and Farm 2020);
- AUTOPILOT (AUTOmated driving Progressed by Internet Of Things) and
- ACTIVAGE (ACTivating InnoVative IoT smart living environments for AGEing well).

The funding started at the beginning of 2017 in duration of 4 years. They are organized under IoT European Large-Scale Pilots Programme [7].

VI. FUTURE

There are still challenges in applying this technology. Here are some of them.

A. Security

Symantec 2018 Internet Security Threat Report [8] stated that number of attacks on IoT devices has grown for 600 times in 2017 comparing to 2016. Security of IoT devices should be taken seriously and it needs to be included from the beginning of defining different parts of system from devices to cloud and end users.

B. Privacy

This year GDPR will be applied in EU and that will influence IoT systems as well. An example of service that influence privacy is search for IoT resources. If you can search for alarm or smart door lock this is indication that someone has such door lock or alarm and this needs to be protected. It should be searchable only to the owner or maintainer in some period. Medical data are especially important in privacy and it should be regulated not only on electronic market domain but also in medical domain.

C. Scalability

Scalability will not be possible without interoperability between different systems because one company cannot provide everything in e.g. Smart City. Currently all data is send to the IoT platforms in the cloud but when huge number of devices will be connected and all of them will generate data then network and cloud capacity will be problematic. 5G networks will solve some of the problems such as increasing bandwidth and they will give possibility to analyse data in machines that will be closer to the source. For that will be used Fog and Edge computing and the IoT systems will need to be changed in order to use them.

D. Business Models

In order to have lots of things and data it is crucial to see the value chain. Each participant in that chain will need to have business model in order survive in this environment. Current business models are in early stages and will be something that will evolve as technology will be used more and more.

E. Energy Efficiency

In some environments such as mobile or smart home, energy efficiency of IoT devices will be important. For example, most of the homes are already build and if they want to upgrade to smart home they need to introduce IoT devices. If all of those devices are connected with wires, then it is expensive. If they are connected wirelessly then we have problem of powering such devices. Those devices are usually powered by batteries. A user doesn't want to change batteries every month in every device, so they need to last for several years. Such devices need to be energy efficient. The other approach is to harvest energy from environment such as: light, motion, heat, electromagnetic waves (from WiFi or mobile network) etc.

F. Long term maintenance

Since IoT is ordinary thing equipped with some electronics which run software, we need to create operating systems, firmware and other type of software that will last or can be updated during the lifetime of the product. E.g. lifetime of

refrigerator is much longer then lifetime of computer. Refrigerators lasts for 10-20 years. How will that influence building of software that lasts that long, or it should be upgraded (with bugfixes and new features) but still need to run on the same hardware? That is the challenge still open.

VII. CONCLUSIONS

The IoT is currently very popular buzzword and everybody has heard the term. Companies are planning to introduce it in their business, but they need to see concrete benefits from the technology. Forecasts are good, and everybody counts on them. On the other hand, engineers and scientists need to solve problems that are still remaining in order to make technical part working. Awareness of the problems of privacy need to be communicated to the users in order to protect them. Regulations from agencies and by law will need to be changed or created for this technology.

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Regulatory Challenges Due to Implementation of Internet of Things Based on 5G Technology

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***Abstract* – Some regulatory challenges due to implementation of Internet of Things based on 5G technology are outlined in this paper. Standardisation and interoperability are the obligatory preconditions for a successful commercial operation of an electronic communications network based on 5G technology but there are other factors and requirements that influence both time plan and business plan for implementation of 5G technology. Some of these factors are radiofrequency plan and radiofrequency spectrum availability, site allocation and coverage, backhaul capacity and legal possibility for co-investment. The role of privacy, security and data protection is emphasized as a possible burden for a fast implementation of a new technology solutions. The importance of regulatory framework that encourages investment in 5G technology is stressed out and shown in the example of Croatia as a member of EU single digital market. The role of national regulatory authority is presented in the case of Croatian Regulatory Authority for Network Industries.**

Key words – Internet of Things, 5G technology, mobile telecommunications network, electronic communications market regulation, national regulatory authority,

I. INTRODUCTION

Almost every information becomes digitalised. Society and industry are undergoing a „Digital Transformation“ [1] as the part of „Industry (R)evolution 4.0“. Both public and private sectors have changed tremendously and have been evolved to „Digital / Information society“ [2] and „Digital Economy“ [3]. This change is especially evident in European union with creation of EU „Digital Single Market“[4] and provokes a rapid development of mobile broadband (MBB), Machine-to-Machine (M2M) communication and Internet of Things (IoT), all of them based on mobile telecommunications networks.

Mobile telecommunications networks that are currently in operation apparently will not be able to fulfil future communications requirements and therefore the solutions based on the new technologies are required. It is widespread opinion that 5G technology and 5G infrastructure platform, a new generation of MBB, has the required potential to fulfil existing and future requirements for both „Digital / Information Society“ and „Digital Economy“ thus enabling MBB network to facilitate the transformation of diverse industries and to achieve the goal of enabling multiple industries with a single electronic communications network. A MBB network based on 5G technology an infrastructure (5G), M2M and IoT, will significantly improve end-users' communication experience. This kind of network will also be a driving force for a change in production and operating systems through the connection between things and between people and things.

In the chapters II and III of this paper some basic information about IoT/M2M and 5G are given in order to emphasize the importance of these new technologies for a new generation of electronic communications networks and MBB. The process of implementation of IoT and 5G has clear and huge implication on electronic communications market regulations and raises some regulatory challenges. Some of those challenges are outlined and described in the chapter IV. In the chapter V the role of national regulatory authority (NRA) has been stressed out end described in the example of Croatian NRA. The Related work and Conclusion complete the paper.

II. INTERNET OF THINGS

When physical objects can communicate with each other and with the outside world, they are said to be connected things or smart objects. One can interact with them remotely, query how they are doing and change their state as required. As things become interconnected, traditional value chains are re-shaped into a new digital eco-systems, increasingly dependent on new business logic and partnership. Connected things need to work together to unlock the full growth potential of IoT. Fulfilling this promise will require new digital eco-systems (Figure 1) [5].

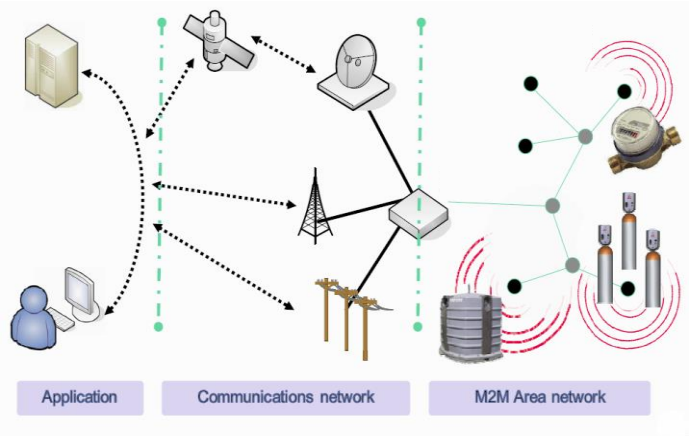

Figure 1. New digital eco-system

International Telecommunication Union (ITU) has established Study Group on Internet of things and smart cities and communities working on ITU-T Recommendation series Y. 4000 [6]. U.S. National Institute of Standards and Technology (NIST), American National Standards Institute (ANSI), European Telecommunications Standards Institute (ETSI), Telecommunications Industry Association (TIA), South Korean Ministry of Science, ICT and Future Planning, Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) and FIWARE Community have started collaboration on the Internet of Things-Enabled Smart City Framework [7].

The concept of M2M communication, which refers to physical telecommunication-based interconnection for data exchange between two "machines", is similar, and here the notion of "machine" corresponds to the notion of "thing" [8]. M2M can be viewed as a subset of IoT, with specific platforms and additional solutions for using mobile network capabilities [9].

Beside services specific for a single sector, such as dynamic pricing of energy consumption, IoT opens entirely new opportunities by combining resources from different sectors and introducing citizens as data and information producers. While research and development of IoT solutions is a global process, implementation is a local process that should take into account the specific requirements of each country/market in order to produce benefits for its citizens and promote public interest. Some policy and regulatory issues fall within the scope of electronic communications, but topics related to privacy, security, competitive market development and consumer protection require responsibility across the entire IoT value chain. NRAs for electronic communications, having wide experience in all these areas, can play significant role in development of trustworthy IoT for "Digital/Information Society" and "Digital Economy" [10].

III. 5G TECHNOLOGY FOR ELECTRONIC COMMUNICATIONS NETWORKS

Despite the name, 5G isn't simply the next generation of existing 4G mobile networks. It's not a mere upgrade, but rather the new infrastructure of a connected intelligent world. The standard is still in development but deployment is expected to begin as early as 2020. [11]. When it arrives, 5G wireless network will support throughput of up to 10 Gigabits per second per individual user, end-to-end latency as little as 1 millisecond and connections for as many as a million devices per square kilometre, or 100 billion devices worldwide [12].

5G really means connectivity between people and connected machines/things that will provide ability to transmit huge amounts of data almost instantaneously to countless devices all over the world. When 5G networks come online, they will drive economic and societal growth in unprecedented ways, and contribute to the creation of new products, services and business. All business and social activities are being transformed. A MBB, based on 5G infrastructure, will improve people's communication experience and will also be a driving force for change in production and operating systems, through the connections between things and between people and things.

5G networks will develop alongside the new services that the technology enables. With its huge technology improvements, the 5G network will become a network platform that will accelerate new industry applications. Some of those applications are:

- Smart grids that supports national energy transformation
- Healthcare that can bring to everyone an access to health system
- Smart manufacturing and logistics drives manufacturing transformation
- Smart driving will increase automotive safety and efficiency
- Agriculture through distributed sensors and crop monitoring
- Media and entertainment through virtual reality and augmented reality to support gaming, remote presentations, intelligent navigation, tour guides, etc…

The 5G communication infrastructure will become a platform that realizes the target of enabling multiple industries with a single network. By taking advantage of the rapid and reliable communication capabilities of 5G networks, as well as the enormous number of connections 5G can support, 5G will enable operators to better serve end-users in all industries. Mobile telecommunications networks operators will be able to position themselves as the "best enablers" for industry applications thus creating a platform for a Smart Society Concept (figure 2) [13].

5G business case contains two major parts: enhanced MBB and differentiated services. Enhanced MBB comprises end-users' willingness to pay for enhancement, network cost of meeting data growth and competitive quality of service. Differentiated services include agile network slicing, pricing structures for new end-users and willingness to pay and fall back connectivity.

Figure 2. Smart Society Concept

IV. REGULATORY CHALLENGES DUE TO IMPLEMENTATION OF INTERNET OF THINGS AND 5G TECHNOLOGY IN AN ELECTRONIC COMMUNICATIONS NETWORK

The transformation of network architecture and service provisioning models and their implications on the electronic communication market raised challenges for regulatory authorities [14, 15]. New requirements relating to content- and service-awareness, computing capabilities, ubiquitous broadband access and mobility, massive connectivity of various devices and objects reflect on security, privacy and data protection. IoT, M2M, Cloud Computing (CC) and new paradigms related to content and media on the Internet are widely used (Figure 3) [16, 17, 18].

Experience has shown that in the regulation of electronic communications all basic types of regulation and regulatory instruments are involved, i.e.:

- No-regulation: without explicit controls, applicable when a competitive market achieves the desired objectives in itself, such as the option to choose a service provider, acceptable price, and others; common situation for nascent technology;
- Self-regulation: the industry itself (communications, computers, media, information and communications technology - ICT in general) sets, implements and administers the regulatory objectives without the formal oversight of governments or regulatory bodies;
- Co-regulation: industry and public bodies determine regulatory solutions together and the government or regulatory authority defines the legal framework for their implementation;
- Regulatory body defines regulatory objectives and rules, as well as regulatory requirements and demands on service providers. This type of regulation is applied in circumstances where there is/are service provider(s) with significant market power, or when different interests in the industry prevent reaching a common solution.

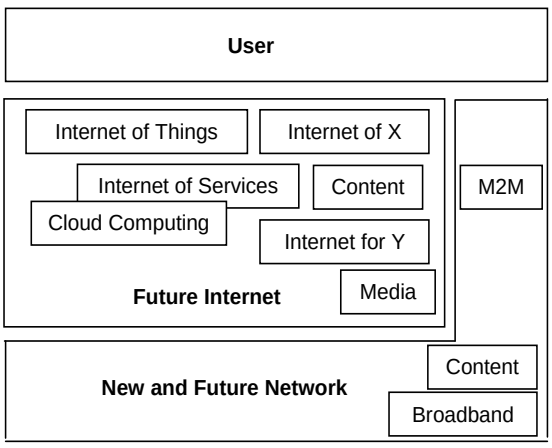

Figure 3. Future of Networking Landscape

Electronic communications have gone through a completely different process: from state monopoly to a competitive market of electronic communications. This transition was governed by statutory regulation. The present situation in the EU is defined by the common regulatory framework for electronic communications [19]. According to a Framework Directive, the national regulatory authorities shall "contribute to the development of the internal market", "promote the interests of the citizens", and "promote competition in the provision of electronic communications networks, electronic communications services and associated facilities and services by, among others [20]:

- ensuring that users, including disabled users, derive maximum benefit in terms of choice, price, and quality;
- ensuring that there is no distortion or restriction of competition in the electronic communications sector;
- encouraging efficient investment in infrastructure, and promoting innovation;
- encouraging efficient use and ensuring the effective management of radio frequencies and numbering resources" [21].

So far, different approaches have been applied to regulate certain issues in electronic communications, and regulatory objectives have changed in line with technological and market changes. The same process is needed in the future, but at a faster rate. The development of the information and communication technology including networks, services, applications and content is exceptional, as is the research and innovation in this area. This must also be reflected in the governance and regulation of electronic communications in order to be able to adapt to changing environments and prepare solutions for evolved and predicted problems. Therefore, there is a need for smart regulations that are effective and solution-oriented, ranging from no-regulation (deregulation), self- and co-regulation, to statutory regulation, has been recognized [22]. Such a regulation space and its three dimensions (type, impact, and topic) is shown in Figure 4.

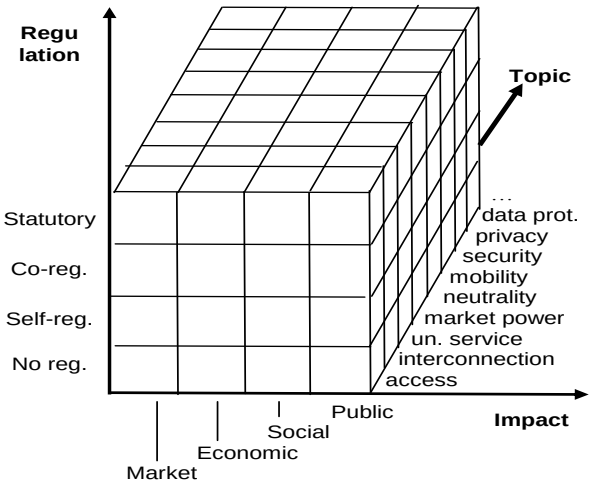

Figure 4. Market regulation space

Changes are also expected in the manner in which regulation is implemented: from vertical solutions for a specific network or service towards solutions for multiple, in some cases all, networks or services. Many systems and services that combine features from different paradigms require such solutions, for instance using IoT for sensing and collecting data and CC to store it and execute applications [23, 24].

Full compliance to standardisation and interoperability is obligatory for a successful commercial implementation of new services for MBB, based on IoT and 5G. Open platforms capable of supporting multiple services and applications, open data, system interoperability and early involvement of citizens are prerequisites for market development and full exploitation of the innovative potential of IoT based on 5G [25, 26]. It is especially important for smaller states to develop an open environment where micro and SMEs, as well as individuals contribute to research, development and implementation of IoT-based solutions.

Radiofrequency spectrum allocation for 5G networks is one of the key regulatory challenges. The 700 MHz band is suitable for deploying national and indoor 5G coverage. EU member states should make it available for wireless broadband by June 30, 2020. Member states can apply a derogation of two years for "duly justified" reasons. The 3.4 – 3.8 GHz band is the primary band suitable for the introduction of 5G use in Europe even before 2020 and capable to put Europe at the forefront of the 5G deployment. The 26 GHz band is the pioneer band for the future deployment of 5G in spectrum frequencies above 24 GHz [27]. The radiofrequency band below 1 MHZ is well-suited for universal coverage, indoor use and IoT/M2M communications while the radiofrequencies above 6 GHz might be more suitable for uses such as smart city and agricultural applications in a specific geographical areas.

The requirement for excellent coverage is not only connected to availability of radiofrequency spectrum but also cause a huge regulatory challenge due to densification of the 5G electronic communication network. There is a need for significantly more radio base stations sites thus causing problem not only with physical construction but also with power supply and data transmission as well as with local government and some civil association due to "a hazard" caused by electro-magnetic radiation. This challenge is also connected with exclusive or restrictive site arrangements, public site owners, spatial planning and practical logistic constraints. Also differentiated services could cause coverage planning more difficult but there is no doubt that roll-out of 5G electronic communications networks will start in (high dense) urban areas and co-investment of two or more network operators is obligatory in order to make a profitable business case and reasonable return of investment.

New radio-frequencies for new wireless technologies assure Quality of Service (QoS) required for IoT/5G services. While limited national resources, like radiofrequency spectrum, numbering and addressing will prove to be an issue in the future, lack of understanding and knowledge of security and privacy may slow down development already today.

In recent years European commission has been working on several documents that will strongly influence data processing business. In April 2016 EU Parliament introduced GDPR [28] and 25 May 2018 is enforcement day. As its web page says "GDPR was designed to harmonize data privacy laws across Europe, to protect and empower EU citizen data privacy and to reshape the way organizations across the region approach data privacy" (www.eugdpr.org).

On the same day e-Privacy regulation aligned with GDPR rules will be enforced as well. Therefore, in a single month, companies will need to ensure they have everything necessary in place to comply with the new GDPR, e-Privacy regulation and the directive on security of network and information systems (NIS Directive) [29].

The question is whether these regulatory directives will ensure trustworthiness or it will become a burden to the faster development of IoT and M2M, especially in the context of Smart City and "Digital/Information Society" [30]. New GDPR and e-privacy directive features, like right to erasure, privacy by design and by default, data portability and data breaches rules will raise the level of trust in IoT technology for sure. However, pseudonymisation as one of the major pillars of GDPR can have negative impact on further development. Transformation of personal data in such a way that the resulting data cannot be attributed to a specific data subject without the use of additional information is very expensive process. Applying data protection and privacy rules on such devices may slow down or jeopardize roll out of IoT [31, 32]. Therefore it is necessary to take care of horizontal architecture of IoT when implementing these functionalities.

There are some other regulatory challenges related to implementation of IoT and 5G. Physical infrastructure access, also for new and non-traditional entries, as well as backhaul, especially in rural areas, where a synergy with already built up and future planned national broadband infrastructure should be taken in consideration from beginning. Regulation shouldn't prohibit network slicing and NRA assessment of some specialised services should be clearly regulatory defined. Furthermore, the issue of network neutrality remains as an important one.

New use cases introduced by implementation of 5G electronic communication networks require more intensive cooperation with other sectoral regulatory authorities. Beside national Agency for Private Data Protection there is also a need to coordinate regulatory activities with i.e. civil aviation agency and Ministry of health.

A part of previously mentioned regulatory challenges is a global one, first of all those related to radio-frequency spectrum. The others are more related to geographically limited space like EU or national market thus on one side enabling implementation of national specific regulatory framework but on another side that might cause a problem with interoperability or to jeopardise the concept of i.e.EU single digital market.

V. THE ROLE OF NATIONAL REGULATORY AUTHORITY

The role of NRA for electronic communications is twofold, the market regulation in collaboration with other regulatory bodies [29], and encouragement of the introduction of IoT/M2M, based on 5G, in national electronic communications market [30]. Some of the requirements and a part of regulatory framework are not subject to change prior to implementation in national legislative. There is still areas where NRA can influence national laws and by-laws related to IoT/M2M and 5G, mostly in collaboration with some other sectoral regulatory authorities. This work should be done prior to 5G roll-out thus indicating market stakeholders and investors clear rules of the game and enabling a commercial success of 5G services at home market.

Croatian National Regulatory Authority for Network Industries (HAKOM) works on identification of the elements that may have an impact on implementation of IoT and M2M, based on 5G, in Croatian electronic communications market. The regulatory framework is fully aligned with the regulatory framework and directives in EU thus leaving a small space for national specific requirements that should be agreed with some other Croatian regulatory authorities, like Competition Agency (AZTN) and Agency for Personal Data Protection (AZOP). HAKOM, as Croatian NRA, works also on creation of an ecosystem open to the implementation of new communication technologies. HAKOM promotes advantages and opportunities of both IoT and 5G, thus encouraging and fostering the idea of human-centric digital age.

VI. RELATED WORK

Relationships between IoT/M2M and 5G are studied and analysed from different perspectives within the research program "Looking to the future 2020", funded and established by HAKOM in collaboration with academia in Croatia [31]. HAKOM established in 2017. the 5G working group with participation of all three Croatian mobile telecommunication network operators.

Future work within working group of HAKOM and Croatian national mobile telecommunications network operators will also include QoS requirements of 5G services and applications, as well as security and privacy issues that may have a major impact on the implementation of Smart City services and applications. Also, HAKOM will look more closely into limited communication resources influencing future development of IoT and 5G like radiofrequency spectrum and identifiers.

VII. CONCLUSION

The implementation of IoT based on 5G will create huge opportunities to build enterprise value in a range of industry sectors, profoundly affecting business operations, asset valuations and revenue models. This process includes not only opportunities but also many challenges and obstacles. Some of them are related to electronic communications market regulation and some other sectoral regulatory authorities. Radiofrequency spectrum allocation is a global problem while implementation of GDPR, ePrivacy and NIS directive are the challenges related more to EU digital single market. The challenges like network densification, network planning, network neutrality, transport network capacity, etc… might occur at all mature electronic communications markets.

The role of the NRA for electronic communications has a broader regulatory perspective involving public policy related to deployment of IoT and 5G. Early involvement of NRA and collaboration with stake holders and other sectoral regulatory authorities will encourage investors and create an eco-system for commercially successful launch of 5G services.

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PAPERS

INTERNET OF THINGS AND CLOUD TECHNOLOGY

IoT solutions for precision agriculture

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***Abstract*—In this paper, precision agriculture is set to provide higher productivity and a better use of resources when compared to traditional methods and this will result in lower costs with higher yields. A crucial activity for crop farming is water irrigation while for livestock farming it is the monitoring of animal health. This paper presents two feasibility studies on IoT solutions for automated irrigation and one study for automated animal monitoring. In each, the proof of concept is verified to operate under normal field conditions.**

***Index Terms*—Internet of Things, precision agriculture, sensor based irrigation, Big Data analytics.**

I. Introduction

Precision agriculture (also known as smart farming) uses internet of things (IoT) solutions together with Big Data methods to provide for more efficient management of resources. It is a significant vertical market [1] that includes the management of crop yields, livestock, seeding, fertilizer use and water. The benefits of precision agriculture (PA) include increased profitability and reduced environmental impact [2].

In the early years, PA consisted mainly of map based technologies using geo-statistical methods like GIS and satellite remote sensing and the main application of PA was to manage fertilizer use [2]. Sensor use was not widespread since sensors were either too costly, too inaccurate or unavailable for the applications required. Surveys during the early 2000's showed that few farmers used PA technologies and the main barriers to the adoption of these methods were the lack of technologies to deal with the large amounts of information, the lack of scientific validation, high costs and no training or technology transfer [2].

This has changed with the development and testing of prototype PA systems, the rapid development of IoT [3] and Big Data [4], and the decreased cost of sensors. IoT solutions in agriculture now form a cycle of i) monitoring through sensors, ii) analysis and planning, and iii) smart control, all linked by a wireless network connected to a cloud service (as shown in Figure. 1) [5]. Big Data analytics [6] and machine learning [6], [7] can be applied to the data to help make informed decisions [8] and the create intelligent control. This paper will consider past feasability studies in irrigation and livestock monitoring [9] and will present the main conclusions found.

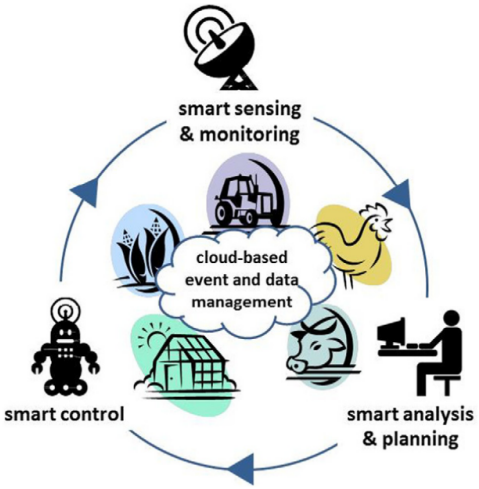

Fig. 1. Precision agriculture IoT wireless system [5]

II. Sensor based Irrigation

The success of crop farming relies on proper irrigation. Under-watering reduces nutrient uptake while over-watering causes leaching which poisons ground water [10]. Early water management [11] relied heavily on projected weather patterns, past farming activities and the manual observation of soil conditions; for instance, McKinion et al. [12] used GIS information [13] (based on soil samples and past farm use) as inputs for crop simulation models to optimize water and nitrogen use on a 201 ha cotton farm. Around the same time an automated irrigation system was prototyped using a central computer control centre [14], [15] linked to field irrigation valves [16].

This system by Damas et al. had the hallmarks of a modern IoT solution [17], [18] since it was made up of rudimentary sensors measuring water pressure and flow volume, simple

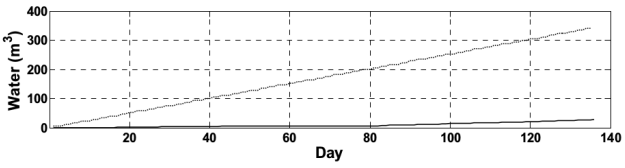

Fig. 2. Water volume for the greenhouse irrigation system (bottom line) as compared to traditional methods (top line) [23]

solenoids controlling the irrigation valves, and a central computer management system [19], [20] all linked together with a network of omni directional UHF radio antennas. 1500 ha of irrigated land was covered with an irrigation system comprised of 1850 valves, 1850 meters and 32 pressure sensors. The management software monitored the sensors [21], controlled the valves while assessing water use to correctly bill the supplied communities. Although the system could more efficiently distribute water to irrigation users it was not fully automated since it lacked control feedback from the fields. This requires the use of soil and moisture sensors [22, 1].

Such an experimental system was developed by Gutirrez et al. [23] to irrigate sage crops in a greenhouse. The main components of the system were sensor units joined to a central micro controller through a ZigBee network. A General Packet Radio Service unit relayed the sensor data over a cellular network to a server with a database. Each sensor unit is comprised of a temperature sensor, a moisture sensor, solar power cells with rechargeable batteries with a ZigBee radio unit. The unit is low-power with a sleep mode to reduce consumption. ZigBee unit was chosen due to its low price and efficient power consumption. The micro controller sends data to the server and receives instructions to activate irrigation. It also directly processes sensor data to implement automatic irrigation. Lastly the irrigation pumping system consists of two pumps activated by relays. A web application is used for monitoring and determination of an irrigation schedule. It is also used to set threshold values on the WIU for the automated scheduling. A SQL database is used for storage.

Testing was done over 136 days to compare it to the traditional irrigation method that used human supervision. Both methods used the same flow rate per drip hole during irrigation. The traditional irrigation schedule consisted of watering 42 production beds for 5 hours three times per week. The automated system watered 14 beds for only 35 min/week for the first 6 weeks then 35 min every three weeks along with automatic watering triggered by the sensor feedback of temperature and soil moisture. Threshold values to trigger automatic irrigation were set based on the producers experience. The total water use (for 14 beds) shown in Figure. 2 show a $\sim 90\%$ reduction in water use using the automated system as compared to human supervision.

Advantages of the system are low power consumption, reasonable cost, long power life due to the solar cells and efficient water management. The study showed that a wireless sensor based irrigation system is an effective solution to cut water use.

An outdoor system was developed by Coates et al. [24] to irrigate outdoor nurseries and orchards. It used a commercial system developed by MEMSIC (Andover, Mass., USA) consisting of soil moisture sensors that communicated over a low power, IEEE 802.15.4 standard mesh network to a base station connected to a computer with a SQL database. The system shares many features with the previous greenhouse system such as solar panels and control relays except everything is geared towards outdoor field irrigation. The actuator units contained a micro controller that received sensor data and controlled irrigation valves with latching solenoids. The application software monitored sensor and actuator operation and sent control instructions to the actuators units based on a preprogrammed schedule or irrigation rules based on sensor information. Advantages of this system are long range connectivity, outdoor design, a grid network enabling communication between nodes and long power life due to solar cells. The estimated cost of a working system with 10 sensor nodes with 1 actuator along with the estimated savings per year due to the reduced labor, fertilizer use and water use costs meant that cost recovery would take about 4.5 years.

The system was tested for network and valve actuator robustness. The network tests shown in Figure. 3 show that nodes connectivity depended on line of sight conditions a ranged from 100 m to 170 m. It was also noted that once the node successfully joined the network, communication remained stable. The actuator stress tests showed that the system withstood over 11000 normal actuations and over 6000 short circuit events. Short circuit testing was crucial since short circuiting valve wires is a common mistake made in the field. Further field testing done for nursery, landscaping and orchard applications revealed no major mis functions. The system showed that a commercially available sensor network could be used to actuate valves for a large scale irrigation system under normal operating conditions.

III. SENSOR BASED LIVESTOCK BEHAVIOR MONITORING

Animal farms require healthy stock to provide maximum profits. Many detectors have been developed to monitor the individual health of animals. These wearable sensors monitor various health indicators to identify disease and infection [25]. For instance sensors that monitor body temperature and humidity are used to detect stress levels in animals [26]. Another indicator of animal health is the identification of various animal behaviors such as movement and eating/drinking patterns. Analyzing these patterns can indicate if an animal is in distress and requires medical intervention.

Nadimi et al. [27] developed an experimental system that monitored animal head movements which were analysed by a trained neural network to identify movement modes of individual animals. The system consisted of a ZigBee mesh wireless network connected to temperature and accelerometer sensors in sensor nodes from Crossbow Technology, Inc. The network transfered data to a cellular modem which connected

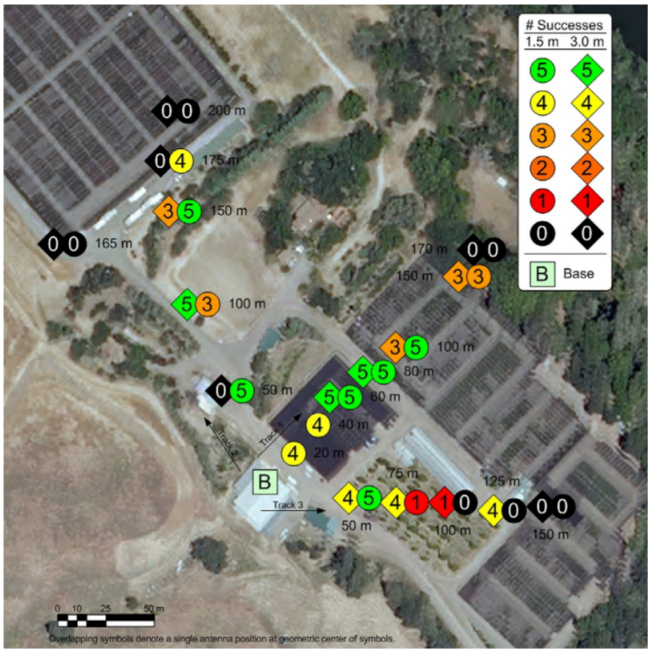

Fig. 3. Network connectivity tests for nodes mounted at differing heights [24].

to a cloud server. Four main movement modes were identified (grazing,lying down, standing and walking) and these were monitored for an eleven sheep flock in both field and barn conditions for 9 hrs a day for five days. The resulting 1782000 measurements were split 75/25 into training and testing datasets and used to train a feed-forward backpropogation 5-layered network. Testing was done to evaluate network health (see Table. I) and the accuracy of the machine learning algorithm (see Table. II). They found that the total packet loss on average was 14.8% which is a significant improvement to previous studies by Nadimi et al. [28]. Similarly, movement mode identification accuracy was better than previous studies using a Kalman filter with a multiple-model adaptive estimation technique [29] and one using decision tress [28]. The study showed the effectiveness of combining a sensor network with predictive data analysis.

IV. Conclusions

The sensor network systems presented here all share the same basic features: a wireless sensor/actuator network connected to a server and database. The studies showed that the wireless sensor networks were feasable with an improvement over traditional methods. Each system generated vaste quantities of data which could be analyzed with Big Data analytics to find trends and correlations. In the case of irrigation, data on irrigation events would be integrated into the systems that control agricultural machinery to improve crop yields and fertilizer use. Time trends would be used to plan future farming strategies based on recorded outcomes. Animal monitoring would flag abnormal animal behavior and make predictions on the possible cause. This data would be used to inform veterinary services about the nature of the health problem to initiate a call-out.

These IoT solutions will improve farming methods and result in more productivity and a better use of resources.

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TABLE I
NETWORK HEALTH STATISTICS [27].

node number	Forwarded packets (%)	Dropped packets (%)	Retry packets (%)	Transmit quality (%)	Receive quality (%)	Retransmission rate (%)
1	31.4	14.1	56	86.6	73.3	6.68
2	45.7	4.3	2.2	80	86.6	5.8
3	42.5	14.2	23	84.3	71.2	25.06
4	44.3	11.8	25.2	73.4	63	44.3
5	30	12.3	50	97.7	93	5.4
6	19.3	17	32.5	100	93	8.58
7	13	7	33	47	100	15.1
8	47.5	14.4	17	80	66	26.1
9	52.5	14	12	72.1	62.4	68.9
10	30.3	11	44.2	100	100	5.8
14	59.3	9.8	22.7	100	100	5.2
16	65.3	3.9	71.4	100	100	8.18

TABLE II
MACHINE LEARNING ACCURACY [27].

Sheep number	Grazing (%)	Lying down (%)	Walking (%)	Standing (%)	Other (%)
1	85.4	83.7	70.2	72.5	53.2
2	80.5	81.4	73.5	68.4	61.8
3	83.9	80.7	69.3	66.7	55
4	79.7	80.1	75.5	71.1	73.3
5	80	79.3	72.1	70	66.5
6	88.3	85.6	77.4	73.5	71.7
7	81.8	82	71.7	75.6	74.3
8	84	89	79.9	77.9	81.2
9	88.5	82.4	73	68.4	73.2
10	82.2	84.9	73.3	71.3	65.6
11	87.6	87	76.8	75	77.9
mean	83.8	83.2	73.8	71.8	68.5
S.D.	3.2	3	3.2	3.4	9

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On HTTP Performance in IoT Applications: An Analysis of Latency and Throughput

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***Abstract*—In recent years, Internet of Things (IoT) industry has developed rapidly thanks to the rise of the smart objects and devices with processing, sensing and actuating capabilities. In order to satisfy a broad range of applications, a variety of application layer protocols has been taken into consideration, since IoT still does not have widely accepted standard protocol. One of prime candidate solutions is HTTP, as a well-known, fundamental client-server protocol and the protocol that is the most compatible with existing network infrastructure. Due to strict IoT specific requirements, however, a detailed characterization of the performance of HTTP for IoT applications is required. This paper presents a detailed analysis of throughput and latency for HTTP/1.1 with pipelining, by evaluating the impact that pipelining factor has on the latency. Based on these performance results, we analyze whether this HTTP/1.1 model should be implemented in IoT systems with significant latency constraints.**

I. Introduction

With the growth of Internet of Things (IoT) industry and increasing number of smart objects and devices in recent years, one of the main factors that will determine the IoT performance will be the communication between these devices. To this end, the selection of the application layer protocol (messaging protocol) that is able to satisfy a broad range of IoT applications is critical. There are many potential IoT protocol candidates, and attempts are being made towards their standardization, such as Message Queue Telemetry Transport (MQTT) [1], Constrained Application Protocol (CoAP) [2], and Representational State Transfer (REST) HTTP [3]. In an attempt to capture new trends in IoT, major industry is also looking for solutions. For instance, Google developed an experimental protocol SPDY [4] which was used as a base for a new version of HTTP protocol HTTP/2.0 [5]. The basic research in this area is however still under development and as of today there is no enough evidence that there is a winning solution or a replacement of the current HTTP/1.1 model.

Despite the fact that HTTP is designed without consideration of the resource constrained devices used in IoT it remains widely accepted within the existing network infrastructure and it is unlikely that there will be an IoT system solution that will not rely on HTTP in some degrees. This is why it is very important to tackle some of the challenges of using HTTP in IoT, such as:

- Latency: A big impediment in adopting HTTP lies in the long time needed for the server to receive and process a request from the client. This latency is a consequence of both HTTP and its underlying TCP.
- Energy/power consumption: This is particularly important issue for resource constrained devices, where large uncompressed and redundant HTTP headers cause high network usage and energy consumption.
- No server push option: As a request/response protocol, a HTTP server has to wait for an explicit request from the client before a data transfer is initialized.
- Head-of-line blocking (HOL) problem: HTTP/1.1 allows pipelining to request multiple objects over the same TCP connection. But since servers must respond to requests in order, an early request for a large object as a lost request can delay all subsequent pipelined requests.

It should be noted that even with all the issues, – HTTP/1.1 is the most stable and widely acceptable solution. From a practical point of view, it maybe even easier to adapt than to implement other protocols. For these reasons, this paper sets the goal to model the HTTP throughput and latency for IoT application, in order to assess the performance. Our focus is on the performance of HTTP/1.1 with pipelining, and the effect of the pipelining factor has on the latency.

As we will show with results HTTP/1.1 with pipelining does perform better than without pipeling, which is the regularly accepted model. But, the improvement is not worth the difficulties that come with its implementation and there are other better IoT solutions.

II. Related Work

Several models of HTTP have been proposed already. A first analytical model was presented in [6] and used to examine the interaction of HTTP with some underlying transport protocols and in a similar way, [7] conducted an analysis of HTTP performances over satellite channels. In [8], the performance of HTTP/1.1 with and without pipelining is evaluated by an approximate mathematical model using several TCP-related parameters and a realistic model for a web-page.

Analytical models of HTTP rely on TCP models, that have an extensive literature. For an infinite data source the stationary throughput in the congestion avoidance phase of TCP has been analysed by some authors, and well established results for RENO have been derived in [9]. This work neglects the effect

of the initial TCP slow start. This gap has been closed in [10]. Based on the work of [9], the authors derived an analytical model for TCP latency which considers TCP's connection establishment, Slow Start (SS) and Congestion Avoidance (CA).

However with a current modeling, standard HTTP behaviours can not easily capture new trends in IoT. This is a reason some authors have decided to address limitations of HTTP and analyse its alternatives such as SPDY and HTTP/2.0. In [11] authors have compared web latency of these two protocols with existing HTTP/1.1. The experimental results showed that implementation of these protocols at the server side may improve the performance and reduce the web latency, however, but no significant improvement has been noticed on the client side. Also in [5] authors tested performances of HTTP/1.1 and HTTP/2.0 and noticed faster page load time with HTTP/2.0. All of this works assumed HTTP without pipelining.

III. Analytical Model

A. Assumptions and Prerequisite

1) HTTP Overview: The typical web-page hosted by the server consists of a base-page (index-file) for the top-level HTML with a number of M embedded objects. In practice [12], first the client will only request the base-page with expected size of $E\{F_0\}$ MSS from the server. Since HTTP uses TCP, the maximum segment size (MSS) or synonymous segment is used to specify the file size. Next requests are sent for the embedded objects, where each object contains an average number of $E\{F_s\}$ MSS. Let us assume an expected number $E\{M\}$ of embedded objects. Then, with $D_{S_M} = E\{D_S(M)\} = E\{M\} \cdot E\{F_s\}$, the page size is given by

$$E\{PS\} = E\{F_0\} + E\{M\} \cdot E\{F_s\} = E\{F_0\} + D_{S_M} \quad (1)$$

Let us assume HTTP/1.1 uses a single persistent TCP connection, where embedded objects are pipelined according to a Pipeline Factor $N, N \leq N_{max}$. The maximum number of pipelined requests sent simultaneously is typically limited by the server to $N_{max} = 4, ..., 8$. Examples for the HTTP/TCP cross-layer actions at the client/server side are shown in Fig.1 and Fig.2 for a web-page with a base-page of size $F_0 = 3$ segments, which contains $M = 4$ embedded objects, each of size $F_s = 13$ segments. Fig.1 represents the pipelined transfer, where after the initial request (blue segment) the base-page (3 green segments) is downloaded. Let RTT be the average round trip time between the client and server, which is very large compared to the transmission time of a segment. In the detailed TCP-subgraph of Fig.1 this allows us to horizontally draw the number of segments sent by TCP per round (per RTT). Next, all $M = 4$ objects are requested at once, as illustrated by the blue segments in the figure. The four objects are downloaded as if one file of size $M \cdot F_s$ is continuously transmitted, as shown by the green segments. Fig.2 illustrates the HTTP with pipelining using at most $N = 2$ requests at a time. When $N = 1$, we have the special case of HTTP/1.1 without pipelining, where only one request is sent at the same time and the response has to be successfully downloaded before the next request can be sent. Depending on the pipelining factor we observe a different behaviour at the TCP layer, thus the TCP protocol has to be considered in more detail.

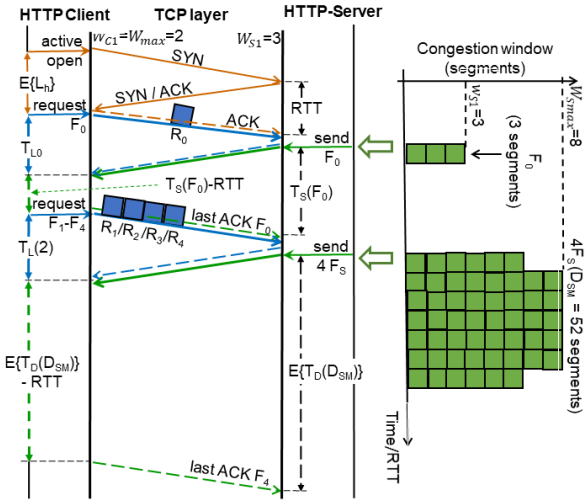


Fig. 1: HTTP/1.1 with 4 pipelined requests

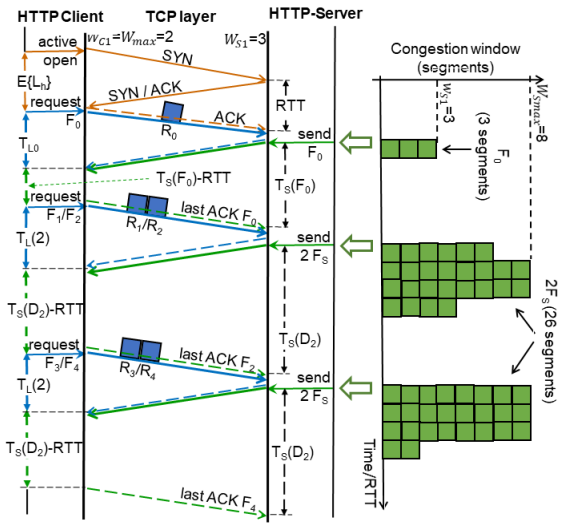


Fig. 2: HTTP/1.1 with 2 pipelined requests

2) TCP Overview: To determine the latencies seen at the HTTP client and server side we use results derived in [10] which allow TCP behaviour analysis and can be easily extended to different TCP versions. Let us give an overview and reference of the expressions in form (Equation, [10]). For the TCP connection establishment process, a loss rate p_s for the small SYN/ACK packets in either direction and a SYN timeout, T_s, of 3 seconds is assumed. To show the dependency on the TCP parameters, the expected latency is referred to as

$E\{L_h(RTT, T_s, p_s)\}$, (4, [10]), or simple

$$E\{L_h\} = RTT + 2 \cdot T_s \cdot (\frac{1-p_s}{1-2p_s} - 1) \quad (2)$$

For the TCP data transfer of a fixed number of d data segments from one host (client or server) to another the data transfer latency follows to be

$$E\{T_D(d)\} = E\{T_{SS}(d)\} + E\{T_{Loss}(d)\} + E\{T_{CA}(d)\}. \quad (3)$$

This takes into account the contributions due to the slow start, $E\{T_{SS}\}$, loss recovery latency at the end of the slow start, $E\{T_{Loss}\}$, and the time for transmitting data in congestion avoidance, $E\{T_{CA}\}$. Each latency term is defined as the time interval that starts when an application places data in the send buffer and ends when the TCP receives an acknowledgement (Ack) for the last byte in the buffer. Each segment is of common size (MSS and Header) and p is the data segment loss rate. Because the data transfer and connection establishment are taken place on the same TCP chanel, so we assume $p = p_s$. For loss probability values we consider the interval $[10^{-2}, 10^{-1}]$ commonly used for low-SNR wireless links that are being used in IoT applications [13]. Since IoT applications require a low latency, the $delayedAck$ option of TCP is disabled. The main behaviour of TCP is controlled by the congestion window, $cwnd$. This is limited by W_{max}, where W_{max} may depend on the advertised window. For d segments TCP starts in Slow Start with initial $cwnd$ of w_1 segments. The expected number of data segments sent before a loss terminates the slow start can be determined by $E\{D_{SS}(d)\} = E\{D_{SS}(d, p)\}$, (5, [10]), where the probability of this loss is given by $l_{SS}(d) = 1-(1-p)^d$. At the end of slow start the expected value of the window size is estimated as $E\{W_{SS}(d)\} = min\{(E\{D_{SS}(d)\}+w_1)/2, W_{max}\}$, (11, [10]). The time to send $E\{D_{SS}(d)\}$ data segments in slow start before a loss occurs is approximately given by $E\{T_{SS}(d)\} = E\{T_{SS}(d, p, RTT, w_1, W_{max})\}$, (15, [10]), and followed by the recovery time due to segment retransmission done by fast retransmission or retransmission timeouts (RTOs), $E\{T_{Loss}(d)\} = E\{T_{Loss}(d, p, RTT, w_1, W_{max}, T_O)\}$, (20, [10]). T_O is the average duration of the first TCP timeout in a sequence of these. The data left after slow start is approximately $E\{D_{CA}(d)\} = max\{0, d - E\{D_{SS}(d)\}$ and sent using CA. Let $R = R(p, RTT, W_{max}, T_O)$, (22, [10]), be the throughput for an unlimited TCP data source first derived in [9], which is used to approximate the expected time to send the remaining data as $E\{T_{CA}(d)\} = E\{D_{CA}(d)\}/R$.

B. Model of HTTP/1.1 with pipelining

In this section we derive an expression for the download time (latency) of a web-page seen at the client side and the achievable throughput. Vaderna et. al. [8] have derived an approximation only for the pipeline factors $N = 1$ and $N = M$. They do not consider the download of the HTML base-page and only take into account the latency observed at the server side. Based on this work, we will derive a more general analysis for $1 \leq N \leq N_{max}$ and most notable, we also take into account the latency at the client side.

The behaviour of the TCP layer depends on the progress of the congestion window $cwnd$, but due to the properties of the HTTP/1.1 protocol this behaviour is quite different for the client (C) and server (S) side. Let us denote the TCP initial window used by slow start at the HTTP client and server side as w_{C1} and w_{S1}, and in the same way an average congestion window as W_C and W_S.

1) Modelling of the client side: The analysis derived in [10] assumes that the application can immediately fill the $cwdn$ offered by TCP with segments, which is not the case for the client side. As shown in Fig.2, the client sends at most a fixed number of N requests to start a download cycle at the server, where we assume conservatively that each request is transmitted using a separate segment with MSS_C bytes. TCP typically starts with an initial window with the range $w_1 = 2, ..., 4$ (see RFC5681, implementations already use initial windows up to 10). Due to the initial slow start phase of TCP, after N sent and acknowledged requests the $cwnd$ has already increased to $W_C = w_{C1} + N > N$ (no delayed ACK). Thus, already after the first download cycle the client can not fill the available $cwdn$, and requires the adapted results derived in [10].

For the first request of the HTML base-page a single segment is sent. With probability p this segment is lost and an RTO will occur. The latency resulting from the retransmission including possible further RTOs has been derived in [9] and is given by $E\{Z^{TO}\}$, (18, [10]), thus the expected latency seen at the client side follows to be

$$T_{L0} = RTT + p \cdot E\{Z^{TO}\} \quad (4)$$

Next the latency seen at the client side for a cycle of N consecutively sent requests is derived. Since our focus is on IoT, we want to reduce the latency which is supported by choosing an initial $cwnd$ equal to the pipeline factor, e.g. $w_{C1} = N$. Furthermore, by setting $w_{C1} = W_{max} = N$, the analysis presented in [10] can be applied. This includes the loss of segments and most importantly, due to the small number of segments sent, the probability for a RTO is high, which results in high latencies. Furthermore, our models assume that the download cycle at the server side starts after the transmission of all N requests are successful, thus the important problem of the head-of-line blocking of requests is taken into account.

Due to the retransmission feature of TCP, at the end of each request cycle, the client will see a $cwdn$ whose utilization is limited to $W_{max} = N$ due to the pipeline factor. This enables us to consider each cycle of N client requests independent from other cycles. In summary, according to Eq.(3) using $d = N$, the latency for each request cycle can be calculated as

$$T_L(N) = E\{T_D(N)\}, N = 1, ..., N_{max} \quad (5)$$

It should be noted, that for $N = 1$ we get $T_L(1) = T_{L0}$.

2) Modelling of the server side - HTML base-page: Let us analyse the download time seen at the server side for the base-page independently from the download of embedded objects. Eq.(3) indicates the latency for the transmission of d segments. Similar to the approach used in [8], we assume that Eq.(3) can also be used to derive the delay for an average number of $d_0 = E\{F_0\}$ segments. With Eq.(3) and $E\{T_D(d_0)\} = T_S(F_0)$ we get

$$T_S(F_0) = E\{T_{SS}(d_0)\} + E\{T_{Loss}(d_0)\} + E\{T_{CA}(d_0)\} \quad (6)$$

Following [10], $E\{D_{SS}(d_0)\}$ segments can be transmitted before a loss terminates slow start and after loss recovery the remaining data $E\{D_{CA}(d_0)\} = \lfloor d_0 - E\{D_{SS}(d_0)\} \rfloor$ is sent using congestion avoidance. Especially for a small number of segments d_0, the congestion avoidance phase is omitted and we have $E\{D_{CA}(d_0)\} = 0$, i.e. no segment is left after slow start and TCP will remain in slow start with final average window given by $E\{W_{SS}(d_0)\}$. Furthermore, $E\{T_{CA}(d_0)\} = 0$ in Eq.(6). Otherwise, if $E\{D_{CA}(d_0)\} > 0$, we use $W_{CA}(p) = 1 + \sqrt{1 + \frac{8(1-p)}{3p}}$, which is the expected congestion window at time of loss event in congestion avoidance, see (13, [9]).

3) Modelling of the server side - embedded objects: The download of the embedded objects is analysed in the same way as done for the base-page taking into account the existing state of TCP. If $E\{D_{CA}(d_0)\} = 0$, we remain in slow start with an initial window set to $w_{S1} = E\{W_{SS}(d_0)\}$. On the other side, if $E\{D_{CA}(d_0)\} > 0$, we assume that TCP stays in congestion avoidance with $W_{CA}(p)$ given above. In the example shown in Fig.1, TCP starts in the first round in slow start with w_{S1} and later continues in congestion avoidance limited by the maximum window size W_{Smax}. Thus, the analytical model derived in [10] can be applied without changes.

Let us first consider the case, where all requests to embedded objects sent by the client are pipelined at once, i.e. $N = M$, which is shown in Fig.1. Since all objects can be considered as a single file of average size $D_{S_M} = M \cdot E\{F_s\}$, its segments can be sent continuously and the $cwdn$ at the server side determines the number of segments sent per RTT round. Using Eq.(1)-(3), the download time for D_{S_M} segments is given by

$$\begin{aligned} E\{T_D(D_{S_M})\} =& E\{T_{SS}(D_{S_M})\} + E\{T_{Loss}(D_{S_M})\} \\ &+ E\{T_{CA}(D_{S_M})\} \end{aligned} \quad (7)$$

It should be noted, that for $E\{D_{CA}(d_0)\} > 0$ the first two terms in Eq.(7) related to slow start are omitted. Furthermore, the related throughput can be approximated as

$$\gamma_S(D_{S_M}) = \frac{D_{S_M}}{E\{T_D(D_{S_M})\}} = \frac{W_S \cdot E\{R_S\}}{E\{T_D(D_{S_M})\}} = \frac{W_S}{RTT} \quad (8)$$

which also allows to derive the average window size, W_S, and the average number of used RTT rounds, $E\{R_S\}$.

For a pipeline factor $N < M$ the server will only continuously send blocks of N objects with size $E\{D_S(N)\} = N \cdot E\{F_s\}$ and wait for the next download until the next requests arrive, which is demonstrated in Fig.2 for $N = 2$. Thus, there are $I_S = \lceil M/N \rceil$ download cycles. Only to simplify the notation, let us restrict to use cases with $M = I_S \cdot N$. At the end of a download cycle, the downloaded file does not use the whole available $cwdn$. As a consequence, the analysis derived in [10] will underestimate the number of RTT rounds required for the download. This is demonstrated in Fig.2, where at the end of the first download cycle the available window is not used by 4 segments. This increases the total download time by one round (RTT), as can be seen by a comparison with Fig.1.

For $N = 1$ this effect has been solved approximately in [8], which we will generalize to arbitrary N. Although the different download cycles are separated by the latency due to request arrivals and some segments do not fill the window in the last round, this has only a small impact on the evolution of the average $cwdn$, since the transmission of the next data block continues with the final $cwdn$ of the preceding one. This allows to use, as approximation, the average $cwdn$ W_S derived for $E\{D_{S_M}\}$ segments transmitted as continuous stream.

Consequently, following [8], x segments are transferred in $\lceil x/W_S \rceil$ RTT rounds. Furthermore, let us assume that the number of segments of N objects with average size $E\{D_S(N)\}$ is distributed according to the density $f_{D_N}(x)$. Then, the average number of RTT rounds required for the download of N objects can be calculated as

$$\widehat{R}(D_N) = \int_0^\infty \left\lceil \frac{x}{W_S} \right\rceil f_{D_N}(x) dx. \quad (9)$$

The average latency seen at the server follows to be

$$T_S(D_N) = \widehat{R}(D_N) \cdot RTT, N = 1, ..., M-1. \quad (10)$$

Let us assume, that a single object is exponentially distributed with mean $F_S = E\{F_s\}$. Consequently, a block of N objects with average size $E\{D_S(N)\} = N \cdot F_S$ follows an Erlang-N distribution given as $f_{D_N}(x) = \frac{x^{N-1} e^{-x/F_s}}{(F_s)^N (N-1)!}$. This yields a solution of Eq.9 given as

$$\widehat{R}(D_N) = \sum_{i=0}^{\infty} e^{-\frac{iW_S}{F_S}} \sum_{k=0}^{N-1} \frac{(\frac{iW_S}{F_S})^k}{k!} \quad (11)$$

For the special case $N = 1$ we get in agreement with [8], a closed form solution given as

$$\widehat{R}(D_1) = \widehat{R}(F_S) = [1 - e^{-\frac{W_S}{F_S}}]^{-1} \quad (12)$$

C. Latency and throughput of HTTP/1.1 with pipelining

As represented in Fig.2, for $M = I_S \cdot N$ and $N = 1, ..., N_{max}$, the overall latency seen at the client for a download of a complete web-page, T_{PS}, can be estimated as

$$T_{PS}(N) = E\{L_h\} + T_{CL}(N) + T_{SL}(N) - (I_S + 1) \cdot RTT \quad (13)$$

where parts observed at the client and server are given as

$$\begin{aligned} T_{CL}(N) &= T_{L0} + I_S \cdot T_L(N) \\ T_{SL}(N) &= T_S(F_0) + I_S \cdot T_S(D_N) \end{aligned} \quad (14)$$

Since Eq.(13) describes the overall latency at the client side, each delay term evaluated at the server side is reduced by the RTT. This is due to the fact, that the first segment (last ACK) for a block of downloaded data at the server side overlaps with the last ACK (first request) send by the client side, as demonstrated in Fig.2. Neglecting TCP connection setup the throughput γ_{PS} is often characterized by an average window given as

$$W_{PS} = \frac{E\{PS\}}{(T_{PS} - E\{L_h\})} \cdot RTT = \gamma_{PS} \cdot RTT \qquad (15)$$

IV. Numerical results

In this section we analyse the impact of the pipelining factor N on the latency of HTTP/1.1. For our examples we chose an average request size of $MSS_C = 800$ bytes [4]. Some parameters for TCP usage in IoT are taken from [14]. We use $MSS = 1460$ bytes for the file downloads and for the TCP timeout event $T_0 = 1s$. Furthermore, the server side's TCP initial is $w_{S1} = 5$. For the HTML base-page we assume an average value of $E\{F_0\} = 5MSS$ as this is usually the index file with links to the embedded objects. Ohter TCP parameters are selected from [10], such as maximum window size $W_{Smax} = 32$, and $RTT = 0.1s$. From [15] two examples are selected. The average response size $E\{F_S\}$ is $8kB$ for the SVG example, and $20kB$ for JS. For both we assume that the number of objects in one page is $M = 12$. For JS the total size of the embedded objects is roughly given by $D_{S_M} = 170MSS$ (see Eq.(1)), which is 2.4 times larger compared to SVG.

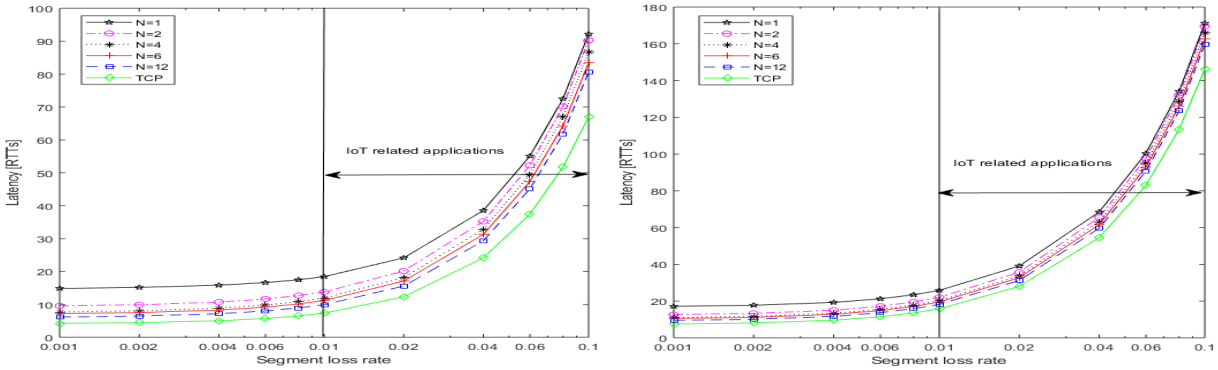
Figure 3 shows the latency to download the web-page seen at the client side normalized by the RTT. The latency is calculated by using Eq.(13), where the delay to download the embedded objects is given by (7) for $N = M$ and (10) for $N < M$. HTTP with $N = M = 12$ pipelined requests achieves a lower latency compared to the remaining scenarios. First we consider an example with a small loss rate of $p = 0.001$ for the SVG example shown in Fig. 3a. Compared to pipelining with $N = 12$, a pipeline factor of $N = 1$ increases the latency at min by 12 RTTs due to the additional requests. By neglecting the connection setup ($\sim$ RTT) the remaining latency does not increase proportionally to the 2.5 times larger web-page of JS, as shown in Fig. 3b. For the low loss rate and due to the small sized web-pages most of the segments are sent during the slow start and the $cwnd$ is restricted only by W_{Smax}. This increases the latency of JS by ~ 2 RTT which can be omitted using a larger W_{Smax}. In case of a high loss rate of $p = 0.1$, slow start already finishes after ~ 9 segments in both examples, thus the data transfer is controlled by congestion avoidance. The high loss rate is the cause of the large number of RTOs, which is the main reason for the drastic increase of the latency. For IoT solutions just looking at these results we can conclude that latency is lower with a higher pipeline factor. However, the issue of HOL blocking that was not taken into consideration presents a very big problem when implementing HTTP with pipelining. Comparing these latency results to other messaging protocols such as MQTT and CoAP [16] with which it is already possible to achieve very low latency without having to worry about HOL blocking, the improvement is not of a significant value.

Finally, it is important to compare the performance of HTTP with that of a simple TCP transmission, which is unaffected by any additional protocol overhead. The latency is again given by (14), where we set $I_S = 0$ and use the whole page-size $E\{PS\}$ instead of F_0. It should be noted, that the reduction by one RTT takes into account, that the TCP connection is initialized at the client side and the latency does not consider the last ACK sent back to the server, as represented in Fig.1. The negative effect of the overhead introduced by HTTP/1.1 strongly increases with decreasing pipelining factor, which shows a similar behaviour inside the range of considered loss rates. A further reduction seems only to be possible by introducing a server push service, which partially reduces the latency of the client initialized TCP connection. The usual applied methods of parallel TCP connections can also reduce the latency, but due to the limited resources of IoT devices, this seems too impractical.

Figure 4 shows the average window size in MSS, which is computed by using (15) and can be viewed as a normalized value of the throughput observable at the client side. Since the TCP connection setup time (see (2)) only depends on the loss rate, it is neglected in (15) to allow a comparison regarding the size of the web-page. As discussed above, in the range of small loss rates ($p = 0.001$), slow start dictates the throughput behaviour and again, with decreasing pipelining factor N, the throughput drops down considerably due to the additional latency introduced by the client requests. For higher loss rates congestion avoidance is increasingly responsible for the data transfer. In this area TCP's average window is approximately given by $\bar{W}_{TCP}(p) \approx 0.75 W_{CA}(p) \sim \sqrt{\frac{3}{2p}}$, [9], which explains the principle slope of the decreasing window observable for all pipelining factors. As example, for $p = 0.1$ we get independent of the size of the web-page $\bar{W}_{TCP}(p) \approx 3.9$, which is further reduced by the latency inserted by HTTP. In this loss area, as observable for both examples shown in Fig. 4, the performance of HTTP is dictated by the loss behaviour of TCP congestion avoidance and the effects of the pipelining factor vanishes. As expected, the exclusive use of TCP determines an upper bound for the achievable throughput.

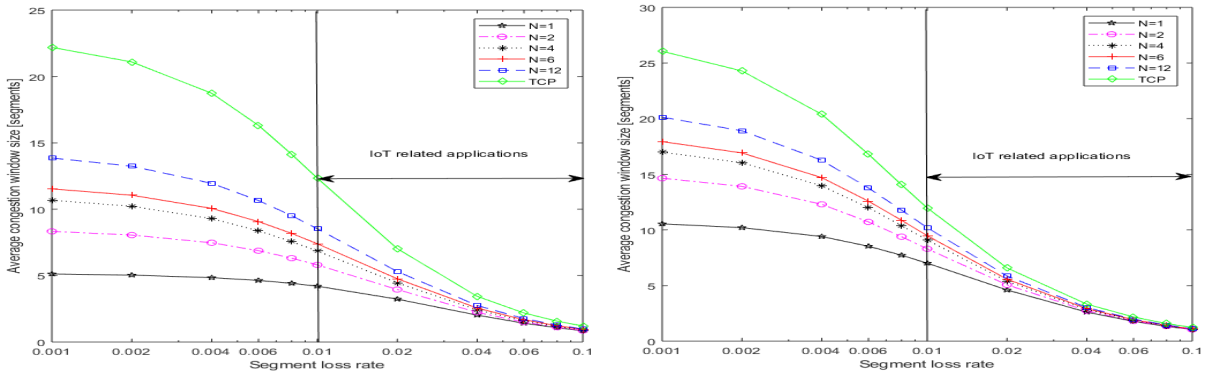
V. Conclusion

HTTP 1.1 as a messaging protocol in IoT comes with many problems. The most widely accepted model without pipelining with its utilization of TCP means that established connections are released on every access, and often it requires multiple connection establishments for communication to be completed. In IoT this kind of communication causes overhead and consumption of network resources, so we decided to analyse HTTP with pipelining. By using HTTP 1.1 with pipelining we have shown that the latency can be reduced and throughput improved.



(a) average response size = $8kB$ (b) average response size = $20kB$

Fig. 3: HTTP/1.1 latency depending on segment loss rate and pipelining factor.



(a) average response size = $8kB$ (b) average response size = $20kB$

Fig. 4: Average congestion window size depending on segment loss rate and pipelining factor.

But these improvement with pipelining comes with a set of other problems such as complex implementation and HOL blocking. With that in mind we think that the future research should be aimed at new messaging protocols and a new HTTP version, HTTP/2.0.

ACKNOWLEDGMENT

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Modelling an Energy-Efficient ZigBee (IEEE 802.15.4) Body Area Network in IoT-Based Smart Homes

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Abstract— The rapid growth of Wireless Sensor Networks and embedded devices as well as their implementation in the context of Smart Homes opens up many possibilities for development of new solutions. However, finding a quality, energy-efficient solution can be a very challenging task. In this paper, the proposed model of an energy efficient ZigBee Body Area Network is presented and tested through various simulations to explore and evaluate its performance in the context of IoT-Based Smart Homes with the goal of providing quality solutions in the fields of both BAN and eHealth.

Keywords— Body Area Network; BAN; ZigBee; Energy Efficiency; Home Sensing Environment; Smart Homes; IoT; Internet of Things; Wireless Sensor Network; WSN

I. Introduction

Due to massive development in the recent years in areas of Body Area Network (BAN) and Internet of Things (IoT), smart homes are becoming an effective solution and help in monitoring health of its users through wearable health trackers [1]. As the market of Smart Homes and IoT grows consistently and the medical field is considered one of many that can critically benefit from development of BAN technology, the research in this field is highly relevant. To ensure the optimal Quality of Service, it is necessary to explore and evaluate several objectives, such as decreasing energy consumption and prolonging battery life expectancy, fault detection, minimizing collision rate, increasing throughput, minimizing end-to-end delay and thus ensuring reliability [2]. Hence, Quality of Service is the capacity to support diverse Smart Home applications in healthcare with different priorities, performance and resource requirements in order to efficiently handle huge amounts of sensor data that the body sensor devices generate. In this paper, summary of the related works is followed by a proposed model of an energy efficient Body Area Network in an IoT-Based Smart Homes as it is well known that energy consumption has always been one of the critical challenges in Wireless Sensor Networks (WSN). The created model is then tested through various simulations in order to evaluate its performance in the context of IoT-Based Smart Homes. This is followed by conclusions and suggestions for future works. All the simulations are performed in OMNeT++ simulator.

II. Related research

There have been many proposed implementations and solutions for monitoring a person's health in a context of an IoT-based Smart Home using various wireless body sensors. Overview of Wireless Body Area Network in eHealth applications is given in [3], describing various efficient healthcare services providing monitoring and information in real time through smartphones and smart embedded sensors. Advances in embedded devices and wireless sensor networks made developing new, low-cost solutions for healthcare in Smart Homes a reality. Described in [4] is an IoT Smart health monitoring system of patients that couples body temperature sensor, pulse rate sensor, body position sensor, and ECG measuring sensor with an Arduino device controlled by an Android application. Another design is presented in [5] where a waist-mounted triaxial accelerometer unit is used to record human movement, allowing monitoring of physiological vital signs of a person while staying at home. In this case, sampled data are transmitted using an IEEE 802.15.4 wireless transceiver to a data logger unit. Another interesting example is described in [6], where monitoring living activity by using ambient and body sensors in network in Smart Home is specifically targeted at elderly. This is of relevance as the immense development of medicine causes the world's population to age rapidly. This combined with limited medical resources asks for new solutions in medical elderly care. Paper gives outlines of a feasible and deployable living activity monitoring model. Energy efficiency is a major issue in any wireless networks. From the side of energy-efficiency, the

focus is largely on the Medium Access Control (MAC) protocols. The importance of an energy-efficient MAC protocol in any wireless network is reviewed in [7]. In [8] the impact of MAC protocols on energy consumption is simulated. Some of the many proposed solutions are SMAC [9], E^{2}MAC [10], ES-MAC [11], I-MAC [12], or AEEMAC [13]. Some concentrate on specific issues, like large scale WSN [14], or low traffic [15]. Finally, [16] gives a survey of energy efficiency of Medium Access Control (MAC) protocols for Wireless Body Area Sensor Networks (WBASNs) along with their advantages and limitations in context of WBASNs.

III. Model proposed

The goal is to create a model which could be used to simulate various scenarios with the goal of evaluating quality of service in Body Area Networks. For this, a custom path loss map will be used as well as custom defined temporal variation of the wireless channel. Details of both are described in the following chapter. In all scenarios, all the nodes send packets to a sink or hub node (node 0) at a constant rate. It is well known that the Medium Access Control (MAC) layer provides flow control for the transmission medium (i.e. physical link). In this case, ZigBeeMAC (IEEE 802.15.4 MAC) is used. ZigBee is a wireless network standard with low data-rate low power and low cost radios. Lately, ZigBee devices are getting more attention as it has varied applications in the domain of Internet of Things (IoT) [17].

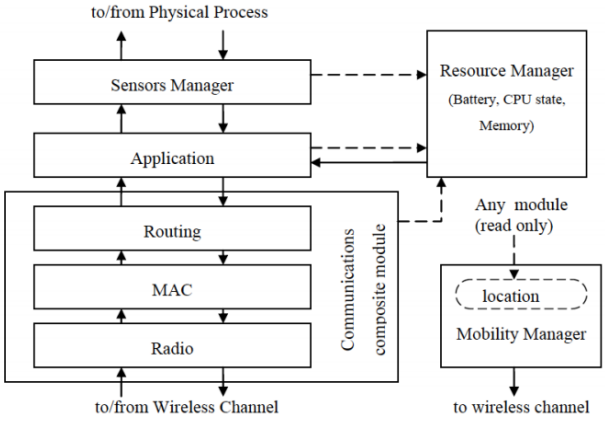

Figure 1. Architecture of nodes in OMNeT++ [18]

The architecture of the nodes is defined as in Figure 1. Network consists of the sink node, as well as five sending nodes. Placement of the nodes is as following: node 0 is placed on the right hip, node 1 is placed on the left wrist, node 2 on the right wrist, node 3 on the left ankle, node 4 on the right ankle and node 5 on the chest. This is shown in Figure 2. In this way, only node 0 would communicate further with other potential objects in a larger monitoring system (Smart Home) or upload data to the cloud. Nodes are static and all simulations last for 50 seconds.

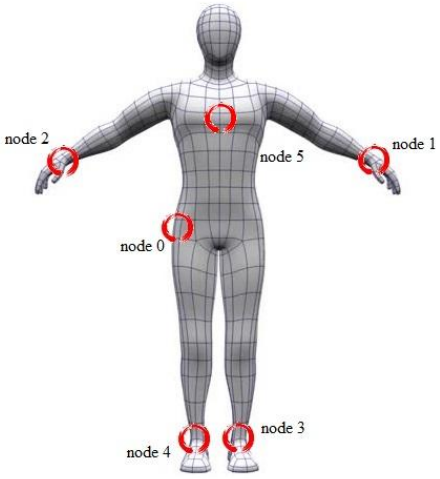

Figure 2. Position of nodes

IV. Simulations and results

All simulations were performed in a discrete event simulator OMNeT++ [18]. OMNeT++ is an extensible, modular, component-based C++ simulation library and framework, primarily for building network simulators. It can be used to test distributed algorithms and/or protocols in realistic wireless channel and radio models, with a realistic node behavior, to evaluate different platform characteristics for specific applications, and to simulate a wide range of platforms.

First simulations show how ZigBee performs when the Guaranteed Time Slot (GTS) functionality is turned on and off as well as when the wireless channel exhibits temporal pathloss variation and when it does not. This gives us four different scenarios. GTS is a TDMA-based scheme that 802.15.4 is using [19]. Guaranteed Time Slots are assigned to devices in the network which lets the devices send their data anytime they want instead of using CSMA/CA mechanism. In this particular scenario, with GTS on, each round has 16 slots, and each of the five nodes is requesting and receiving three slots (thus 15 slots in total are devoted to it). The remaining slot is always the first slot after the beacon, and is using a contention based scheme. When GTS is off then all 16 slots are using contention-based access. Temporal pathloss variation represents signal variations within different environments [20] and is used to provide a more comprehensive representation of path loss within the different channels and their relation to the environment. In all four scenarios, the rate of the nodes sending packets is varied and each scenario is run with five different seed sets in order to reach representative and conclusive results. The

results of the simulation, packets received per node, are pictured in Figure 3 below.

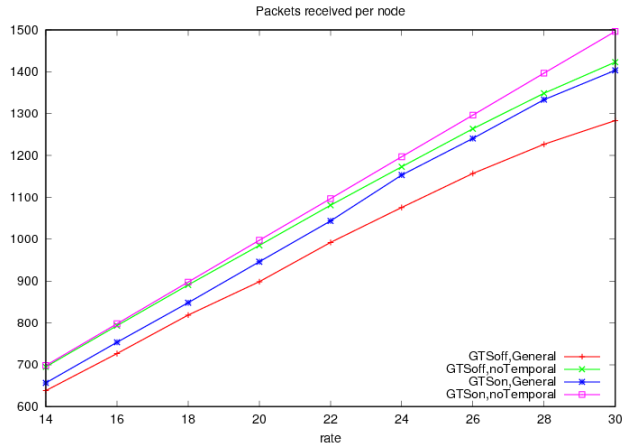

Figure 3. Packets received per node

The X axis shows sending rate for each node measured in packets/sec while the Y axis shows the average number of packets received by the sink node (node 0) per each of the sending nodes. The time of the simulation is 50 seconds. This means, in the ideal case scenario, there would be 1500 packets received for the 30 packets/sec case. It is interesting to note that for any traffic, e.g. for low-traffic (16 packets/sec), GTS on and no temporal pathloss variation in the wireless channel, the curve reaches the maximum possible value, 800 and shows no losses. Furthermore, the protocol generally has better performance with GTS turned on, which is to be expected as TDMA schemes make a more efficient use of the wireless medium and reduce interference [21]. It is also visible that the performance is superior without the temporal variation of the channel. This is also not surprising as the temporal variation causes deep fades that break the connectivity between the sink node and the nodes sending the packets [22]. Finally, observe as the traffic rate increases, early indications of saturation appear. This is most visible in the case of GTSoff General. Complementary to Figure 3, Figure 4 shows total loss rate of packets.

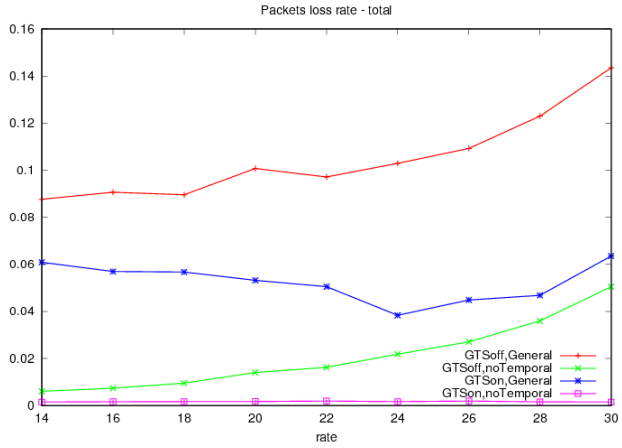

Figure 4. Packets loss rate

The X axis again shows sending rate for each node measured in packets/sec while the Y axis shows the percentage of packets lost per each of the sending nodes. It is easily visible the results correspond with the previous Figure 1, showing no losses for the case where GTS is on and the wireless channel exhibits no temporal pathloss variation. As expected, in the opposite scenario (GTS off and wireless channel exhibiting temporal pathloss variation), the losses are almost up to 15%, more than any other case. Furthermore, as the traffic rate increases, the early indications of saturation from the previous graph are here visible as well since the curves are starting to grow exponentially. As mentioned, the scenarios are run for five seed test so the confidence level of calculation is quite high. However, as the previous figures show average results for all nodes, it would be useful to also see the variability of the results. The following Figure 5 shows the variability of all the scenarios for packets loss rate (as it is more clear than the graph for the packets received).

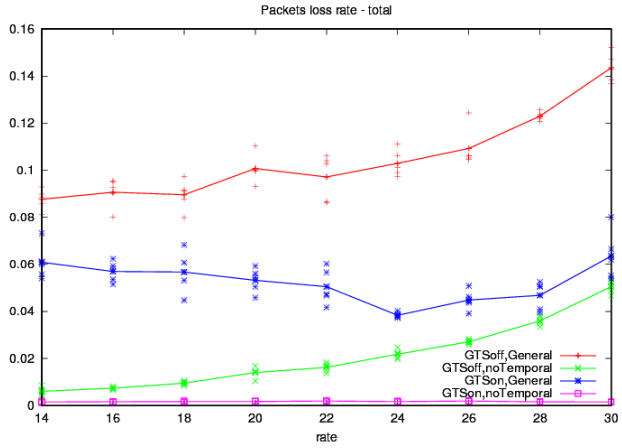

Figure 5. Variability in packets lost

We can see some reasonable variability. Each point represents a result from an individual seed but also from an individual node. As defined in the model, all the sending nodes have different path losses to the hub and thus are expected to have different performance. It would be logical for this to be especially impactful in both of the scenarios where there's a wireless channel with temporal variation and these path losses differences would manifest themselves as different probabilities of link outages. Indeed, the results show that the variability has highest range when the temporal variation in the wireless channel is present. As the losses are more significant when there's temporal variability, it would be interesting to see the reasons for packet drops in these cases. Thus, Figure 6 shows breakdown of packets sent on MAC level.

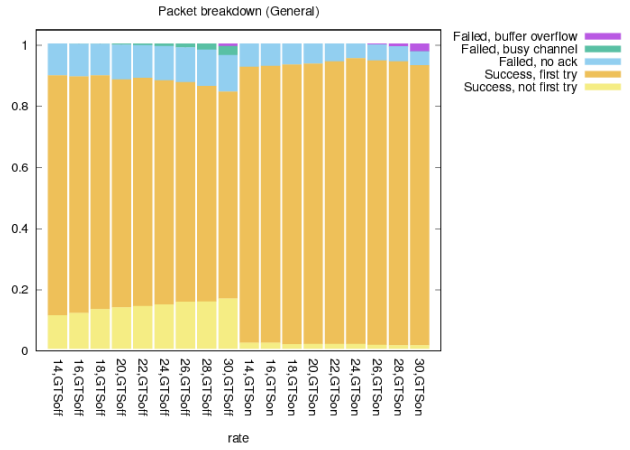

Figure 6. Breakdown of sent packets on MAC level

In Figure 6, the X axis shows rate of sending packets in packets/sec, first for the scenario when GTS is off and then when it is on. The Y axis shows the percentage of packets. First, it is clear to see that a large portion of packets for the first case (up to 40%) have needed to be resent. About half of them, up to 20%, have been received successfully upon resending while others have failed, mainly due to lack of ACK signal (a direct result of the deep fades in the channel and loss of connectivity), but also due to channel being busy. This is obviously not an issue when GTS is used since there is no contention between the nodes. Such high resend rate makes GTS off option nonviable as it causes delays and lowers the performance while wasting energy. Thus, taking only scenarios with GTS on into consideration, in Figure 5 is shown the breakdown of packets received at the radio layer by the sink node (node 0).

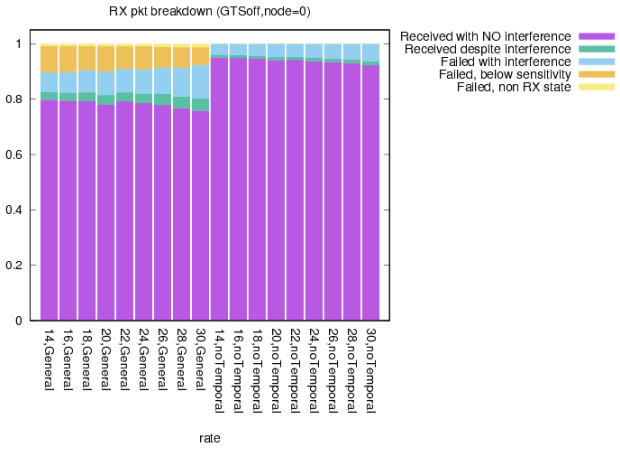

Figure 7. Breakdown of packets received on radio level

The presumed reason for packets failing due to lack of an ACK signal were the deep fades in the channel and loss of connectivity. Figure 7 confirms this as there is a portion of packets lost due to lack of sensitivity (very low received signal) in the case of wireless channel with temporal variability, while this category doesn't exist in the opposite case. The number of packets failed due to interference is slightly higher with the temporal variability, which is to be expected. In a real-life scenario, temporal variability will obviously have an impact. Also, as previously shown, GTS gives us better performance with higher energy efficiency due to lower rate of resends. Thus, the scenario which would be optimal to model and analyze the ZigBee network with real-world accuracy would be the one with both GTS and temporal variability. In other protocols, e.g. SMAC it cannot be guaranteed whether the time of transmitting packets after adaptive listening is long enough. This could lead to collision of data which would negatively affect both performance and energy efficiency (due to high rate of resending). In a IoT WBAN, we must presume sensed information is collected and sent with high frequency and among many devices. As such, any drop in rate of successfully sent packets lowers the energy efficiency. ZigBee is an energy efficient, low energy solution with high reliability due to guaranteed time slots. This is the reason why it proves to be the prefered in varied applications in the domain of Internet of Things.

V. Conclusion

Body Area Networks are impacting eHealth and Smart Homes through wearable sensors, and its significance is vital in context of Internet of Things (IoT). As such, many fields can benefit from BAN relevant research. Energy efficiency is a major issue in any wireless networks. Medium access control (MAC) protocols play an important role in providing a fair and efficient allocation of the available bandwidth. Although a lot of research has been conducted on MAC protocols, the issues still remain. The

proposed model consists of six ZigBee sensors, including the sink node, which are placed strategically on human body. Next, several scenarios were explored and evaluated. The five seed sets ensure high confidence levels in the results. Variability, as well as breakdown of packets on both MAC and radio level was examined. The importance of Guaranteed Time Slots in ZigBee sensors was proven to be crucial in acquiring necessary Quality of Service (QoS). The impact of temporal pathloss variation in wireless channel represents signal variations within different environments and is used to provide a more comprehensive representation of path loss within the different channels and their relation to the environment. This serves as a realistic image of evaluation of Body Area Network and is going to serve for future research where ZigBee MAC layer and its protocols will be further explored.

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Energy efficiency of Machine-to-Machine protocols

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***Abstract*—The paper provides a comparison of energy consumption for a few commonly used M2M protocols, used on energy constrained devices in M2M communication systems. It was implemented on Arduino hardware platform. Energy consumption for each protocol is measured on boards with both Ethernet and WiFi communication modules. Servers with which Arduino is communicating are all implemented on a Raspberry Pi, which also serves as an M2M gateway. Traffic is captured for each protocol on both wired and wireless interface and compared to energy consumption.**

Keywords—Arduino, M2M, energy consumption, Raspberry Pi, HTTP, CoAP, MQTT

I. INTRODUCTION

Machine-to-Machine (M2M) communication is considered as one of the most demanding, but promising technologies for implementation of new generation of networks. M2M communications are typically characterized by connecting a large number of autonomous devices to other devices in both wireless and wired systems. These devices communicate with a central controller or with each other without human intervention. Many of these devices do not have unlimited energy supply, they are battery-powered and therefore, energy efficiency is an important factor in M2M systems.

Energy efficiency is defined as ratio of useful energy used for work out of total energy available from energy sources. The goal is to achieve maximal energy output with minimal energy waste and potentially negative effect on the environment.

One of the most common applications of M2M communication is a smart home system. These systems have wired and wireless devices connected to it, depending on the device function and location. Some of these devices have to have their own power source and on a home network with good signal strength, most of the power consumption is due to the efficiency of the device itself and efficiency of the running program. As there are many M2M protocols that can be implemented to run on such devices we take a look at performance of a few of these protocols implemented on an Arduino hardware platform. Protocols which are analyzed are Hypertext Transfer Protocol (HTTP) [1], Message Queuing Telemetry Transport (MQTT) [2] and Constrained Application Protocol (CoAP) [3].

II. RELATED WORK

In [4] the most important messaging technologies proposed as the foundation of the next generation of Internet of Things (IoT) and more specifically the Industrial Internet applications are reviewed. An understanding of both the architecture and the message/data sharing requirements of each target system is an important pre-requisite for choosing the most appropriate messaging solution.

Similarly [5] presents the most representative application layer protocols that have gained attention for IoT, while providing a comparison among each other and argue about their suitability for the future of the IoT.

The architecture proposed in [6] consists of the IoT Home Gateway for aggregating data from devices, the Web Based Service Definition Engine for defining the user's required services and the IoT Service Platform for executing the service via the aggregated data and the user's defined services. The proposed IoT Home Gateway provides device management to remove heterogeneity of various devices, the Auto-configuration for dynamic device discovery and the device information exposure to provide required information to third-party and other IoT service platforms. Also it supports discovery of constrained devices such as Arduino by the Auto-configuration mechanism. As a result, we showed implementation results that control various devices according to home energy saving scenario.

The paper [7] proposes an energy consumption model for energy constrained devices in Machine-to-Machine communication system. The model specifies generic tasks that are executed on M2M devices. It was implemented on devices on Waspmote and Arduino hardware platforms. Power consumption was calculated for the states of the proposed model. The model with calculated consumption values is applicable for testing algorithms and techniques for achieving higher energy efficiency. Furthermore, the paper presents a basic operating cycle in which tasks from the specified model are executed on M2M devices and M2M gateway in an energy efficient way. Energy consumption during 24 hours by using the suggested operating cycle is compared on Arduino and Waspmote hardware platforms.

III. IoT Application Protocols

A. HTTP Protocol

Hypertext Transfer Protocol (HTTP) is a connectionless client/server protocol ubiquitous in IT and the web. Because there are countless open source tools that use HTTP, and every coding language has HTTP libraries, it is very accessible. The focus on HTTP in IoT is around Representational State Transfer (REST), which is a stateless model where clients can access resources on the server via requests. In most cases, a resource is a device and the data that a device contains. HTTP provides a transport, but doesn't define the presentation of the data. As such, HTTP requests can contain HTML, JavaScript, JavaScript Object Notation (JSON), XML, and others. In most cases, IoT is standardizing around JSON over HTTP.

HTTP communication is usually established over TCP/IP connections. HTTP can be also established other protocol, such as unreliable UDP [1].

B. MQTT Protocol

Message Queue Telemetry Transport (MQTT) protocol is an application layer protocol designed for resource-constrained devices. It uses a topic-based publish-subscribe architecture. This means that when a client publishes a message M to a particular topic T, then all the clients subscribed to topic T will receive the message M. Like HTTP, MQTT relies on TCP and IP as its underlying protocols. However, compared to HTTP, MQTT is designed to have a lower protocol overhead.

The reliability of messages in MQTT is taken care by three Quality of Service (QoS) levels. QoS level 0 means that a message is delivered at most once and no acknowledgments of reception is required. QoS level 1 means that every message is delivered at least once and confirmation of message reception is required. In QoS level 2, a four-way handshake mechanism is used for delivery of a message exactly once [2].

C. CoAP Protocol

Constrained Application Protocol (CoAP) is a recently developed application layer protocol intended to be used in the communication of resource-constrained devices. This protocol is based on REST architecture and supports request-response model like HTTP. In addition to request-response model, CoAP also supports publish-subscribe architecture using an extended GET method. Unlike MQTT, the publish-subscribe model of CoAP uses Universal Resource Identifier (URI) instead of topics. This means that subscribers will subscribe to a particular resource indicated by the URI U. When a publisher publishes data D to the URI U, then all the subscribers are notified about the new value as indicated in D.

The major difference between CoAP compared to MQTT and HTTP is that CoAP runs on top of the UDP while the latter run on top of TCP. As UDP is inherently not reliable, CoAP provides its own reliability mechanism. This is accomplished with the use of "confirmable messages" and "non-confirmable messages". Confirmable messages require an acknowledgement while non-confirmable messages do not need an acknowledgement [3].

IV. Measurement Model

Measurement model specifies a simple task executed on M2M device that is the same for each protocol measured. The goal is to achieve minimum energy consumption for the same amount of usable data sent.

Measurement model defines two types of devices: peripheral device and central device. Peripheral device is a device which collects data from its environment by using one or more sensors. Peripheral devices usually have limited source of energy and their energy consumption should be as low as possible. Device which collects data from peripheral devices is called central device. Peripheral device periodically sends the message to the central device and then waits in powered mode for the timer to expire.

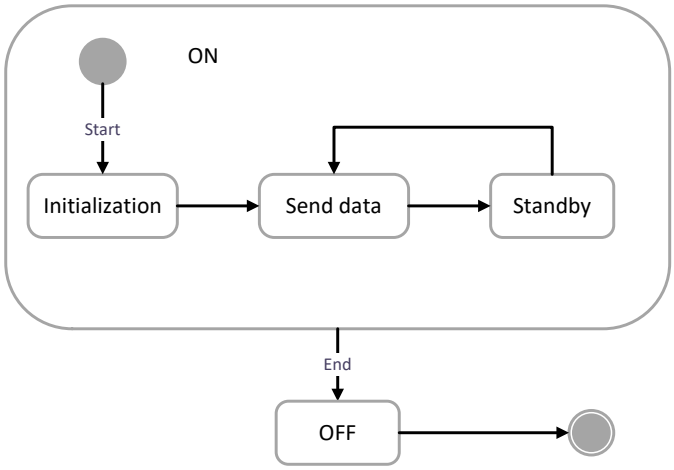

Figure 1 Peripheral device state diagram

In this measurement models all protocols are configured to use features of the protocols which ensure minimal data loss.

For HTTP the POST method is used to communicate with the central device and the response is always status code 204. Similarly to HTTP, method PUT is used in CoAP communication with response status code 2.05. The request and response messages for both protocols can be represented by a sequence diagram in Figure 2.

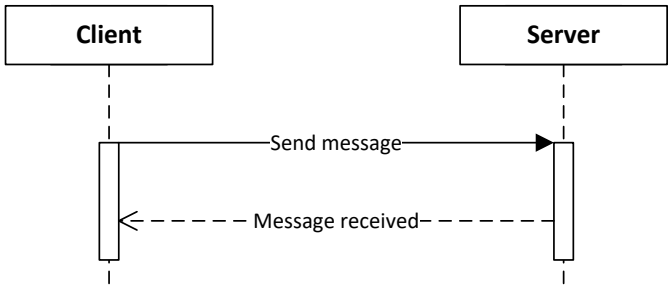

Figure 2 HTTP and CoAP message received acknowledgment

The messages received and sent on server side are shown in Figure 3 for HTTP and Figure 4 for CoAP.

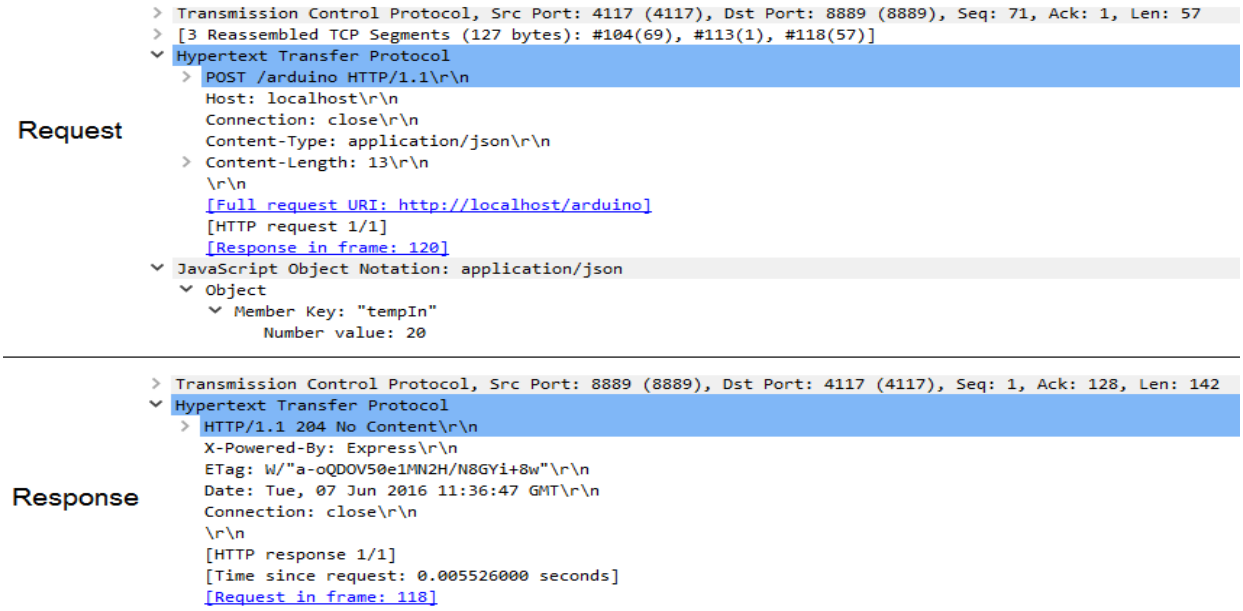

Figure 3 HTTP POST request and response

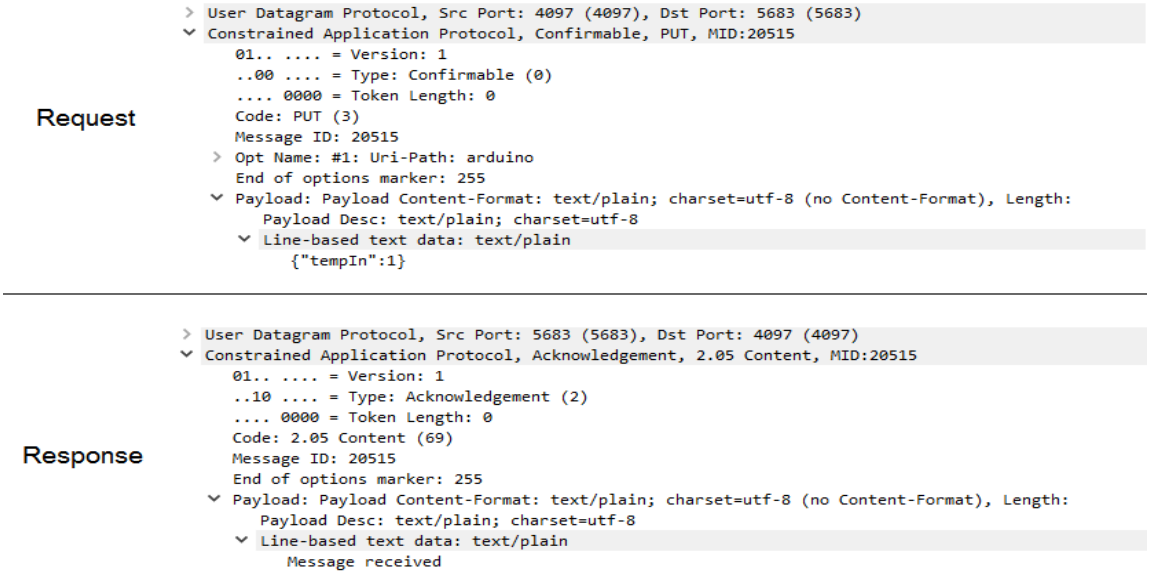

Figure 4 CoAP PUT request and response

As MQTT functions as a pub/sub model the response depends on the Qos specified, in this case it is Qos-1. As mentioned in Section III. and shown in Figure 5. the response to published message comes when all clients have received the message at least once. These messages are shown in Figure 6.

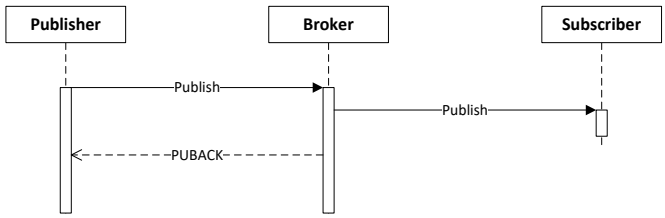

Figure 5 MQTT message delivered acknowledgment

Publish

```
> Transmission Control Protocol, Src Port: 50684 (50684), Dst Port: 1884 (1884), Seq: 1, Ack: 1, Len: 23
v Data (23 bytes)
    Data: 3415000761726475696e6f00037b74656d70496e3a317d
    [Length: 23]

0000  b8 27 eb b9 13 6e e8 99  c4 9d 60 33 08 00 45 00   .'...n.. ..`3..E.
0010  00 4b 4a d3 40 00 40 06  66 0d c0 a8 04 30 c0 a8   .KJ.@.@. f....0..
0020  04 4c c5 fc 07 5c 2e 9d  2f 30 df 13 b1 f8 80 18   .L...\.. /0......
0030  05 59 90 3e 00 00 01 01  08 0a 05 bc 68 5c 00 0a   .Y.>.... ....h\..
0040  74 81 34 15 00 07 61 72  64 75 69 6e 6f 00 03 7b   t.4...ar duino..{
0050  74 65 6d 70 49 6e 3a 31  7d                       tempIn:1 }
```

PUBACK

```
> Transmission Control Protocol, Src Port: 50684 (50684), Dst Port: 1884 (1884), Seq: 24, Ack: 24, Len: 4
v Data (4 bytes)
    Data: 40020001
    [Length: 4]

0000  b8 27 eb b9 13 6e e8 99  c4 9d 60 33 08 00 45 00   .'...n.. ..`3..E.
0010  00 38 4a d5 40 00 40 06  66 1e c0 a8 04 30 c0 a8   .8J.@.@. f....0..
0020  04 4c c5 fc 07 5c 2e 9d  2f 47 df 13 b2 0f 80 18   .L...\.. /G......
0030  05 59 04 58 00 00 01 01  08 0a 05 bc 68 64 00 0a   .Y.X.... ....hd..
0040  78 a5 40 02 00 01                                 x.@...
```

Figure 6 MQTT message delivered acknowledgment

V. PROTOCOL ENERGY CONSUMPTION COMPARISON

This section describes the measurement process for models shown in Figure 1.

The server for all protocols is run on a Raspberry Pi 3 device, which runs a Node.js application that implements HTTP API, MQTT broker and CoAP server. Wireshark is also run to help us identify the time frames when the client is sending messages.

The client for each protocol is implemented on an Arduino Uno hardware platform, with either WiFi or Ethernet Shield.

On Arduino we run a program specified in our model, therefore after initialization the device can be in either of two states shown in Figure 1.

Figure 7 shows our measurement setup.

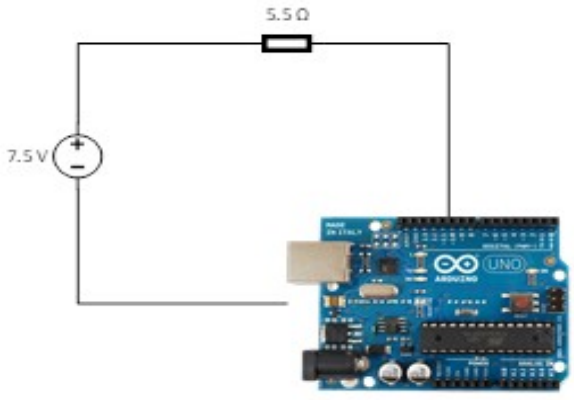

Figure 7 Measurement power circuit

Total amount of energy consumed by the device in a certain time *t* can be calculated by using the following expression:

$$E = P_D \times t \tag{1}$$

Where P_D is the power of the device which can be calculated by using the expression:

$$P_D = U_D \times I_D \tag{2}$$

Where U_D is the voltage on the device which can easily be measured by using an oscilloscope, while I_D is the current which can be calculated by using Ohms law:

$$U = I \times R \tag{3}$$

In order to see the amount of energy consumed in each state for each protocol of the model proposed in Section IV, a measurement needs to be conducted for each variation. Based on this information, the exact amount of energy which can be saved by using different protocols and/or connection interfaces. Arduino is connected to a constant 7.5V power supply to provide a more stable power input. For our measurement, we had at our disposal an oscilloscope Rigol DS1102D.

Since we are unable to measure the current on the device by using an oscilloscope, we used a known resistance which was connected with our device in a power circuit so that the current passing through the resistor is the same as the current passing through the Arduino device (serial connection). Our power circuit is shown in Figure 5 and Figure 6. We used a resistor with impedance of 5.5 Ω and precision tolerance of 1%.

In the serial connection of the Arduino device and a resistor with known impedance, Kirchoffs voltage law can be applied:

$$U_{total} - U_R - U_D = 0 \quad (4)$$

By using the expressions 3 and 4 we get the equasion:

$$U_{total} = U_R + U_D = I_R \times R_R = I_D \times R_D \quad (5)$$

Since in serial connection we can assimilate the current going through all the elements, we have:

$$I_{total} = I_R = I_D \quad (6)$$

By measuring voltage U_R on the resistor with the oscilloscope, we can easily calculate the current on the known resistor which is equal to the current on the device:

$$I_D = U_R / R_R \quad (7)$$

To help us identify the time frames when Arduino is sending packages we compare measured voltages to the time when the packages are captured on the server. We use U_{base} as an average voltage when the device is in standby state and U_{avg} as the average voltage when Arduino is sending packages. Both values are calculated in designated time period by using the equation:

$$U_{avg} = \frac{1}{T}\int_0^T u(t)\,dt \quad (8)$$

VI. RESULTS

As shown in Figure 1, average power consumption of a certain protocol is calculated for both states and on both interfaces and shown in Tables 1 and 2 and Figures 3 and 4. The data is collected and averaged over 25 cycles. A cycle is a transition between states, described in Figure 1, and lasts 5 seconds.

TABLE I. ETHERNET POWER CONSUMPTION

Protocol	State	
	Send data	***Standby***
CoAP	1338 mW	1293 mW
HTTP	1333 mW	1287 mW
MQTT	1347 mW	1297 mW

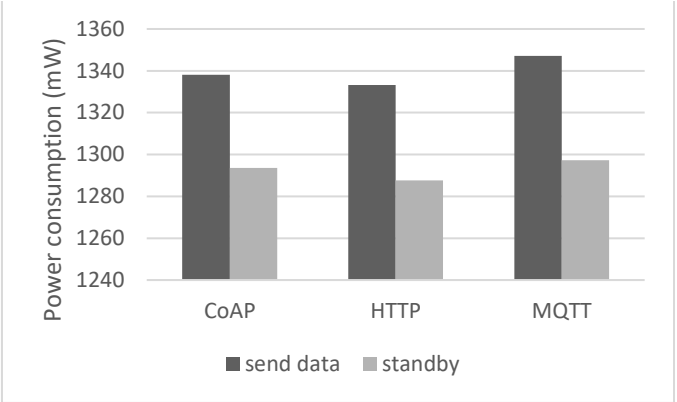

Figure 8 Ethernet power consumption

TABLE II. WIFI POWER CONSUMPTION

Protocol	State	
	Send data	***Standby***
CoAP	987 mW	934 mW
HTTP	1037 mW	985 mW
MQTT	988 mW	940 mW

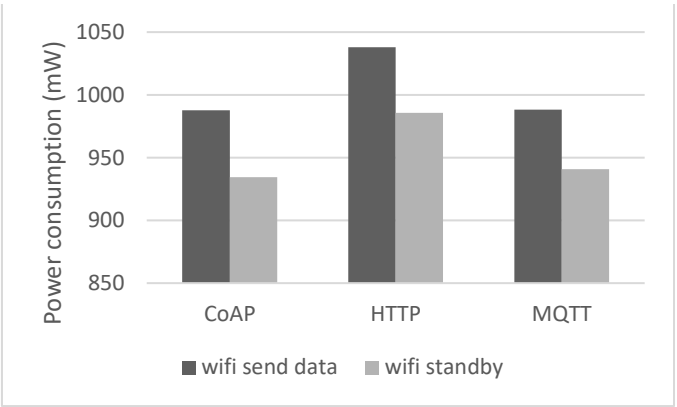

Figure 9 WiFi power consumption

We see from these results that Arduino with Ethernet Shield draws more power than WiFi shield. Furthermore, the difference in power consumption between states is also greater on Ethernet. On average, all protocols consume similar amount of power (within a margin of error) on Ethernet, while on WiFi HTTP consumes about 50 mW more power while either state.

Energy consumption of protocols on an Arduino device with Ethernet or WiFi Shield is presented in Table 3 and Figure 5.

TABLE III. ENERGY CONSUMPTION

Protocol	Interface	
	Ethernet	***WiFi***
CoAP	26,7 mWh	19,7 mWh
HTTP	53,3 mWh	41,5 mWh
MQTT	26,9 mWh	19,7 mWh

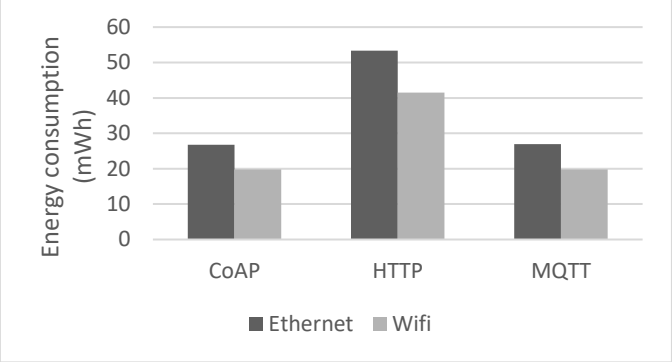

Figure 10 Energy consumption

From the results it can be seen that all protocols consume more energy when they are sending data via Ethernet interface. While CoAP and MQTT both consume almost equal amounts of energy, HTTP consumes two times as much. This is due to larger headers that HTTP has compared to CoAP or MQTT, which results in more packages sent and received, i.e. power is consumed over a longer period.

CONCLUSION AND FUTURE WORK

Energy efficiency is an important aspect which needs to be taken into consideration while designing M2M systems with devices that do not have unlimited power supply. We proposed a basic model for M2M devices and M2M gateways which specifies a generic task executed on devices. This model is used to measure energy consumption of protocols HTTP, CoAP and MQTT.

As shown in our results in Section V. protocols CoAP and MQTT preformed significantly better than HTTP. It is not surprising as CoAP and MQTT were designed as lightweight protocols to be used specifically in IoT, unlike HTTP. Our results also show that both CoAP and MQTT consume almost equal amounts of energy for sending data. While there are many energy efficient protocols that can be used in M2M protocols, an understanding of both the architecture and the message/data sharing requirements of each target system is an important pre-requisite for choosing the most appropriate messaging solution.

There are a lot of ways to expand on this work. Firstly we could include other protocols like Advanced Message Queuing Protocol (AMQP), Extensible Messaging and Presence Protocol (XMPP), Data Distribution Service (DDS) and Java Message Service (JMS), mentioned in [4] and [5]. In this work we only presented energy consumption of an Arduino Uno device when it is sending messages to a server. The device can also be set to receive packages rather than only sending them, or a combination of both. As described in [7] we could also do our measurements on different devices, not just Arduino.

ACKNOWLEDGMENT

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Mobility Management for Internet of Things Environments

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***Abstract*—Most standard mobility management protocols such as IETF Mobile IP and its variants are not suitable for Internet of Things (IoT) environments with constrained device and network characteristics. This article presents a reliable mobility management mechanism for IoT environments, called CoMP, which is based on IETF CoAP. More specifically, it extends the CON message of the CoAP protocol to reliably transmit the signaling message under unreliable IoT network environment. In addition, CoMP utilizes a separate location management server for keeping track of the changing IP addresses of the mobile sensor nodes, without using tunneling scheme. The architecture and algorithm to achieve both reliability and simplicity for IoT mobility management are proposed. Finally, performance has been evaluated by both mathematical analysis and simulation.**

***Key Words*—Reliable Mobility Management, Handover for IoT Networks, CoAP Mobility**

I. Introduction

In recent years, the Internet of Things (IoT) technology has been being increasingly applied to diverse application areas including healthcare monitoring, disaster management, vehicular management, and so on. In IoT, most of the objects are mobile, and may thus require IP mobility management, maintaining the IP connectivity. Unfortunately, most of standard mobility management protocols such as IETF Mobile IPv6 (MIPv6) [1] and its variants such as HMIPv6 [2], PMIPv6 [3], and NEMO [4] are not suitable for IoT environments. This is because the IoT environments are usually comprised of constrained devices with limited power, which are interconnected to each other over unreliable wireless networks.

The most standard mobility management protocols have high signaling overhead due to tunneling and binding operations, and are quite complex, thereby incurring high processing overhead as discussed by Khan [5]. The signaling and processing overhead can result in large power consumption during movement of power-constrained IoT sensor nodes. Furthermore, these standard mobility management protocols do not address the characteristics of a constrained IP network, such as a limitation in packet size, high packet loss ratio, and sleep mode operation. Ahmad et.al [6] recently proposed power aware mobility management scheme for IoT communication. However, their work has focused on optimal selection of an access point of the next available network by considering the energy consumption of a particular application during handover. However, they did not consider the high energy consumption due to the signaling and processing overhead during handover operation.

Under unreliable constrained wireless network of the IoT environments, the loss of the signaling message may frequently occur [7]. The MIPv6 and its variants do not take into this situation. Consequently, as a constrained device or node moves around different wireless networks, its IP connectivity may be quite often disrupted, and the power can be drained rapidly. This may result in the loss of important sensing data, or delay of time-critical data in new IoT application service such as healthcare monitoring and disaster management [8].

The IETF CoRE WG has defined a REST-based Web transfer protocol, the Constrained Application Protocol (CoAP) for introducing the Web service paradigm into networks for smart objects [9]. CoAP makes it easy to integrate physical devices with contents on the Web, while satisfying requirements, such as multicast support, low signaling overhead, and simplicity for constrained environments.

In this article, in order to solve the problems mentioned above, we propose a reliable mobility management mechanism for IoT environments, called CoMP, which is based on IETF CoAP. In the reference [10], we presented a mobility management architecture using CoAP in IoT environments. The architecture and procedures for seamless mobility management for mobile CoAP sensor nodes have been proposed. In this article, we have extended the work in [10], proposing the reliable IP mobility management scheme. More specifically, the retransmission mechanism of CoAP is utilized so that the handover latency can be dramatically reduced in case of the packet loss of the signaling message for the time-critical applications such as healthcare or disaster recovery services.

CoMP extends the CoAP message formats to provide the IP mobility management. More specifically, it extends the CON message of the CoAP protocol to reliably transmit the signaling message under unreliable IoT network environment. In addition, CoMP utilizes a separate location management server for keeping track of the changing IP addresses of the mobile sensor nodes, without using tunneling scheme. The usage of application layer signaling protocol, i.e., CoAP, separate location management server, and no tunneling makes the mobility management architecture to be very simplified. Furthermore, the reliable message handling mechanism of CoAP can maintain the IP connectivity under unreliable IoT environments.

Comparing with other related works, the originality of our approaches is as follows. The proposed mobility management protocol at application layer, called CoAP-based Mobility Management Protocol (CoMP), uses a separate location management function, which is based on CoAP. The high reliable mobility management scheme with low signaling overhead can be obtained due to simplicity of the mobility management architecture. CoMP runs in the application layer so it does not affect the lower layers, and it also has very low signaling overhead compared with other protocols, such as MIPv6 and its variants. To the best of our knowledge, there

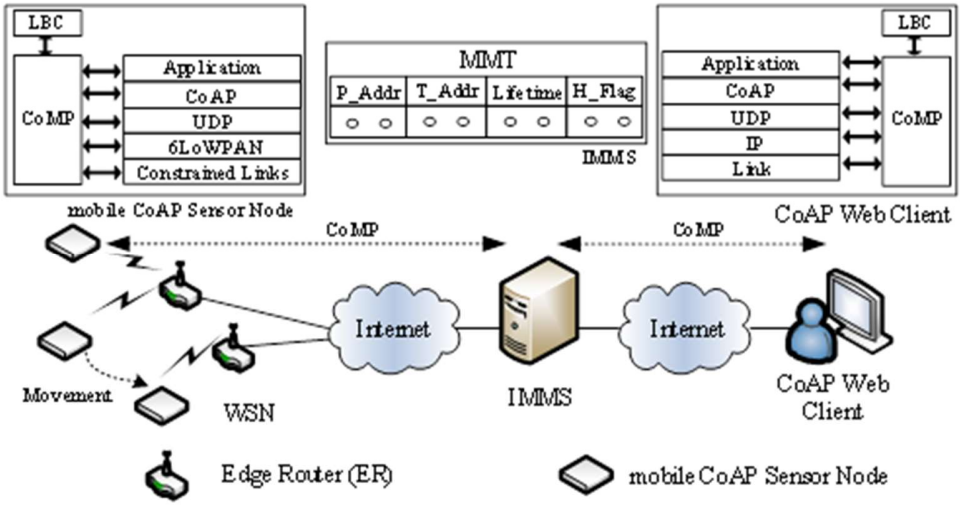

Figure 1. Reliable mobility management architecture using CoMP

have been no previous research attempts at providing reliable IP mobility functionality using CoAP in IoT environments. The architecture and algorithm to achieve both reliability and simplicity for IoT mobility management are described subsequently. Finally, performance has been evaluated by both mathematical analysis and simulation. In particular, the retransmission model for supporting the reliable mobility management has been investigated in detail.

II. Reliable Mobility Management

In this section, we describe a reliable mobility management architecture. We also describe the detailed signaling procedure for the reliable mobility management.

A. Architecture for Reliable Mobility Management

In Fig. 1, we show the reliable mobility management architecture. The components of the architecture consist of the mobile constrained sensor node (mCSN), IoT Mobility Management Server (IMMS), and CoAP Web Client (CWC). The IMMS maintains the location information in the Mobility Management Table (MMT), which is necessary to perform mobility management, keeping track of the changed IP address of a mCSN. The CWC is Web browser which is equipped with CoAP protocol. The protocol stack of mCSN consists of IEEE 802.15.4 MAC, IPv6 over Low Power Personal Area Network (6LoWPAN), CoAP and CoMP. Here, a Local Binding Cache (LBC) locally maintains the permanent IP address P_Addr, temporary IP address T_Addr, and lifetime which is retrieved by the edge router in visited network accessing DHCP server.

We present the CoMP handover procedure which consists of four procedures, i.e., registration, connection, bind and hold to provide the mobility management. The signaling messages of CoMP use a Confirmable (CON) message of CoAP. First, mCSN and CWC register their own P_Addr and T_Addr to the MMT of IMMS by exchanging the CoAP POST Request/Response messages to each other. As the CWC tries to establish connection with the mCSN, CWC requests a GET request message to IMMS to retrieve the IP addresses of a mCSN. As a response, the CWC receives the ACK response message with the current T_Addr and its Lifetime, which are stored at LBC of mCSN. Then, the CWC stores the T_Addr and Lifetime in the LBC of CWC. Afterwards, the CWC can exchange data with the mCSN directly.

Next, let us consider the case in which the mCSN moves from the old Edge Router (old-ER) to the new Edge Router (new-ER). As the mCSN moves away from old-ER and enters into the new network domain of new-ER, it requires the IP handover operation. To do this, the mCSN first detects the radio signal strength (RSS) from the access point connected to the old-ER. As the RSS from old-ER drops below to the threshold value, the mCSN prepares the handover operation in advance.

Before the mCSN performs the handover, it notifies the handover start operation by exchanging the Hold message to IMMS. The Hold message uses the CoAP PUT request/response message with *Hold* flag (*H_Flag*). The *H_Flag* indicates that mCSN is performing the handover procedure. The mCSN may not receive the request of CWC until *H_Flag* is set to "0" by PUT request message for binding update. Thus, the usage of *H_Flag* can prevent the packet loss during the handover operation of mCSN. The PUT messages can also be used for the status notification as the mCSN experiences the power failure or enters into the sleep mode.

As the mCSN moves into in the overlapped region of two network domains: old-ER and new-ER, the mCSN tries to get new temporary IP address, i.e., T_Addr from new-ER through DHCP. Then, the mCSN sends the PUT request message for binding update to IMMS. Its message includes T_Addr, P_Addr, and the *H_Flag* which is set to "0". As the IMMS receives PUT request message, IMMS sends it to the CWC by referring to MMT. As the IMMS and CWC receive the PUT request message for binding update, they update the T_Addr and the *H_flag* in MMT and LBC. Finally, the IMMS and CWC can retrieve the data from the mCSN in new network domain. In this way, the CWC and the mCSN can exchange the data without packet loss during the handover operation. The CoMP signaling messages are configured by extending the Option Delta and payload in the CoAP message format [10].

B. Mobility Management Procedure of CoMP

Fig. 2 shows a signaling flow diagram for CoMP. All control messages use a confirmable message as Fig. 2 shows. The signaling flow diagram includes the registration, connection,

holding, and binding. We assume that CoAP node B obtains the P_Addr, T_Addr, and Lifetime by WSN BS1.

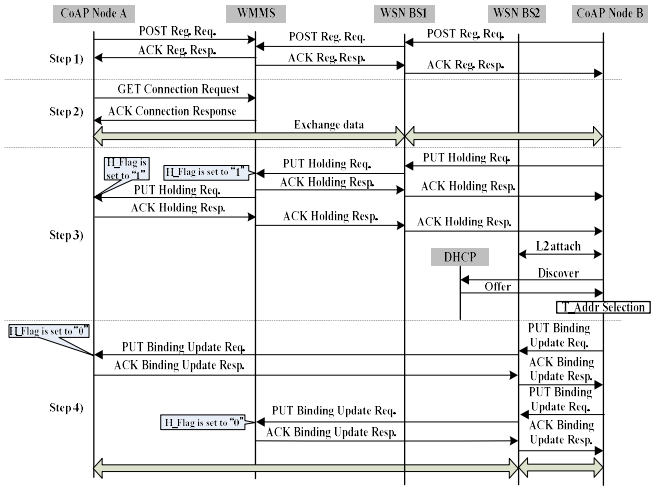

Figure 2. Signaling flow diagram of CoMP

Step 1) Both CoAP node A and CoAP node B register their own P_Addr and lifetime in the MMT of the WMMS by exchanging the POST registration request message and ACK registration response message.

Step 2) The CoAP node A performs the connection procedure in order to retrieve the destination IP address of the T_Addr and the P_Addr of the CoAP node B. To do this, the CoAP node A requests the GET connection request message to the WMMS. As a response, CoAP node A receives the ACK connection response, which includes the T_Addr and Lifetime of CoAP node B in MMT of the WMMS. The CoAP node A then inserts the T_Addr and Lifetime with the corresponding P_Addr of CoAP node B in the LBC. The CoAP node A then tries to connect to the CoAP node B by referring P_Addr and T_Addr. Afterwards, the CoAP node A can exchange the data with the CoAP node B directly until the Lifetime of T_Addr of the CoAP node B expires.

Step 3) We consider the case in which the CoAP node B moves from WSN BS1 to WSN BS2. As the CoAP node B moves away from WSN BS1 and enters the network domain of WSN BS2, it requires the IP handover operation. In order to perform the handover operation, the CoAP node B first detects the radio signal strength (RSS) from the WSN BS1 BS on the link layer. As the CoAP node B detects the degradation of the RSS from WSN BS1 BS the CoAP node B sends a PUT holding request message to the WMMS to hold the request messages from the other CoAP nodes in order to prevent the packet loss of the request message of other CoAP nodes. As the WMMS receives the PUT holding request message, the WMMS updates the H_Flag of the CoAP node B in the MMT to "1". WMMS then sends the PUT holding request message to CoAP node A. Next, the CoAP node A updates the H_Flag in the LBC to "1". As a response, the CoAP node A sends the ACK holding response message to the WMMS. As the RSS from WSN BS1 is less than threshold value (R_{th}), i.e., the wireless signal quality of RSS from WSN BS1; the CoAP node B cannot send or receive the data from WSN BS1, CoAP node B disconnects the connection WSN BS1. CoAP node B then discovers the WSN BSs, as CoAP node B can discover the WSN BS2. The CoAP node B tries to perform the connection attachment to WSN BS2. CoAP node B then retrieves new T_Addr through DHCP server, which includes both discovery and offer procedures.

Step 4) After obtaining a new T_Addr, the CoAP node B then sends a PUT binding update request message to both WMMS and CoAP node A through WSN BS2, simultaneously, by referring to the T_Addr of the CoAP node A in the LBC in order to inform the new T_Addr to WMMS and CoAP node A. The PUT binding update (BU) request message includes the P_Addr, the T_Addr and the Lifetime of the CoAP node B. After WMMS and CoAP node B receive the PUT BU message, the T_Addr and the Lifetime are updated in MTT and LBC and the H_Flag is set to "0". Finally, the CoMP node A can retrieve the data from the CoAP node B. In this way, the connection between the CoAP node A and the CoAP node B can be seamlessly maintained during the handover operation.

C. Message Format of CoMP

In this subsection, we describe the message format for CoMP. We used the CoAP message format and extend the option delta. In the CoAP message format in [2], the option delta and option length is defined to address the resource. We extend the option delta value to support CoMP. Table II shows the extended option delta and its description of CoMP message. In the option delta, the 2048-2053 are newly defined. The range of 2048 … 64999 of option delta are used for the designated expert in CoAP standard [2]. The message type field includes CoAP methods, i.e., GET, PUT, POST, and DELETE. Fig. 3 shows a PUT BU request and ACK Binding Update acknowledgement (Back) response. CoAP node A constructs and sends PUT BU request message including Ho_P_Addr, and New_T_Addr in option value. As a response, CoAP node A receives ACK Back response message.

PUT BU Request:
CON [0x7d34] PUT /bind?P_Addr=Ho_P_Addr#T_Addr=New_T_Addr

2	2	4	8	16 (bit)
1	0	0	3	0x7d34
2048		4	1	
2049		128	Ho_P_Addr	
2050		128	New_T_Addr	

ACK Back Response:
ACK [0x7d34] 2.04

1	2	0	2.04	0x7d34

Fig. 3. Example of PUT binding request and ACK binding response message

III. MATHEMATICAL ANALYSIS OF HANDOVER DELAY OF COMP

In this section, we analyze the performance of the handover latency of CoMP. The handover latency can dramatically increase due to the packet loss of signaling message, which may be caused by the collision, congestion, and system failure in both the wireless link and wired links. The retransmission of the

signaling messages in case of packet loss can greatly reduce the handover latency in the constrained IoT networks. The CoMP employs the retransmission mechanism of CoAP in case of the packet loss of the signaling message. More specifically, the PUT messages used for binding update and holding in CoMP are retransmitted in case of packet loss. Although this may increase the handover latency of CoMP, the reliability can be guaranteed. The CoAP retransmission algorithm is described below.

Algorithm CoAP_Retransmission (*P, T, Rc, m*)
/* This algorithm describes the reliable transmission of CoAP message by using *T*, *Rc* and *m* */
P: CoAP message with sequence number
T: Timeout // T=ACK_TIMEOUT*ACK_RANDOM_FACTOR [9]
Rc: Retransmission count // initially *Rc*=0
m: Maximum number of retransmission counts // *m* =4

```
1   Begin
2   If (T == 0 OR Rc == 0) Then {
3       T = ACK_TIMEOUT*ACK_RANDOM_FACTOR;
4       Rc = 0; m = 4; }
5   Else {
6         If (Rc < m) Then {
7            Send the CoAP message to lower layer;
8            While (T < Timeout) //wait until T is expired
9                If (mCSN receives Acknowledgement)
10               Then { T=0; Rc=0;
11                        Call CoAP_Retransmission (P+1, T, Rc, m);}
12               Else Call CoAP_Retransmission (P, T*2, Rc+1, m);}
13        Else Discard P; } // P is discarded
14  End
```

In order to analyze the handover latency of CoMP, we first derive the average number of transmissions and retransmissions with considering CoAP retransmission mechanism. In reference [11], the probability of CoAP packet error rate by impact of signal to noise radio (SNR) has been investigated for the CoAP message being composed of *f* fragmented packets. The author [11] studied the impact of the SNR on the physical level packet loss rate of an 802.15.4 link. By [11], the packet loss rate *P* is shown in Equation (1) below:

$$P = 1 - (1 - S)^{2m}, \quad (1)$$

where *S* is the symbol error rate and *m* is the length in bytes of the MAC packet. The symbol error rate *S* is related to the SNR [11].

The probability *A* of having an erroneous CoAP packet at the application layer including the retransmission at MAC layer is derived as $A = P^{(r+1)}$. Here, *r* is the maximum number of retransmission allowed for the MAC layer (default value is 5). However, the entire IEEE 802.15.4 maximum transmission unit (MTU) is 127bytes. Hence, the CoAP packet should be fragmented. If a CoAP message is comprised of *f* fragments, the probability of CoAP packet error rate A_f is given by:

$$A_f = \sum_{j=0}^{f} A * (1 - P)^{j-1}, \quad (2)$$

where the maximum number of fragments is fixed to 12. In the reference [11], the packet error rate by impact of SNRs (1, 1.5, 2, and 2.5 (dB)) has been investigated.

We derive the average number of retransmission counts and the average number of transmissions for simple stop-and-wait mechanism of CoAP with A_f . The average number of retransmission counts *R* for CoAP message with *f* fragmented CoAP messages is derived as:

$$R = \sum_{i=0}^{m-1} i(1 - A_f)A_f^i + (m - 1)A_f^m, \quad (3)$$

where *m* is maximum number of retransmissions, with typical value of 4, and *i* is the retransmission count.

The average number of transmission *S* including retransmission for CoAP packet is calculated as:

$$S = \sum_{i=1}^{m} i(1 - A_f)A_f^{i-1} + mA_f^m. \quad (4)$$

With maximum *m* retransmission, the probability of CoAP messages being not transmitted is A_f^{m+1}.

The average retransmission delay *D* for transmitting the CoAP signaling message can be calculated as:

$$D = \sum_{k=0}^{m-1}(1 - A_f)A_f^k\{T_r + (2^k - 1)T_w\} + A_f^m(2^m - 1)T_w, \quad (5)$$

where *k* is the retransmission count and the timeout T_w is the amount of time in which the mCSN waits for an acknowledgement packet from remote device. The roundtrip time T_r is the time from the start of the transmission until an ACK message is received. It is approximately equal to end-to-end delay.

By using the average delay of CoAP message derived above, we can calculate the total handover latency of CoMP. The handoff latency at mCSN is the time interval during which a mCSN cannot send or receive any packets during handover operation. The total handover latency consists of the link switching time (t_{L2}) which is caused by L2 handover between new-ER and mCSN, the movement detection delay (t_{MD}) at mCSN, the IP configuration delay and duplicate address detection by DHCP (t_{DHCP}), and location update latency (t_{BU}). t_{BU} is the sum of $2t_{(mCSN,\ IMMS)}$ and $2t_{(IMMS,\ CWC)}$, which are transmission delay of PUT request/response messages for binding update between mCSN and IMMS, and between IMMS and CWC, respectively. The total handover delay T_{CoMP} is then calculated as follows:

$$T_{CoMP} = t_{L2} + t_{MD} + t_{DHCP} + 2t_{(mCSN,\ IMMS)} + 2t_{(IMMS,\ CWC)}. \quad (6)$$

It is noted that t_{BU} increases as the retransmission count increases.

IV. Performance Evaluation

Table I shows the basic parameters for evaluating the performance of CoMP. Most parameters used in this analysis are set to typical values found in [12]. In order to analyze the average number of transmissions and retransmissions, and the handover latency, we use the packet loss rate by SNRs with *f* fragments of a CoAP message in reference [11]. It is assumed that wireless link bandwidth and wired link bandwidth are 250Kbps and 100 Mbps, respectively.

Table 1. Parameters for Delay Analysis (Kbps, ms, Bytes)

Param.	Value	Param.	Value	Param.	Value
t_{DHCP}	5000	$t_{(mCSN,\ ER)}$	4.4	$t_{(CWC,\ IMMS)}$	50
t_{MD}	100	$t_{(mCSN,\ IMMS)}$	79.4	*S*	113
t_{L2}	50	$t_{(mCSN,\ CWC)}$	79.4	*m*	4

The quality of service requirements for the handover delay depends on the message type for IoT applications such as discrete or continuous message data. As the probability of packet error rate becomes 50%, the CoAP message is

retransmitted about 2 times. Fig. 4 shows the average delay of SNRs by impact of T_r. As the retransmission count increases, the average delay also increases. If the CoAP message is retransmitted due to the packet error or wireless network failure, the average delay is about 3 seconds. Fig. 5 shows the total handover delay with CoAP retransmission mechanism by impact of T_r. As the packet lose rate is about 50%, the handover latency increases to 4.3~4.5 seconds. In this way, the CoMP supports reliability in handover operation. On the contrary, the related standard mobility protocol such as MIPv6 and HMIPv6 do not support the reliability. As the failure of signaling message occurs, these mobility protocols do not support automatic retransmission mechanism.

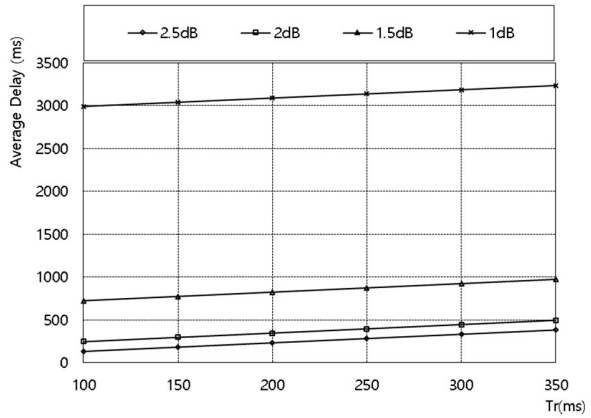

Figure 4. Average delay of SNRs by impact of $\boldsymbol{T_r}$

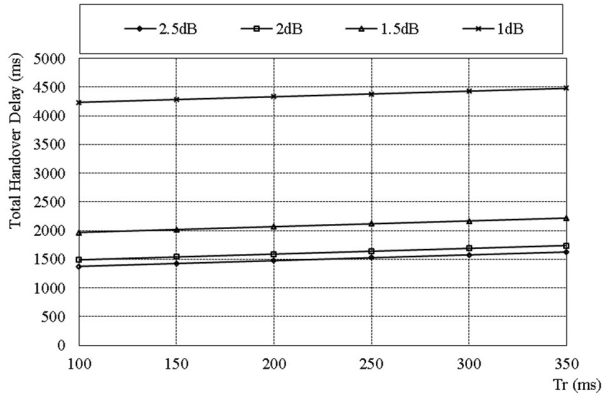

Figure 5. Total handover delay with considering CoAP retransmission mechanism by impact of $\boldsymbol{T_r}$

V. CONCLUSION

In this article, we have presented an architecture and CoMP protocol for reliable mobility management mechanism in IoT environments. We extend the IETF CoAP protocol for achieving the reliability in IoT mobility management. In addition, we introduce the binding and holding modes to prevent the loss of signaling message during handover operation. The mathematical analysis of the handover delay of CoMP is given. The performance evaluation shows that CoMP can effectively support the reliable mobility management.

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CLOUD TECHNOLOGY

Cloud-based services for the Internet of Things

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***Abstract* - In this paper, cloud-based services aimed for the connectivity, monitoring, and management of the IoT devices are presented. To set up a network with a large number of devices in the constrained environment can be a challenge. Also, collecting, storing and analyzing data generated from sensors attached to the devices most often requires developing custom-made applications which imply time and cost consumption. Several cloud providers are offering IoT services that unite needed features into full solution offering connectivity between devices and the cloud, processing of data sent from devices and interaction with connected devices through the application. One of them is AWS IoT (Amazon Internet of Things) which is fully scalable, reliable and simple to use. This platform can collect data from a large number of different devices and connect them to endpoints for other tools, allowing a developer to tie received data into the independent application. Other aspects, like security, resource management, integration and centralized management are also covered. In this paper, we will evaluate the performance of the AWS IoT web services by connecting small, single-board computers, like Raspberry Pi through different scenarios.**

Keywords – Internet of Things; IoT Architecure; Amazon Web Services IoT; MQTT; Raspberry Pi

I. INTRODUCTION

The Internet of Things (IoT) is the computing concept that describes interconnection of everyday objects that deliver Information over the Internet. Everyday growing number of objects has promoted the Internet of Things protocols and technologies as one of the most commonly used in the modern systems. Although the concept of the IoT is originated more than ten years ago, it is still one of the most widespread topics across a range of industries, including traffic industry, manufacturing, military, healthcare, sports, education – in almost every aspect of human life. IoT objects refer to a wide variety of devices which are most often equipped with electronic circuits and sensors [1]. These devices, implemented in IoT solutions, made Internet sensory thereby achieving improved tracking and analyzing systems.

There are several challenges that need to be overcome during the implementation of the IoT technology. A typical IoT solution includes different devices used for collecting, producing, analyzing and storing data. These devices may differ by their hardware and software platform, but all must meet the requirements which can be breaked up into these components: memory storage, processor, power source and power management, wireless connectivity and ability to connect sensors.

Connecting devices to the Internet enables the devices to communicate with each other and with cloud services and applications. For the purpose of the connectivity, there are a variety of communication standards and protocols used, of which most widespread are IEEE 802.15.4, Internet Protocol version 6 (IPv6) and IPv6 over Low Power Wireless Personal Area Network (6LoWPAN) [2]. Regardless the specific communication protocol used to deploy IoT solution, all the IoT devices should make their data available to the other IoT object, or application. This can be achieved by connecting devices to the cloud using Application Programming Interfaces with built-in functions for end-users [3]. Gerber in [4] discusses strategies that can be applied during the planning of data-driven IoT architectures. These strategies simplify development, manage complexity, increase scalability and flexibility and can be breaked up into following: adopting a layered architecture, implement security, automate operations, ensure interoperability and follow a reference architecture. Leading mentioned challenges, requirements and strategies, we have built a simple IoT solution which is described in following chapters.

II. ARCHITECTURE

Implementation of the IoT solution requires unprecedented collaboration, coordination, and connectivity for each piece in the system, and throughout the system as a whole [5]. All objects must work together, be integrated with other devices, and communicate and interact seamlessly with connected systems and infrastructures. To manage such a complexity of the implementation of an IoT solution, a multi-tiered architecture is used. This modular approach enables to develop and maintain each tier as an independent module, on a separate platform. As written in [6] "a typical IoT solution is characterized by many devices (i.e., things) that may use some form of gateway to communicate through a network to an enterprise back-end server that is running an IoT platform that helps integrate the IoT information into the existing enterprise.". Leading this, each IoT solution can be described as a three-tier architecture in which physical devices (e.g. device tier) over the gateway (e.g. control tier) communicates with the datacenter (e.g. cloud tier). A detailed survey on domain-specific IoT architectures can be found in [7].

The bottom layer of the architecture is the device layer. This is the starting point and a source of information implemented through various of different devices which are most often equipped with electronic circuits and sensors, software and network connectivity [8]. These devices are constrained in terms of power supply and size

and therefore, often programmed using microcontrollers. Software component of the device may include operating system suited for small constrained devices and a layer that provides access to the hardware features of the microcontroller such as flash memory, general-purpose input/output (GPIO) and serial interfaces. This layer also in charge for handling communication between upper layers and the devices through the drivers and communication protocols [6].

Control tier bring in control functionalities to the architecture. The main tasks of this layer are security, connectivity, transportation and aggregation of data received from the bottom layer and pre-processes it before sending it to cloud services and applications for further processing and analytics.

The Cloud tier includes the software infrastructure and services required to store, analyze and visualize data. This layer interacts with very large numbers of devices and gateways using different protocols and data formats, but then normalize it to allow for easy integration into the rest of the enterprise. Depending on the solution, it is possoble to trigger alerts or carry out actions in response. Also, it has to support device management through a central registry to identify the devices/gateways running in an IoT solution and the ability to provision new software updates and manage the devices. At the side of a storage, it must support the volume and variety of IoT data.

There is a growing number of cloud providers offering IoT specific services [9]. Industry partners such as Microsoft, Amazon, Google, and IBM have introduced IOT based platforms such as Microsoft Azure IoT, Amazon Web Services (AWS) IOT, Google Cloud Platform, and IBMBluemix Watson for effectively monitoring the remote applications [10].

According to [11], [12] and [13], top three IoT platforms in 2018 are:

- Amazon Web Services IoT,
- Microsoft Azure IoT,
- Google Cloud Platform,

In this paper, we will evaluate the performance of the top-rated AWS IoT platform by connecting small, single-board computer through different scenario (Fig. 1). AWS offers a suite of web services that can be combined [14] and make up a cloud computing platform [9]. At the end of 2017, AWS had more than 90 services, spanning a wide range, including compute, storage, networking, database, analytics, application services, deployment, management, mobile, developer tools and tools for the Internet of things [7].

III. AMAZON WEB SERVICES IOT

Comparing to other platforms AWS IoT platform serves solely as a platform for providing bi-directional communication between IoT objects and the cloud [15]. It consists of the following components:

A Thing – thing are all devices, applications, or physical objects that are supported by AWS IoT cloud application.

The device gateway is an entry point for IoT objects connecting to AWS. The main responsibilities of the device gateway are to manage connections and security. At the side of the connectivity, Device Gateway supports Message Queue Telemetry Transport (MQTT), MQTT over Web Sockets, MQTT over the Secure WebSocket and HTTP protocols. IoT devices can communicate even if they are not using same protocols.

Message Broker mediates communication between MQTT client applications and can handle up to thousands connected MQTT clients. The main responsibilities of a broker are receiving messages, filtering messages, deciding who is interestes in messages and then sending messages to them.

Authentication and authorization – Amazon IoT connects devices to services and other devices with a secure way [9]. Each device must be identified through the process of authentication to get access to resources. After device is authenticated, it can perform actions which are defined through the process of authorization.

The Registry is responsible for assigning a unique identity to each device registered in the AWS IoT, no matter what type it is or how it connects.

Device Shadows represents a persistent, virtual version of each device that includes latest state so that other devices or applications can evaluate messages and communicate with the device.

The Rules Engine makes it possible to build IoT applications that gather, process, analyze and act on data generated by connected devices at global scale without having to manage any infrastructure.

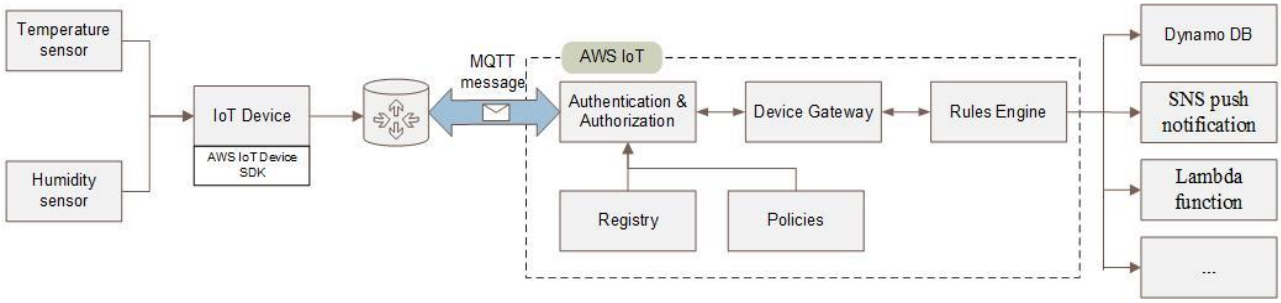

Figure 1. AWS Internet of Things Components

IV. MQTT - IOT COMMUNICATION PROTOCOL

IoT is characterized by communication between machines (M2M communication). The interconnected things are often located in isolated areas where connection to the Internet is realized over the cellular network or slow DSL connection. This characteristic can be recognized in rural areas where most of the facilities are built. Unreliability is one of the main disadvantages of such networks, which reflects high packet loss rate [16]. There are several protocols proposed for M2M/IoT communication with a focus on mentioned constrained environments. The specific characteristics of proposed protocols can simplify the design and the operation of IoT application because a large portion of error handling can be done by the protocols [16]. Most frequently adopted protocols are MQTT and CoAP (Constrained Application Protocol).

MQTT is a machine-to-machine (M2M)/Internet of Things connectivity protocol. It was designed as an extremely lightweight broker-based publish/subscribe messaging protocol for small code footprints (e.g., 8-bit, 256KB ram controllers), low bandwidth and power, high-cost connections and latency, variable availability, and negotiated delivery guarantees [17]. Communication between devices and AWS IoT relies on this protocol.

The MQTT protocol relies on a messaging server following the hub and spoke model of Message Oriented Middleware (MOM) [18]. In such architecture, a client needing data (end user devices) registers its interests with a server, an MQTT broker (central server). The client producing data (publisher) sends data to a server and this server forwards the data to the subscriber. One of the major advantages of this architecture is the decoupling of the clients needing data and the clients sending data, i.e. temperature sensor nodes need not know the identities of clients that are interested in data and conversely [19]. So, the publishers and subscribers do not need to be familiar with each other and do not need to participate in the communication at the same [20]. It is intended for devices with limited power and memory capabilities, where the network is expensive, has low bandwidth or is unreliable.

MQTT minimizes network bandwidth and device resource requirements while attempting to ensure reliability and delivery. This approach makes the MQTT protocol particularly well-suited for connecting the machine to machine (M2M), which is a critical aspect of the emerging concept of an Internet of Things [21]. This protocol has been applied in a large number of different embedded systems. For example, oil and gas companies use it to monitor oil pipeline thousands of miles away; hospitals use this protocol to track patient's condition. Facebook uses this protocol for messaging applications. Fig. 2 shows proposed a model of MQTT protocol which runs on TCP/IP connection.

Using MQTT over Web Sockets every browser can be MQTT publisher or subscriber. As long as the browser is subscribed to the specific message, it will keep receiving messages, anywhere in the world. Messages which are retained on the server are delivered when a client subscribes to one of the topics instantly.

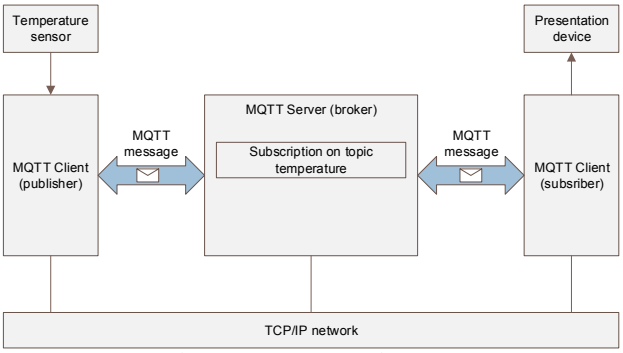

Figure 2. MQTT protocol

V. USE CASE

Using three-tier architecture, we've implemented a simple IoT solution in a lab environment which encompasses all three layers. The main goal is to collect data using sensors and single board computer which is connected to AWS IoT. Using AWS IoT Device SDK and MQTT protocol, the data is sent to AWS IoT.

On the device tier, a Raspberry Pi Model B is used. This is the third generation of the credit-card sized single board computer from the Raspberry family. Main differences between RPi model 3 and prior versions are integrated wireless module (802.11n), integrated Bluetooth module (Bluetooth 4.1) and 1.2GHz 64-bit quad-core ARMv8 CPU. Using this type of RPi there is no need for additional modules for connecting end device to the network.

The Raspberry Pi itself doesn't come with the pre-installed operating system. There are a number of operating systems designed specifically for the Raspberry Pi, available on the Raspberry official web page, of which the most popular are Raspbian, Windows IOT Core, RISC OS. To make a Raspberry run, we used Raspbian, an official operating system for the Raspberry Pi which is based on Debian and optimized for the Raspberry Pi hardware.

The next step is to choose external hardware which will be attached to the Raspberry Pi's GPIO pins. There are a variety of different low-cost and simple to use sensors which can be attached to the Raspberry Pi. For the purpose of this paper, a temperature sensor DS18B20 is used (Fig. 3). This is a commonly used digital temperature sensor featured with small size, low-cost hardware, strong anti-interference capability and high precision. It provides 9-bit to 12-bit Celsius temperature measurement and communicates over a 1-wire bus that by definition requires only one data line (and ground) for communication with Raspberry [10].

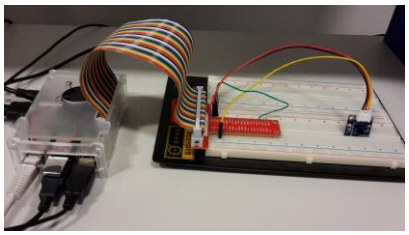

Figure 3. DS18B20 sensor connected to Raspberry Pi in lab environment

A. *Registry*

In order to connect the device to AWS IoT, a device must be registered in the Registry. The Registry gives a unique identity to each device regardless of the type of device or which communication protocol is the device using. Devices connected to AWS IoT are represented by the thing in the registry. Each thing is uniquely identified by Amazon Resource Name (ARN):

arn:partition:service:region:account:resourcetype/resource

General format for ARN consists of following parameters:

- partition - The partition that the resource is in. For standard AWS regions, the partition is aws.
- service - The service namespace that identifies the AWS product, for example Amazon S3, DynamoDB or AWS IoT
- region - The region the resource resides in.
- account - The ID of the AWS account that owns the resource
- resourcetype/resource - indicator of the type of resource followed by the resource name itself.

For example:

arn:aws:iot:us-east-2:682503558106:thing/Rpi_1

Some parts of the ARN (resource name and region) will be later used in creating MQTT connection.

The Registry determines an identity for objects and tracks metadata such as the devices attributes and conditions as presented in following portions of code.

```
$ aws iot list-things
{
    "things": [
       {
            "thingTypeName":"tempSensor"
            "attributes": {
                "model": "DS18B20"
            },
            "version": 1,
            "thingName": "RaspberryPi_1"
        }
    ]
}
```

B. *Authentication and authorization*

To enable access to AWS IoT resources, all devices must be authenticated to the AWS IoT platform and authorized to carry out actions. The AWS IoT platform uses mutual authentication and encryption for all types of requests, so to exchange data between device and AWS IoT, identity must be proved. There are following methods that can be applied to prove identity:

- Signature version 4 – AWS method of authentication which can be used in connections using HTTP protocol or Web Sockets,
- X.509 certificate-based authentication using digital certificates that use X.509 public key infrastructure standard to associate a public key with an identity contained in a certificate. This type of authentication is used in HTTP or MQTT connection,
- Customer created token-based authentication which can be used in HTTP connection or Web Sockets.

Raspberry Pi will communicate with AWS services over MQTT protocol, so an appropriate certificate must be issued, which can be done through AWS IoT Management Console. There are three options to create a certificate: one-click certificate creation, creation with certificate signing request (CSR) or using own certificate signed by own trusted CA. The first option will generate a certificate, public key, and private key using AWS IoT's certificate authority. Certificate and private key needs to be downloaded to the end-device.

After the device is registered to AWS IoT and identity has been applied, the process of authentication is done. Still, it remains to set up authorization – a process of verifying which actions a device can perform. Authorization in AWS IoT is performed through AWS IoT policies. Policy in AWS IoT is a JSON structure containing one or more policy statements.

Each statement has three parameters: an Effect, an Action, and a Resource. Depending on the effect value, the action will be allowed or denied. The action part specifies which actions to the device the policy is allowing or denying. The Resource specifies which devices or resources are affected. The following policy grants all devices permission to connect to the AWS IoT message broker, and publish a message to a specific topic.

```
{
   "Version": "2018-02-19",
    "Statement": [{
        "Effect": "Allow",
        "Action":["iot:Connect", "iot:Publish"],
        "Resource": ["*"]
    }]
}
```

C. *AWS IoT device SDK*

The AWS IoT device SDK is a set of tools using which is possible to connect hardware device to AWS IoT. The AWS IoT Device SDK enables end devices to connect, authenticate, and exchange messages with AWS IoT Core using the MQTT, HTTP, or Websocket protocols. The AWS IoT Device SDK supports C, JavaScript, and Python, and includes the client libraries, the developer guide, and the porting guide for manufacturers.

To connect our device with AWS IoT we used JavaScript/Node.js SDK. The aws-iot-device-sdk.js package contains libraries for JavaScript applications which access the AWS IoT Platform via MQTT or MQTT over the Secure WebSocket Protocol. It can be used in Node.js environments as well as in browser applications.

Using device class from AWS IoT device SDK for JavaScript a secure connection to the AWS IoT platform is accomplished. This class provides features to simplify handling of communication. Following portion of code is example of instantiating a new device with parameters.

```
var awsIot = require('aws-iot-device-sdk');

var device = awsIot.device({
   keyPath: <PrivateKeyPath>,
  certPath: <CertificatePath>,
    caPath: <RootCACertificatePath>,
  clientId: <UniqueClientIdentifier>,
      host: <CustomEndpoint>
});
```

After device has been connected, it can start to send messages to given topic. A temperature values from DS18B20 temperature sensor are sent along with Rpi_1 topic.

```
setInterval(function){
   var temperature = ds18b20.temperatureSync();
   var date = new Date();

   device.publish('Rpi_1',JSON.stringify({
       temperature:temperature,
       timestamp: date.getTime();
   }));
}
```

D. *Rules*

After data has been received on the AWS IoT, it is possible to interact with other AWS services using AWS rules. An AWS IoT rule can be made in AWS management console and it consists of a SQL SELECT statement, a topic filter, and a rule action. Devices send information to AWS IoT by publishing messages to specific MQTT topics. By defining a rule it is possible to evaluate received messages and specify what to do when a message is received. The rule is triggered when an MQTT publisher sends a message on a topic that matches the topic filter, the rule will. Through the rule actions it is possible to extract information from an MQTT message and send it to another AWS service, for example insert a message into the database, invoke Lambda function, send a message as an SNS push notification, or republish messages to an AWS IoT topic. On the image below, a screenshot of the management console is captured. There are three rules defined when Raspberry Pi publish a message on specific topic (Fig. 4). Executed rules can be monitored through management console (Fig. 8).

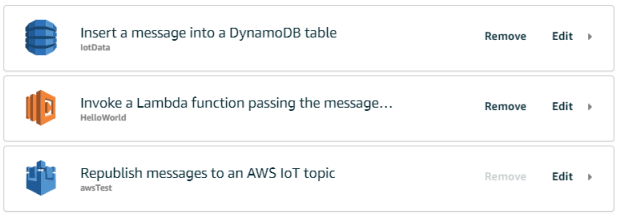

Figure 4. Rules in AWS IoT management console

E. *Management Console*

Using AWS IoT Device Management Console it is easier to organize securely, monitor (Fig. 5., 6., 7., 8.), and remotely manage IoT devices. Management Console is used to register devices individually or in bulk, manage permissions, organize devices into groups, monitor and troubleshoot device functionality. It is possible to remotely update the software running on devices even after they have been deployed.

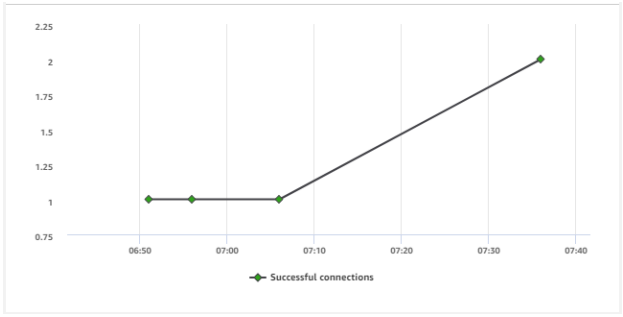

Figure 5. Successful connections

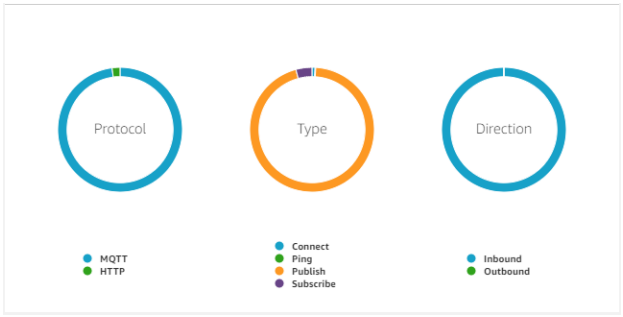

Figure 6. Messages

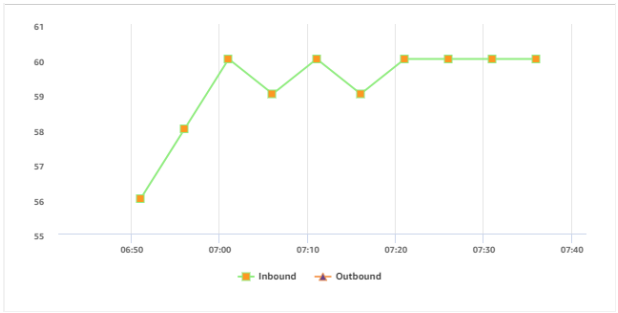

Figure 7. Messages published

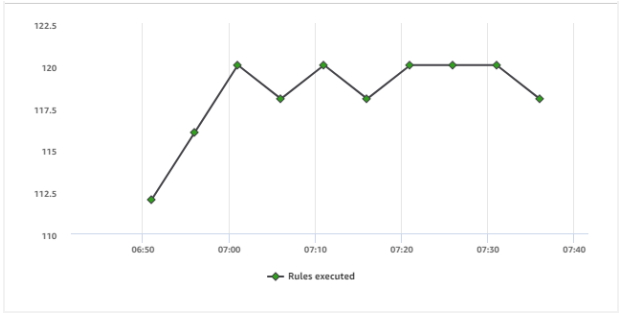

Figure 8. Executed rules in AWS IoT management console

VI. CONCLUSION

In this paper, we presented top-rated IoT cloud-based platform Amazon Web Services IOT by connecting small, single-board computer Raspberry Pi. We have briefly described architecture and components of the AWS IoT

through implementing a simple IoT solution in a lab environment which encompasses all three layers – device layer, a control layer and cloud layer. The main goal was to collect data using sensors and send data to AWS IoT web services using AWS IoT Device SDK and MQTT protocol. We've presented some of the web services available on the AWS IoT which can be invoked using AWS IoT Rules. Other aspects, like security, resource management, integration and centralized management are also covered.

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Pricing and Bidding Strategies for Cloud Spot Block Instances

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***Abstract* - Cloud providers offer idle resources - Spot instances, in an auction-like mechanism. Spot instances provide a dynamic and efficient manner for renting cloud resources. However, failures are often due to Spot price fluctuations. Recently introduced variety of Spot instances - Spot Block instances, run uninterrupted for a predefined duration. In this paper, we propose a model for Spot Block prices determination. Analysis of different bidding strategies in creating Spot Blocks requests is provided. Two auction-based pricing mechanisms are analyzed: Uniform price auction and Generalized Second-price auction. Cloud provider's revenue under these pricing mechanisms is also addressed.**

Keywords - Cloud resources*; *Spot Block instance; pricing; bidding; auctions

I. INTRODUCTION

Cloud computing is a paradigm for enabling network access to a scalable and elastic pool of shareable physical or virtual resources with self-service provisioning and administration on-demand [1]. Resources in a cloud are generally purchased as cloud instances, i.e. Virtual Machines (VMs) with the required CPU, memory and I/O resources. In addition, different types of VMs provide different levels of guarantees in terms of availability and termination. The price that cloud customers pay for required resources is determined by instance type and pricing mechanism. As the pioneer of cloud computing, Amazon Elastic Compute Cloud (EC2) uses three different purchasing options to improve revenue management: Reserved instances, On-demand instances and Spot instances. Reserved instances are purchased with long-term (usually a year or three years) availability guarantees, On-demand instances are purchased for specific time periods and are guaranteed to be available once assigned, and Spot instances are purchased through an auction mechanism, but their availability depends on the time-varying spot price. Reservation pricing mechanism incurs a relatively high fixed cost for cloud customers. However, it provides guaranteed access upon request, and the instances are not revocable once provisioned. With On-demand instances, cloud customers do not have guaranteed access upon request, but the instances are not revocable once provisioned. Hence, Reservation and On-demand pricing mechanisms provide guarantees on minimum sustained availability [2]. These pricing mechanisms are considered as static, since prices for cloud resources cannot be increased or decreased for under and over-utilization of the resources, respectively. With Spot Instances, cloud customers can bid in an auction mechanism for idle resources. However, this purchasing option offers no guarantees on minimum sustained availability. Cloud customers submit their requests by specifying the maximum hourly price they are willing to pay for the required resources. Spot prices are dynamically set by cloud provider depending on the availability of the idle resources and current demand. Spot instances are allocated to the customers if their bid is higher than the Spot price. When the Spot price exceeds the maximum bid price, the Spot instance is terminated. Cloud provider can also revoke Spot Instances when the supply of available Spot Instances decreases due to increased demand for On-demand and Reserved instances, and the maximum bid price is equal to the Spot price [3]. Recently, Amazon introduced a new variety of Spot instances, namely Spot Block instances. These instances run continuously for a finite duration (1 to 6 hours). Pricing is based on the requested duration and the available resources. Spot Block prices are typically 30% to 45% less than On-demand prices [4]. Submitting the bid, cloud customer specifies the maximum price willing to pay per hour along with the Block duration parameter (the number of hours that Spot Block instance will run). When there are enough available resources for the requested duration, Spot Block instance will launch and run continuously for a flat hourly price. At the end of the Spot Block duration, the instance is terminated. This model of purchasing cloud resources is suitable for tasks that need to run uninterrupted for up to 6 hours.

Main contribution of this paper is the development of a novel model for Spot Block price determination. A unit bid is introduced in order to enable comparison of cloud customers bids. In addition, we analyze three different bidding strategies under two auction mechanisms: Uniform price auction and Generalized Second-price auction. Cloud provider's revenues under various scenarios are addressed. The remainder of the paper is organized as follows. Section II presents a brief literature review. Modelling of Spot Block prices, bidding strategies and auction setup for two observed auction mechanisms are introduced in Section III. Experimental evaluations and results are given in Section IV. Section V contains discussion on obtained results Finally, concluding remarks are presented in Section VI.

II. LITERATURE REVIEW

Cloud providers introduced dynamic forms of pricing mechanisms in order to maximize their profits and balance supply and demand for cloud resources [5-7]. Auction mechanisms can be effective and promising solution, since they support cloud customers for truthful bidding (submitting bids that reflect real willingness to pay). The auctions ensure that cloud resources are assigned to the customers that value them the most. In addition, these mechanisms provide price variation depending on the changes in supply and demand by creating competition among cloud customers [8]. Various auction-based allocation and pricing mechanisms can be used for cloud resources [9-12]. Uniform price auction is a widespread method for Spot pricing mechanism [13]. The concept of the marginal bid (the highest unsuccessful bid) for cloud resources allocation and pricing under Second-price auction is proposed in [14]. Combinatorial auctions are often used for pricing and allocation of cloud resources. A comparison of combinatorial one-to-many auction and fixed pricing mechanisms is presented in [15], where the two mechanisms based on the combinatorial auctions are proposed. The auction-based mechanisms show better performances than fixed pricing mechanisms. A periodical auction mechanism, based on the limited English combinatorial model for allocation of cloud resources is proposed in [16], where the genetic algorithm with the objectives to maximize the provider's profit and to reduce customers' requests execution times is used. A fair multi-attribute combinatorial double auction for allocation and pricing of cloud resources is proposed in [17], where additional parameters such as fairness, reputation and imposing of penalty on the providers that make a false Quality of Service (QoS) assurance in order to win the auction are included in the analysis.

Bidding strategies for allocation and pricing of Spot instances are widely addressed [2, 18-23]. Guidelines for cloud customers in creating bids for Spot instances with consideration of the tradeoffs between cost, wait time and interruption rates are presented in [18]. A descriptive statistics approach for the analysis of Spot pricing along with consideration of typical pricing patterns including the presence of seasonal components, extremes and trends is presented in [2]. The availability and cost aware bidding framework based on the formalization of Spot instance failure model and non-linear programming model is proposed in [19]. Bidding and pricing strategies for optimizing cloud customers' utility and cloud provider's revenue are analyzed in [20].

In this paper, the two well known auctions: Uniform price auction and Generalized Second-price auction are used for Spot Block pricing. Three bidding strategies within four different scenarios are addressed. The aim of the analysis is to get an insight into cloud provider's revenues, cloud customers' payoffs and potential savings in Spot Block instances provisioning. To the best of our knowledge, this is the first paper addressing this issue.

III. PROBLEM STATEMENT

Let us consider a setting with a single cloud provider, where the provider offers its idle resources, i.e. Spot instances, in an auction-like manner. We assume that all cloud instances have the same characteristics in terms of computing and storage performances. Analysis can be easily extended to various types of cloud instances. Without loss of generality, our analysis is executed into N consecutive time slots of one hour duration. The number of available idle instances, that may be offered in the form of Spot Block instances, varies according to the number of initiated and released Reserved, On-demand, Spot instances and Spot Block instances that already run. This largely depends on the demand for cloud resources. The total number of cloud instances is denoted as M. In this paper, we assume that each instance in each time slot (unless already initiated as Spot Block instance) can be initiated as Reserved, On-demand or Spot instance, i.e. this instance is unavailable for initiation as Spot Block instance. The probability that cloud instance is unavailable is denoted as Q. Considering that sufficient number of the participants in the market is needed for revenue maximization in long term [17], we assume that number of the cloud customers, denoted as B, is always greater than the number of the available Spot Block instances.

The number of the customers that initiate request for Spot Block instance can be modelled using Poisson distribution [24]. In this paper, the two parameters for Poisson distribution, λ_1 and λ_2, are used for the periods of high and low traffic load, respectively.

In order to initiate a certain Spot Block, cloud customer creates a bid. Submitting a bid, cloud customer defines two parameters: the value of the bid, i.e. the maximum price per hour that customer is willing to pay for a given Spot Block, and the Spot Block duration, expressed in hours (up to 6 hours). Bids are submitted at the beginning of each time slot. Cloud provider allocates the available Spot Block instances, denoted as M_i, $M_i \le M$, to customers that value them the most. Customers with the greatest bid values can initiate instances that will run for predefined duration without termination. The value that customer pay for Spot Block initiation is not the value of the bid, but the value of Spot Block price per hour. Depending on applied auction mechanism, these prices can have different values.

A. Modelling of Spot Block prices

Spot Block prices differ depending on the duration of Spot Block usage. The Spot Block price per hour for Spot Block instance in time slot $i \in [1, N]$ for the duration of t is denoted as: $p_{i,t}$, $t = \{1, 2, 3, 4, 5, 6\}$. These prices are not known in advance. Their values for current time slot are set depending on cloud customers bids and applied auction mechanism. However, Spot Block prices for the previous time slot $i-1$, $p_{i-1,1}$ and $p_{i-1,6}$, are publicly available [25]. The greatest Spot Block price is set for the maximum Spot Block duration of 6 hours, while the lowest Spot Block price is set for Spot Block duration of one hour. Therefore, it applies:

$$p_{i-1,1} < p_{i-1,2} < p_{i-1,3} < p_{i-1,4} < p_{i-1,5} < p_{i-1,6}. \quad (1)$$

Spot Block prices for Spot Block duration of 2, 3, 4 and 5 hours in time slot $i-1$ can be easily calculated from $p_{i-1,1}$ and $p_{i-1,6}$. We assume that

$$p_{i-1,6} = (1+\theta)\cdot p_{i-1,1}, \quad \theta \in (0,1). \tag{2}$$

The parameter θ is introduced in order to evaluate the difference between the values of Spot Block prices per hour for Spot Block duration of one hour and six hours. Therefore, Spot Block prices for duration t can be presented as follows:

$$p_{i-1,t} = \left(1+\frac{(t-1)\cdot\theta}{5}\right)\cdot p_{i-1,1}, \quad t=\{2,3,4,5\}. \tag{3}$$

B. Bidding strategies

Cloud customers submit their bids in time interval $i \in [1, N]$ based on information about on-demand prices and Spot Block prices per hour in previous time interval. On-demand price for equivalent on-demand instance (instance with the same computing and storage performances offered on-demand) is denoted as p_o. Set of all bidders in time interval $i \in [1, N]$ is denoted as B_i. The bid of the cloud customer $j \in B_i$ in time slot $i \in [1, N]$ can be expressed as follows:

$$b_{i,j} = \left(\upsilon^i_{j,t_j}, t^i_j\right), \tag{4}$$

where υ_{j,t_j} represents the value of the bid for the duration of t_j.

Depending on their willingness to pay, customers may perform the following bidding strategies: bidding close to the Spot Block price for one hour in previous time interval, $p_{i-1,1}$; bidding close to the Spot Block price for six hours in previous time interval, $p_{i-1,6}$ and bidding close to the on-demand price. These strategies are chosen according to a discrete probability distribution.

When cloud customers place bids close to the Spot Block price for one hour in previous time interval, their bids take values

$$b_{i,k} \in \lfloor p_{i-1,1}-\delta_1,\ p_{i-1,1}+\delta_1 \rfloor, \tag{5}$$

where $i \in [1, N]$, $k \in [1, |B_i|]$. δ_1 denotes a small variation of the Spot Block price for one hour in previous time interval. The probability of choosing the first bidding strategy is denoted as q_1, $q_1 \in (0,1)$.

For the second bidding strategy, it applies:

$$b_{i,l} \in \lfloor p_{i-1,6}-\delta_6,\ p_{i-1,6}+\delta_6 \rfloor \tag{6}$$

where $i \in [1, N]$, $l \in [1, |B_i|]$, $l \neq k$, δ_6 denotes a small variation of the Spot Block price for one hour in previous time interval. The probability of choosing the second bidding strategy is denoted as q_2, $q_2 \in (0,1)$.

The third bidding strategy is characterized by bid values from the range

$$b_{i,m} \in [\,p_o-\delta_o,\ p_o], \tag{7}$$

where $i \in [1, N]$, $m \in [1, |B_i|]$, $m \neq l \neq k$. δ_o is used to denote the lower bound in variation of the on-demand price per hour. The probability of choosing the third bidding strategy is denoted as q_3, $q_3 \in (0,1)$. Obviously, $q_1+q_2+q_3=1$.

C. Auction Mechanisms

Comparison of bids is not as straightforward as in the case of bidding for regular Spot instances. The complexity is introduced by allowing that Spot Block instance runs without termination even if the value of the bid is already exceeded. Considering that Spot Block prices per hour are different for different Spot Block duration, bids cannot be simply sorted depending on their value. In this paper, we propose a model for translation of bids into unit bids in order to enable their comparison in an auction mechanism. Each bid is represented by a new value of the bid and by the same Spot Block duration, as follows:

$$\overline{b_{i,j}} = \left(\overline{\upsilon^i_{j,t_j}}, t_j\right), \tag{8}$$

where $\overline{\upsilon^i_{j,t_j}}$ represents the unit bid value of cloud customer j in time slot $i \in [1, N]$. In accordance with (3), the unit bid value can be calculated as:

$$\overline{\upsilon^i_{j,t_j}} = \begin{cases} \dfrac{5\cdot\upsilon^i_{j,t_j}}{5+(t^i_j-1)\cdot\theta}, & t^i_j=\{2,3,4,5,6\} \\ \upsilon^i_{j,t_j}, & t^i_j=1 \end{cases}. \tag{9}$$

Once unit bids in certain time slot are determined, the allocation of Spot Block instances is performed based on the set of winning bids, i.e. cloud customers with the winning bids can initiate required Spot Block instances. Cloud customers payoffs differ depending on the applied auction mechanism. In this paper, we analyze Uniform price auction and Generalized Second-price auction in order to obtain cloud provider's revenues in provisioning of Spot Block instances. The set of the winning bids contains M_i the highest unit bids,

$$W_i^I = \left\{ \overline{\upsilon_{1,t_1}^i}, \overline{\upsilon_{2,t_2}^i}, \cdots, \overline{\upsilon_{M_i,t_{M_i}}^i} \right\}, \quad (10)$$

where M_i denotes the number of the available Spot Block instances in time interval $i \in [1, N]$. This number varies since Spot Block instances can be occupied without termination up to 6 hours.

In Uniform price auction, each winning bidder pays the same price equal to the lowest winning bid. The set of the cloud customers payoffs in time interval $i \in [1, N]$ under Uniform price auction is:

$$P_i^I = \left\{ \overline{\upsilon_{1,t_1}^i}, \overline{\upsilon_{2,t_2}^i}, \cdots, \overline{\upsilon_{M_i,t_{M_i}}^i} \right\}, \quad (11)$$

where $\overline{\upsilon_{1,t_1}^i} > \overline{\upsilon_{2,t_2}^i} > \cdots > \overline{\upsilon_{M_i,t_{M_i}}^i}$. Therefore, Spot Block price for Spot Block duration of one hour in time slot $i \in [1, N]$ is $p_{i,1}^I = \overline{\upsilon_{M,t_{M_i}}^i}$. According to (3), Spot Block prices in general can be represented as:

$$p_{i,t}^I = \left(1 + \frac{(t-1)\cdot\theta}{5}\right) \cdot p_{i,1}^I, \quad (12)$$

where $t = \{2, 3, 4, 5, 6\}$.

Cloud provider's revenue under Uniform price auction in time slot $i \in [1, N]$ can be expressed as:

$$R_i^I = \sum_{q=1}^{|W_i^I|} p_{i,t_q}^I + \sum_{h=1}^{|W_{i-1}^I|} p_{i-1,t_h}^I + \sum_{z=1}^{|W_{i-2}^I|} p_{i-2,t_z}^I + \sum_{e=1}^{|W_{i-3}^I|} p_{i-3,t_e}^I + \sum_{g=1}^{|W_{i-4}^I|} p_{i-4,t_g}^I + \sum_{r=1}^{|W_{i-5}^I|} p_{i-5,t_r}^I, \quad (13)$$

where $t_h \geq 2$, $t_z \geq 3$, $t_e \geq 4$, $t_g \geq 5$, $t_r = 6$. W_{i-1}^I denotes the set of winning bids in time interval $i-1$, W_{i-2}^I denotes the set of winning bids in time interval $i-2$, etc. Equation (13) implies that cloud provider's revenue in one time slot depends on the Spot Block prices determined in current time slot and the prices of Spot Block instances initiated in five previous time intervals with corresponding duration (in time slot $i-5$, relevant requests are those with duration of 6 hours, in time slot $i-4$ relevant requests are those with duration that is equal or greater than 5 hours, etc).

When cloud provider applies Generalized Second-price auction winning bidders pay the value of the next highest bid. This means that each cloud customer has different set of possible payoffs. For each bidder, the set of unit bids is determined. However, Spot Block prices for each winning bidder are determined based on the unit bid of the next highest unit bidder. The set of the cloud customers payoffs in time interval $i \in [1, N]$ under Generalized Second-price auction is:

$$P_i^{II} = \left\{ \overline{\upsilon_{2,t_2}^i}, \overline{\upsilon_{3,t_3}^i}, \cdots, \overline{\upsilon_{M_i+1,t_{M_i+1}}^i} \right\}, \quad (14)$$

where $\overline{\upsilon_{2,t_2}^i} > \overline{\upsilon_{3,t_3}^i} > \cdots > \overline{\upsilon_{M+1,t_{M_i+1}}^i}$.

In this case, the Spot Block price per hour of cloud customer $q \in W_i^{II}$ can be expressed as follows:

$$p_{i,t_q}^{II} = \left(1 + \frac{(t_q - 1)\cdot\theta}{5}\right) \cdot \overline{\upsilon_{q+1,\,t_{q+1}}^i} \quad (15)$$

where $t_q = \{2, 3, 4, 5, 6\}$ and $\overline{\upsilon_{q+1,\,t_{q+1}}^i}$ is the next highest unit bid. Since cloud customers pay different Spot Block prices, we assume that the lowest winning unit bid in previous time interval is known in advance. These information provide decision support in choosing appropriate bidding strategies.

In accordance with (13), cloud provider's revenue under Generalized Second-price auction in time slot $i \in [1, N]$ can be expressed as:

$$R_i^{II} = \sum_{q=1}^{|W_i^{II}|} p_{i,t_q}^{II} + \sum_{h=1}^{|W_{i-1}^{II}|} p_{i-1,t_h}^{II} + \sum_{z=1}^{|W_{i-2}^{II}|} p_{i-2,t_z}^{II} + \sum_{e=1}^{|W_{i-3}^{II}|} p_{i-3,t_e}^{II} + \sum_{g=1}^{|W_{i-4}^{II}|} p_{i-4,t_g}^{II} + \sum_{r=1}^{|W_{i-5}^{II}|} p_{i-5,t_r}^{II}. \quad (16)$$

IV. Performance Evaluation

In order to analyze proposed scenarios, simulations in open source programming language Python 2.7 are performed in 1000 iterations. Time period of 5 days is simulated (Monday-Friday). Each day is divided into $N = 24$ time slots of one hour duration. Time slots from $i = 7$ up to $i = 20$ belong to the period of high traffic load [26]. The number of customers initiating requests in this the period of high traffic load is modelled by Poisson distribution parameter $\lambda_1 = 1.5$, while the period of low traffic load is modelled by Poisson distribution parameter $\lambda_1 = 0.5$. The number of cloud instances is $M = 50$. The average number of cloud customers is $B = 250$. The assumed probability of cloud instance unavailability (due to reserved, on-demand or spot instance initiation) is $Q = 0.33$.

The initial Spot Block prices for Spot Block duration of one hour and six hours are chosen from publicly available data for Amazon Spot Block instance *m4.10xlarge* in EU (Frankfurt) region and Windows

operating system [25]. Spot Block prices for duration of one hour and six hours are $p_{0,1}$=3.04 \$/*hour* and $p_{0,6}$=3.4 \$/*hour*, respectively. According to (2) and (3), θ=0.12 while Spot Block prices for Spot Block duration of 2, 3, 4 and 5 hours are: $p_{0,2}$=3.112 \$/*hour*, $p_{0,3}$=3.184 \$/*hour*, $p_{0,4}$=3.256 \$/*hour* and $p_{0,5}$=3.328 \$/*hour*, respectively. On-demand price per hour of equivalent on-demand cloud instance is p_o=4.24 \$/*hour* [25].

Considering these prices, it is reasonable to assume that values for parameters determining boundaries in bidding for appropriate bidding strategy are: $\delta_1 = \delta_6 = \delta_o = 0.2$.

We observe four scenarios depending on dominant bidding strategy. Scenarios 1, 2 and 3 analyze setting where cloud customers predominantly choose the first (q_1=0.50, q_2=0.30, q_3=0.20), the second (q_1=0.30, q_2=0.50, q_3=0.20), and the third bidding strategy (q_1=0.20, q_2=0.30, q_3=0.50), respectively. The fourth scenario analyzes the setting where all available bidding strategies are equally possible, q_1=q_2=q_3=0.33. After the first round of auctions, the Spot Block price for Spot Block duration of 1 hour (unit bid) is known publicly in the case of Uniform price auction. In the case of Generalized Second-price auction, the lowest winning unit bid is known.

Table 1 shows the average winning bids (expressed in \$) for all observed scenarios in the periods of high and low traffic loads under both auction mechanisms. These values are approximately the same, i.e. both auctions have nearly the same impact on cloud customers in the terms of bidding. Although customers pay different Spot Block prices under these auction mechanisms, their bid values are nearly the same. This means that in the terms of cloud customers' incentive to bid truthfully (submitting bids that reflect their actual willingness to pay), the applied mechanisms have the same effect.

TABLE I. AVERAGE WINNING BIDS [\$]

Scenario	Uniform price auction		Generalized Second-price auction	
	High traffic load	*Low traffic load*	*High traffic load*	*Low traffic load*
1	4.090	3.942	4.090	3.941
2	4.112	3.978	4.112	3.977
3	4.131	4.018	4.131	4.018
4	4.116	3.990	4.116	3.989

Table 2 shows the average revenue per instance (expressed in \$) that cloud providers achieves in the Spot Block market. This revenue depends on the Spot Block prices defined in an auction mechanism in current time slot and the Spot Block prices defined in previous five intervals. This is due to the fact that Spot Block instances can be run in 6 time slots without termination. The results in Table 2 show that Generalized Second-price auction provide slightly greater revenues in comparison with Uniform price auction.

TABLE II. AVERAGE CLOUD PROVIDER'S REVENUE IN TIME SLOT PER INSTANCE [\$]

Scenario	Uniform price auction		Generalized Second-price auction	
	High traffic load	*Low traffic load*	*High traffic load*	*Low traffic load*
1	3.142	3.268	3.197	3.360
2	3.090	3.235	3.137	3.318
3	3.039	3.189	3.083	3.263
4	3.081	3.226	3.128	3.305

The average savings (expressed in %) over On-demand instances are shown in Table 3. These values present the potential savings that cloud customers obtain for using Spot Block instead On-demand instances. It is notable that all scenarios provide savings greater than 20%. The greatest savings (28.334%) are achieved in the scenario where the dominant strategy is bidding close to On-demand price under Uniform price auction in the period of high traffic load.

TABLE III. AVERAGE SAVINGS OVER ON-DEMAND PRICES [%]

Scenario	Uniform price auction		Generalized Second-price auction	
	High traffic load	*Low traffic load*	*High traffic load*	*Low traffic load*
1	25.907	22.917	24.600	20.746
2	27.122	23.708	26.011	21.755
3	28.334	24.794	27.283	23.051
4	27.331	23.915	26.221	22.062

V. DISSCUSSION

Recently introduced Spot Block instances provide several advantages over classic Spot instances for both cloud providers and cloud customers. Cloud providers have better utilization of idle resources, while cloud customers can initiate these instances up to 6 hours without termination. In addition, the determined Spot Block price per hour for required Spot Block duration is fixed for this specified time interval. Therefore, once determined, the given price is fixed regardless on changes in supply and demand in cloud instances market. This is a great improvement in comparison with Spot instances, where cloud provider can terminate the instance whenever the spot price exceeds customer's bid. In general, Spot Block prices are greater that Spot prices, but significantly lower that On-demand instances. The results show that regardless of the chosen bidding strategy, greater revenues in average are achieved under Generalized Second-price auction. However, from cloud customers' perspective, Uniform price auction is more convenient, since it provides greater savings over On-demand price. This

approves that Spot Block instances are cost-effective solution for occasional workloads that require uninterrupted provisioning in duration less than 6 hours.

VI. CONLUSION

This paper presents analysis of auction-based pricing mechanisms for pricing cloud provider's idle resources in the form of recently introduced Spot Block instances. Uniform price auction, as a widespread pricing mechanism for cloud resources, is compared with Generalized Second-price auction. Initiating request for the access to the Spot Block instance, cloud customer choose one of the three possible bidding strategies. Depending on dominant bidding strategy, we observe several scenarios. In this paper, a model for Spot Block prices determination under these pricing mechanisms is proposed. This model provides an appropriate insight into price dependences of chosen auction mechanism. However, it requires that Spot Block prices in previous time interval are known in advance. We analyze average winning bids, average revenues per instance and average potential savings over On-demand pricing mechanism. In all observed scenarios, the significant savings over On-demand instances are achieved. In addition, Uniform price auction provides slightly less Spot Block prices and greater savings over On-demand instances. The results show that regardless on the chosen auction mechanism and regardless on chosen bidding strategy Spot Block instances are cost-effective solution that embodies advantages of On-demand instances and Spot instances.

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An Impact of General Data Protection Regulation on a Smart City Concept

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***Abstract* - The paper deals with a possible impact of implementation of General Data Protection Regulation on a Smart City concept in the area of electronic communications. The stake holders at electronic communications market will need to ensure full compliance with the General Data Protection Regulation, ePrivacy regulation and the directive on security of network and information systems. Rigid application of data protection and e-privacy rules may slow down or even jeopardize roll out of the solutions for both Internet of Things and a Smart City concept. The roles of national regulatory authorities have been described in the case of Republic of Croatia.**

Keywords – General Dana Protection Regulation, Smart City, electronic communications market regulation, Internet of Things, National Regulatory Authority

I. INTRODUCTION

Last years European commission has been working on several documents that will strongly influence data processing business. In April 2016 EU Parliament introduced General Data Protection Regulation (GDPR) [1]. In EU internet page is described that "GDPR was designed to harmonize data privacy laws across Europe, to protect and empower EU citizen data privacy and to reshape the way organizations across the region approach data privacy".

GDPR is a data protection law which is going to come in force on 25th of May, 2018 [2]. This regulation applies to any organisation that controls or processes the data of an EU resident. The regulation has a significant impact on business in all industry sectors, bringing changes for business in terms of both cost and effort. The introduction of new rights for individuals, such as Right to be Forgotten and the Right to Portability, as well as introduction of mandatory breach notification, are likely to increase the regulatory burden for both companies and governmental institutions. They need to review their current data protection compliance programs in order to determine next steps and furthermore decide on the level of investment they need to make, so as to address the change. On the same day e-Privacy regulation aligned with GDPR rules will be enforced as well. Therefore, in a single month, companies will need to ensure they have everything necessary in place to comply with the new GDPR, e-Privacy regulation [3] and the Directive on security of network and information systems ("NIS Directive") [4]. This has also a huge impact on electronic communications market regulation in EU with influence on EU single digital market and EU Digital agenda 2020 [5].

In parallel there is an another interesting process ongoing. The global societal challenges related to health, ageing and wellbeing, energy, transport and environment, inclusive, innovative, reflective and secure societies are and will be expressed particularly in the city. Smart systems connecting physical world and information world and providing autonomous mode of operation are recognized as part of the solution. Particularly important is the role of the Internet of Things (IoT) [6 - 9]. Smart City is a concept of urban development that comprises economic, social and environmental aspects of a city and quality of life of citizens. Basic technology behind such a complex development is Information and Communication Technology (ICT) enabling interaction and collaboration among citizens, services related to city physical and social infrastructure offered to them, and implementation and operation of smart systems for a smart city. International Telecommunication Union (ITU), among some other organisations, has established Study Group on Internet of things and smart cities and communities working on ITU-T Recommendation series Y. 4000 [10 - 14].

In this paper possible impact on electronic communications markets regulation in EU by implementation of GDPR, together with "ePrivacy regulation" and "NIS Directive", has been elaborated. General influence of GDPR omnibus data protection laws on electronic communications market regulation has been outlined in the second section of the paper. An impact of GDPR on a Smart City concept is described in the third section. The role of a national regulatory authority (NRA) for electronic communications in EU is discussed in the section four in the case of Croatian NRA, Croatian Regulatory Authority for Network Industries (HAKOM).

II. POSSIBLE IMPACT OF GDPR ON ELECTRONIC COMMUNICATIONS MARKETS IN EU

The transformation to digital society and digital economy is one of the results of ongoing process of digitalisation and globalisation. The creation of digital single market in EU has provoked that digital economy in EU has become increasingly reliant on the control and processing of personal data. On one side this process creates enormous opportunities for business but on another side could become obstacle or even a huge hurdle in implementation of new technologies. The process is accompanied by a growing public awareness and concern for the importance of personal data protection. The EU's response to this concern is GDPR:

Personal data protection is one of the key issues to be addressed by telecommunications network operators, given the importance of transparency and the risk of personal data breaches. Personal data management and protection gains a high attention especially by large operators which processes a large data volume about their end-users and end-users services. The implementation of GDPR and full compliance to GDPR, ePrivacy and „NIS Directive" introduce numerous requirements regarding the confidentiality and security of personal data. This process implies also a number of changes that the operators will need to implement, particulary in terms of personal data processing and protection.

Each operator, as the first step, has to find out where they have personal data, as well as to identify all data flows, boith internal and external, i.e. in the own country, outsided own country but within EU and outside EU. The operators have to perform an assesment whether local data protection laws and regulatory obligations need to be considered. They have to identiy all possible data sources, not only digital ones but also paper ones, audio and video recording, pictures, archived documents, etc.

Keeping space with the evolving threat landscape is a challenge even without the GDPR's stipulation for defences of contemporary threats in ICT. The problem partly comes from the way cyber security has evolved because every new way of attack produces a need for a new security solution to be added. Although each such additional solution may fulfil its role as it has been intended to do, it does mostly with little or even no interaction with the rest of the security infrastructure. This is not only hard to manage but can easily lead to gaps and inconsistencies in the response to new threats. Especially across a multi-vendor environment. The challenge is compounded by the adoption of trends such as mobility, cloud computing and IoT, all of which expand the effective attack surface, exposing new vulnerability and eroding the traditional concept of a telecommunication network border.

One of possible responses to those new threats is to increase processing and control. Additional processing power also adds complexity, thus multiplying the number of data points to be aggregated and interpreted when evaluating the best response to any detected event. Any "state of the art" solution will not only need to overcome the above-mentioned challenges but continually adapt to changes in the usage of technology and evolving threat landscape. Independently which solution will be applied, total cost of ownership for network operator will be increased by full implementation of GDPR in order to fully and timely comply to the GDPR requirements. These costs could arise to a level that there is no positive business case for an operator to implement a new technical solution or an end-user service which is based on a new technology like IoT. Furthermore, an additional obstacle in implementation of new technology due to GDPR could be complexity of administrative procedures that should be undertaken by both operators and end-users in order to fully comply to GDPR requirements, as well as additional costs connected to these procedures.

III. AN IMPACT OF GDPR ON A SMART CITY CONCEPT

Electronic communications have gone through a completely different process, from state monopoly to a competitive market of electronic communications. This transition was governed by statutory regulation. The present situation in the EU is defined by the common regulatory framework for electronic communications [15]. According to a Framework Directive, the NRAs shall "contribute to the development of the internal market", "promote the interests of the citizens", and "promote competition in the provision of electronic communications networks, electronic communications services and associated facilities and services by *inter alia*: (a) ensuring that users, including disabled users, derive maximum benefit in terms of choice, price, and quality; (b) ensuring that there is no distortion or restriction of competition in the electronic communications sector; (c) encouraging efficient investment in infrastructure, and promoting innovation; and (d) encouraging efficient use and ensuring the effective management of radio frequencies and numbering resources".

Different approaches have been applied to regulate certain issues in electronic communications, and regulatory objectives have changed in line with technological and market changes. The same process is needed in the future, but at a faster rate. The development of the information and communication technology including networks, services, applications and content is exceptional, as is the research and innovation in this area. This must also be reflected in the governance and regulation of electronic communications, including the Internet, in order to be able to adapt to changing environments and prepare solutions for evolved and predicted problems. Different types of problems require different regulation tools, i.e. different solutions for different circumstances. The need for smart regulations that are effective and solution-oriented, ranging from no-regulation (deregulation), self- and co-regulation, to statutory regulation, has been recognized [16]. Such a regulation space and its three dimensions is shown in Figure 1. These three dimensions are: type, impact and topic.

Changes are also expected in the manner in which regulation is implemented: from vertical solutions for a specific network or service towards solutions for multiple, in some cases all, networks or services. Many systems and services that combine features from different paradigms require such solutions, for instance using IoT for sensing and collecting data and cloud computing to store it and execute applications [17-19].

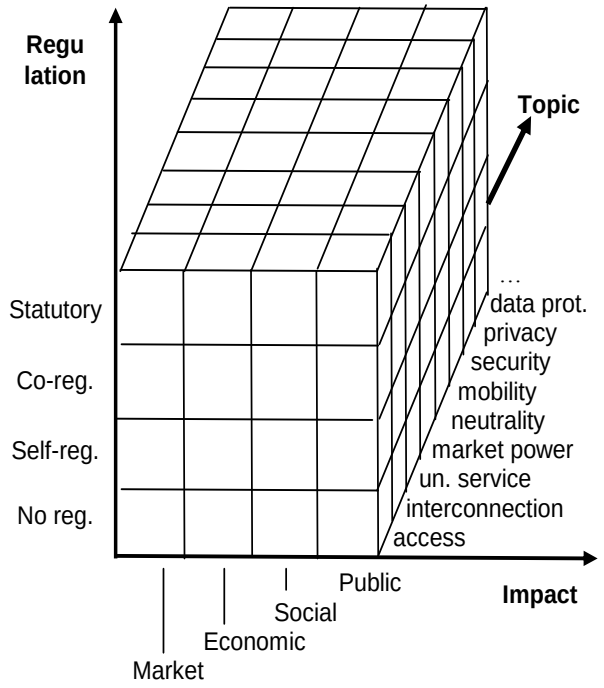

Figure 1. Market regulation space

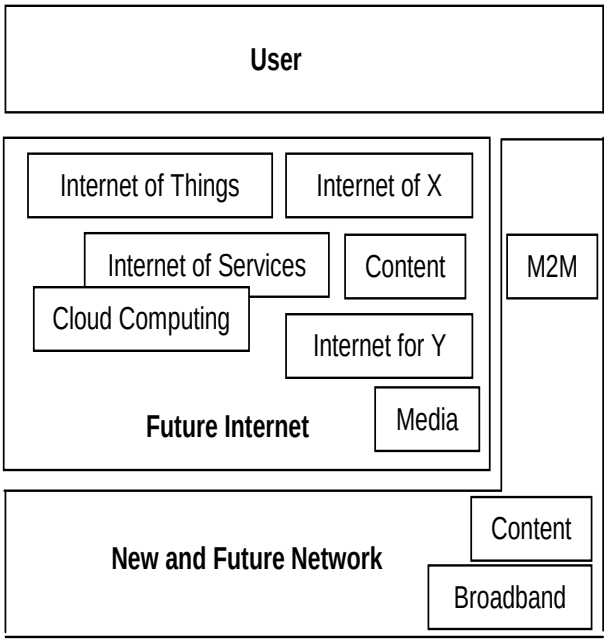

Figure 2. Future of Networking Landscape

Research and development of IoT solutions for Smart City is a global process but implementation is a local process that should take into account the specific issues and requirements of each city in order to produce benefits for its citizens and promote public interest. One of these specific local requirements is also data protection law and regulatory framework. The question is whether these regulatory directives will ensure trustworthiness or it will become a burden to the faster development of IoT, especially in the context of Smart City [20]. New GDPR and e-privacy directive features, like right to erasure, privacy by design and by default, data portability and data breaches rules will raise the level of trust in IoT technology for sure [21]. However, pseudonymisation as one of the major pillars of GDPR can have negative impact on further development [22]. New requirements relating to content- and service-awareness, computing capabilities, ubiquitous broadband access and mobility, massive connectivity of various devices and objects reflect on security, privacy and data protection. IoT, cloud computing as the enabler of Internet of Services (IoS), communication Machine-to-machine (M2M), and new paradigms related to content and media on the Internet are widely used, as it is shown in the Figure 2.

Transformation of personal data in such a way that the resulting data cannot be attributed to a specific data subject without the use of additional information is very expensive process. IoT devices, like sensors or actuators, that collect such data, usually have limited processing power and are battery powered. Applying data protection and privacy rules on such devices may slow down or jeopardize roll out of IoT. Therefore it is necessary to take care of horizontal architecture of IoT when implementing these functionalities.

IV. THE ROLE OF HAKOM AS CROATIAN NRA

HAKOM, as Croatian NRA, together with academia in Croatia within the research project "Looking to the future 2020", work on creating an ecosystem open to the implementation of new communication technologies as IoT enablers. One of the goals of the project is to promote advantages and opportunities of IoT, thus encouraging and fostering the idea of human-centric digital age. The project members work, among other topics, on identification of the elements that may have an impact on the further development of IoT. While limited national resources, like radiofrequency spectrum, numbering and addressing will prove to be an issue in the future, lack of understanding and knowledge of security and privacy may slow down development already today. The role of HAKOM as the NRA for electronic communications is twofold, the market regulation in collaboration with other regulatory authorities and encouragement of the introduction of IoT.

Some policy and regulatory issues fall within the scope of electronic communications, but topics related to privacy, security protection require responsibility across the entire IoT value chain. National regulatory authorities for electronic communications having wide experience in all these areas can play significant role in development of trustworthy IoT for Smart City [23]. A close cooperation of HAKOM with national Private data protection agency, as well as with government and market stake holders, is essential prerequisite for a successful implementation of GDPR without jeopardising operators' business plan and time plan for implementation of new technical solutions and innovative end-user services, based on new technologies.

If there is no NRA for private data protection and/or there is no national act/law about private data protection, there is a concern about human rights and privacy of the citizens. Theoretical example of possible violations are numerous [24] while practical experience already confirms cases of privacy violation in applied Smart City concepts, not only outside Europe, but also in EU [25, 26].

V. CONCLUSION

A new approach to security, ePrivacy and data protection is required in order to fully and timely comply to GDPR requirements. The operators of electronic communications network have to connect together all key components of the security infrastructure in a seamless fabric thus enabling a successful implementation of the solutions and innovative end-user services, based on a new technologies. This process could be very expensive for an operator and can jeopardize their business plan an time plan for implementation of the solution that boost development of digital society, digital economy and single digital market in EU. Typical example is implementation of IoT as the base for a Smart City concept where administrative procedure and additional solution complexity due to obligatory compliance to GDPR requirements can not only significantly increase the cost of ownership but also turn the solution to high complexity and make it unattractive for end-users, or even unusable for them.

The role of the NRA for electronic communications is discussed from broader regulatory perspective involving public policy related to deployment of IoT and development of trustworthy IoT. This has to be done in close cooperation with national private date protection regulatory authority, government and market stake holders. An ultimate common goal is to boost digital economy by deployment and innovative end-user services which are based on new technologies and in the same time to fully comply to GDPR and to turn out GDPR requirements from obstacles and challenges into business opportunities.

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DIGITAL TRANSFORMATION AND OPEN SOCIETY

Linear Regression Analysis of Energy Consumption Data for Smart Homes

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Abstract - **Due to the population and economic growth, global demand for energy is expected to increase considerably in the coming years. A large part of the energy demand comes from energy use in buildings. Consequently, energy efficiency requirement in buildings is considered to be one of the most important goals to promote global energy sustainability. This challenge has motivated recent research in the design of smart home energy management systems based on a set of sensors that analyse how energy is consumed in buildings.**

In this paper, linear regression model is used to analyse energy consumption data from two real smart homes. The datasets include operational data in two homes and were collected as part of the Smart* project.

Keywords - ***Smart homes; linear regression analysis; energy efficiency.***

I. INTRODUCTION

With the world population projected to grow to 9.2 billion by 2040, the demand for energy is expected to increase substantially in the future [1]. The Annual Energy Outlook projects that between 2015 and 2040 world energy consumption increases by 28% [2]. Much of the energy demand comes from residential and commercial buildings which accounts for over nearly 40% of global energy consumption [3]. Due to the high energy required by appliances, ventilation and lighting, buildings are considered to have the highest impact on energy consumption [3].

Improving energy efficiency in buildings will play a key role in reducing the energy consumption and ensuring sustainable energy management. The need for efficient energy management implies the need for new technologies that can manage energy consumption in buildings [4]. Smart technology is one of the new techniques used in homes to addresses the increasing energy demand. Smart technology is a home energy management technique that regulates energy consumption in homes through automated devices that collect energy consumption data [5]. In recent years, smart homes have attracted a great interest from the research community. Smart home systems have become a promising means of managing energy usage in households and have the potential to significantly reduce energy consumption and improve the quality of life [5]. The challenge of smart homes has been reported to be meaningful extraction of the consumption data collected [6]. Data mining techniques are often used to analyse the energy consumption data [6].

In this paper, the energy consumption data of two real homes (Home B and Home C) from UMass Smart Dataset is analysed [7]. The dataset was collected during the period 2014-2016 as part of the Smart* project [7]. Linear regression model is used to analyse the data and R^2 is estimated to measure the correlation between the energy usage and the outside temperature. The paper is organised as follows. Section II gives a literature study on energy management, smart home technology and linear regression analysis. Section III discusses the datasets used and the methodology followed. Section IV presents the results retrieved from the linear regression model and the analysis of the results. Finally, Section V concludes the paper.

II. LITERATURE REVIEW

A. Energy Management and Smart Homes

The term energy management refers to "the process of monitoring, controlling and saving energy in a building or organization" [6]. The objective of energy management is to protect the climate, conserve resources, reduce costs and ensure sustainable generation of energy [6]. The four-step process of energy management, according to Energy Lens involves: measuring energy consumption data and collecting the consumption data, analyzing the data to measure the amount of energy that could be

saved, taking the necessary actions to save energy, and tracking the progress by analyzing the consumption data and repeating the process until a stopping criterion is satisfied [8].

To measure the energy consumption data, smart home technology is often employed. Smart home technology introduces the concept of device networking in a house or building [5]. The smart home technology makes use of digitals devices known as smart meters [5]. These smart meters can be read in intervals over a wireless network. The smart metering system allows power utilities to remotely read consumption data, manage meters and provide customers with detailed energy usage information [9]. The features of smart meters include automatic transfer of consumption data, two-way wireless communication with meters, automatic management of consumption data and transfer of timely consumption data [9]. One of the benefits of using smart meters is that customers are provided with detailed energy usage information. It is expected that this information will prompt customers to reduce their consumption by between 10 % and 5% [9]. Another benefit is that the cost of data collection is reduced through remote collection of meter data. Furthermore, more accurate can be provided for billing information [9]. Many important aspects of the building such as outdoor weather, individual energy consumption of appliances, temperature, can be collected.

The use of smart meters is associated with high costs including the capital costs of smart meters, maintenance costs and communication costs. Due to the fact that smart metering is a recent technology, its implementation is perceived as risky [9].

B. Linear Regression Analysis of Energy Consumption Data

Extracting meaningful values from the meter data collected is one the key challenges in smart home technology [6]. Information about the household energy usage patterns can be extracted by using linear regression analysis. Regression analysis is usually the best option and the fastest method to analyse the consumption data of buildings [6]. The regression model is used to correlate the energy usage with the outside air temperature. The first step is to acquire an interval consumption dataset. To obtain correlation, historical weather data known as degree days is used [10]. Degree days can either be heating or cooling. Heating degree days (HDD) is used when investigating heating energy consumption while cooling degree days (CDD) is used when investigating cooling energy consumption [10]. A base temperature for the HDD must be chosen. This base temperature represents the temperature below which the building requires heating and varies from building to building [10].

A relationship between the energy consumption and the degree days is established by plotting an X-Y scatter chart. The equation of the trend line enables estimation of energy consumption from the degree days [10]. Energy consumption can be predicted and compared with the actual energy consumption. The R^2 value is an important measure of how good the correlation is [10]. Higher R^2 values (closer to 1) indicate better correlation between the energy consumption and the degree days. A good correlation further indicates that the heating or cooling is working well and the methodology used is satisfactory [10].

III. METHODOLOGY

A. Data Collection

The dataset studied in this work was chosen based on certain criteria that include long-term measurement periods of not less than a year, data consumption of all the appliances in the building and consistent time-intervals. The Smart* datasets contains power data from three real homes collected over a period of 2 years (2014-2016) [7]. The current focus for Smart* project was to collect data from as many data as possible from many sensors in real homes [7]. The Smart* project uses a live-system to collect environmental and operational data in real homes [7]. This includes home electricity consumption at 30-minute intervals, energy usage at every circuit, outdoor weather data, indoor temperature, and data from, for example wall switches and doors. For the purpose of this study, only two datasets were used (Home B and Home C). The work focuses on individual appliances consumption and home aggregate.

B. Linear Regression Analysis

The methodology discussed in Section II was used to implement a linear regression analysis on the energy consumption data. Using the Energy Lens Software, the 30-minute interval data was converted to weekly kWh data. The Degree Days.net tool was used to access degree days based on the weather ID, Western Massachusetts. For this analysis, the regression the base temperature was chosen to be 17˚C. The regression analyses were done for home B and home C for the periods 2014 and 2015 to find out if correlation changes. The heating and cooling degrees days were analysed for both homes.

IV. RESULTS

A. Home B

Home B is a two-story building with approximately 157.9 square meters. It has eight rooms and four full-time occupants. Home B has central air conditioner used for heating and cooling in addition to a gas-powered heating system [11]. Figure 1 and Figure 2 below represent the linear regression analysis results for CDD and HDD for periods 2014 and 2015.

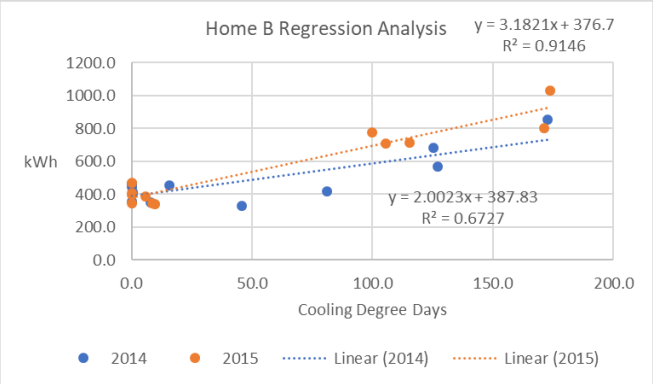

Fig. 1. Home B regression analysis for cooling degree days (CDD)

From Figure 1 above, there is an improvement in the value of R^2 from 2014 to 2015. This indicates that there has been an improvement in the cooling control and hence an improvement in energy consumption [12-15] of Home B.

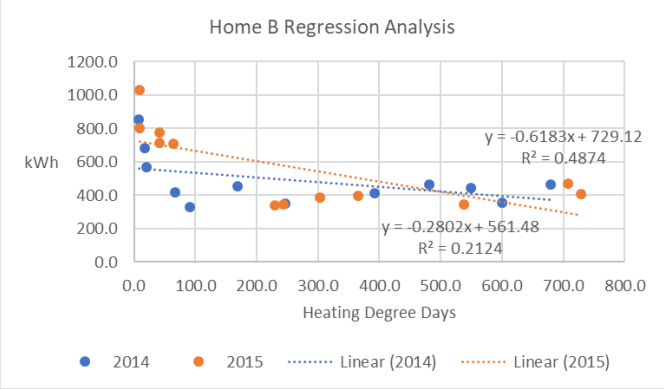

Fig. 2. Home B regression analysis for heating degree days (HDD)

The correlation for 2014 and 2015 of the HDD and kWh is poor with the R^2 values below 0.7. According to Bizee Degree Days, a negative coefficient (on HDD, CDD, or the constant) is usually an indication that the regression [16-21] is not a good one [10]. This means that a linear regression is not a good fit for the data. Other types of regression models [22-23] can be investigated [24-26]. This data was fed into The Degree Days.net Baseline Regression Tool. The Degree Days.net Baseline Regression Tool tests many regression models that will give the best correlation. The results obtained from the tool are tabulated below.

TABLE I. HOME B MULTIPLE REGRESSION MODEL RESULTS

y = a*HDD + b*CDD + c*days	2015	2014
HDD coefficient (a)	0.16	0.23
CDD coefficient (b)	3.63	2.57
Constant (c)	10.00	9.72
R^2	0.86	0.68
R^2 adjusted	0.86	0.67

From the equation in the above table, y represents the energy usage over the period in question; HDD is the heating degree days over the period in question; CDD is the cooling degree days over the period in question; days is the length (in days) of the period in question; a, b, and c, are regression coefficients [10]. Using a multiple regression model, the correlation improved to above 0.7 for 2015. This indicates that has been an improvement in the heating control and hence an improvement in energy consumption of Home B.

B. Home C

Home C is also a two-story building with 325.2 square meters.

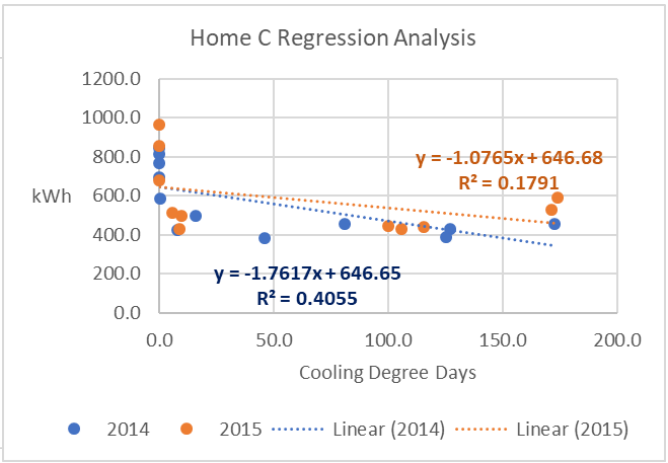

Fig. 3. Home C regression analysis for cooling degree days (CDD)

Figure 3 depicts the regression analysis results for cooling degree days. The regression line for Home C has negative coefficients for both years, indicating that the linear regression model is not a good fit. The Degree Days.net Baseline Regression Tool was used to analyze the data and the results are tabulated in Table 2.

TABLE II. HOME C MULTIPLE REGRESSION MODEL RESULTS

y = a*HDD + b*CDD + c*days	2015	2014
HDD coefficient (a)	0.93	0.23
CDD coefficient (b)	1.81	2.57
Constant (c)	7.21	9.72
R^2	0.68	0.68
R^2 adjusted	0.67	0.67

The R^2 values calculated using the regression tool are 0.67 for both 2014 and 2015. Therefore, the cooling control of Home C can be improved which will in turn improve the energy consumption. The results also show that there hasn't been any improvement from 2014 to 2015.

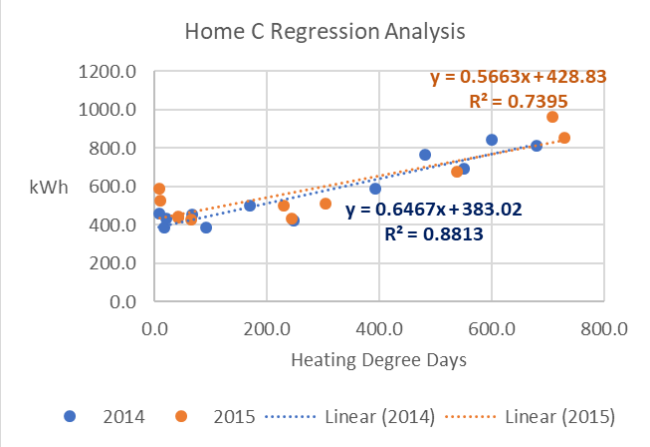

Fig. 4. Home C regression analysis for heating degree days (HDD)

For the heating degree days of 2014 and 2015, both R^2 values are above 0.7 (Figure 4). This indicates a good correlation. There is a decrease in the R^2 value for 2015. The heating control is worsening as compared to 2014. This implies an increase in energy consumption from 2014 to 2015.

V. CONCLUSIONS

Linear regression analysis was done on the energy consumption datasets of homes B and C obtained from Smart*. A good correlation was seen for Home B's cooling degree days and Home C heating degree days. An improvement in energy consumption was observed in Home B for period 2015 due to better heating and cooling control. No improvement in cooling control was realized in Home C. Furthermore, the heating control of Home C deteriorated in 2015. Therefore, it can be concluded that the energy consumption for Home C has increased. To decrease this consumption an intervention is required and a detailed study must be conducted to determine which equipment is consuming more energy. Linear regression model proved to be inadequate for HDD of Home B and CDD of Home C. Better correlations were realized after using multiple regression models from a regression toolkit.

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Customer-Centric Culture as Enabler of Digital Transformation

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***Abstract* — The telecommunications industry is characterized by digital transformation. In an environment of technological changes and innovative and dynamic business, becoming more customer-centric is a core business requirement for today's communication service providers (CSPs). Improving the customer experience starts with organizational culture. Customer-centric culture can help grow revenues, improve efficiency, productivity and quality of service. This paper explores what organizational culture is, why it is important and why customer-centric internal culture is a key factor in providing quality customer service. Also, it is given a use case with directions of change from current established internal culture towards possible desired customer-centric culture for telecommunication market in Bosnia and Herzegovina.**

I. INTRODUCTION

Digital transformation is the strategic use of modern technologies to radically change the way companies are following changes in customer expectations and market conditions. In this process, leadership is required to encourage organizational culture in which knowledge, innovations and continuous improvement are valued. Accordingly, everyone in the organization must be aware of new technological trends and align their work with new processes and working procedures. Customer-centricity is the most important organizational characteristic in establishing a truly data-driven and innovative culture across various industries and sectors, [1]. It is also a novel paradigm which is shaping the evolution of the future telecommunications business. There is an urgent need to transform CSPs from network-centric to customer-centric businesses to accommodate increased customer expectations and competitive pressure. Customer experience has a direct impact on user loyalty and revenue and will decide the future of telecom services. In the upcoming period, customer experience will continue to grow in importance for CSPs. In this environment it is expecting culture change intensifying because customer experience is a reflection of an organization's culture and operating processes.

Global changes in telecom sector are reflected on the market in B&H. Delivering a high-quality customer experience, consistently, across the entire organization, starts with internal culture. It is a difficult and time consuming process. Strong understanding of customer experience is crucial in transformation from network-centric to customer-centric business strategy. It is a top priority to differentiate operators in order to have a competitive advantage. CSPs need a more sophisticated, real-time view of performance that provides a deeper understanding of how customers are using and experiencing specific services. Moving from network-centric toward customer-centric operations and introduction of Customer Experience Management (CEM) are important steps in that transformation process, [2]. This transforming will be challenging for CSPs due to a lack of relevant skills and technical complexities.

A specific set of common beliefs, attitudes, assumptions and values in an organization that determines the way in which employees in the organization act and interact with each other are strongly affected in the way things are done in the organization and create a special identity of the organization. Organizational culture is a set of abstractions that have a clear and very realistic effect in the organization. A customer-centric company must have a program for changing the organizational culture of the company, which aims to develop a strong and harmonized organizational culture that can support the successful realization of the strategic goals of the company. Corporate values of the company represent the core of the company's identity, common principles, beliefs and business philosophy e.g. customer orientation, teamwork, focus on change, growth and development of the company, company ambassadors. The necessity of adapting existing organizational culture to dynamic changes in the market has prompted many authors to deal with this problem.

This paper highlights the importance of organizational changes in telecommunications companies. The second section summarizes characteristics of the modern customer–centric business management. In the third chapter the importance of internal organizational culture is discussed. At the end it is given a possible scenario of changing current internal culture towards an innovative customer-centric solution.

II. CUSTOMER-CENTRIC BUSINESS MANAGEMENT

A. Customer-centric business strategy

In a huge and complex digital world, there is a clear need for CSPs to understand the relevance of customer

experience from the perspective of the end user. Customer experience awareness and high level of personalization are crucial in the process of transformation into a customer-centric company. CSP has the opportunity to use the concept of customer awareness by combining technology, strategies and resources to significantly improve customer satisfaction and loyalty. Strategies for embedding customer-centricity into the organization are given in Figure 1 and explained in [3]. One of the strategies may also be to develop a customer-focused internal culture in the organization.

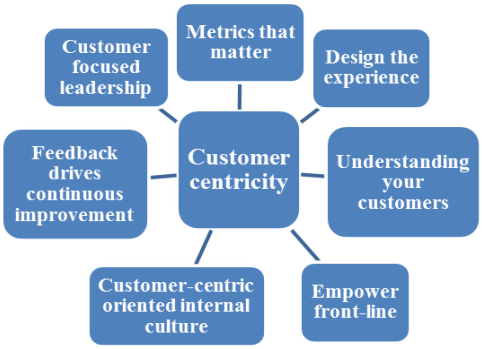

Figure 1. Strategies for embedding customer-centricity into the organization.

Strong understanding of customer experience is necessary in the process of CSP transformation into a customer-centric business strategy. It is important to offer a great experience in all touch points, from awareness stage, through the purchasing process and finally through the post-purchase process. Customer-centricity is a strategy that is based on putting the customer first, and at the core of business. The shift towards becoming a truly customer centric organization is both complex and long but, as even the smallest changes to policy and processes can have a significant benefit for both employee and customers. Customer-centric organization is characterized by four key abilities, Table1. These abilities are demanding a high degree of engagement from every employee. This can be achieved through goal setting and training, but it also requires the right organizational structure, optimization of the organizational structure, internal interfaces and culture.

TABLE 1: KEY ABILITIES OF CUSTOMER-CENTRIC ORGANIZATION [4]

Key Abilities	***Explanation***
Being attentive	Being flexible and available. Offer a high level of personalization.
Being proactive	Predict customers' troubles and refer about them early before they become a problem
Being consistent	Offer consistent, perfect and immediate information through all channels.
Being adaptive	Adapt services and products in accordance with customer's needs.

In many cases, a customer experience management system will also play a key role. It is a business assurance tool that monitors and actively controls the impact that the user's perception of a product, brand or service has on the business result of a service provider. The user's perception is based on their individual expectations. Many service providers find they need to adapt their business processes to make use of the new insights they receive from CEM. These process adaptations can be expected to produce significant improvements in business results. The CEM's task is to help identify any deficiencies within the organization and take all the necessary corrective actions. Also, using CEM insight enables each department within the CSP to fulfill and overcome its tasks with a constant awareness of the impact of customer experience. Customer-experience-related criteria of success can make investment decisions easier and point to return on investment actions and changes [4].

B. Customer-centric metrics

Introduction of customer-centricity concept should be supported by the right metrics. For a customer-centric business, the most valuable asset is the customer. The two most important customer centric metrics that should be carefully monitored are: churn rate and customer lifetime value (CLV). The churn rate is a percentage of customers who end their relationship over a specified time period. It is calculated as a measure of the number of customers who left in the last 12 months divided by the average number of total customers during the same period. The profits generated during the retention phase are often known as customer lifetime value. It measures the profit that the organization makes from any given customer. It is calculated as the customer's revenue, minus money spent for serving, and adjusts all payments for the time value of money. A customer-centric business strategy maximizes customer lifetime value and ultimately creates a differentiation compared to competition. CLV is using in CSPs' strategy for better segmentation of the customer base. By analyzing data consumption patterns and identifying customers who contribute the highest average revenue per user (ARPU), CSPs can create personalized initiatives to prevent them from churning. In accordance with the above, the evolution of product-centric metrics into customer-centric metrics is given in Table 2.

TABLE 2: TRANSFORMING FROM PRODUCT-CENTRIC TO CUSTOMER-CENTRIC METRICS [5]

Product-centric metrics	***Customer-centric metrics***
Product Profitability	Customer Profitability
Current Sales	Customer Lifetime Value
Brand Equity	Customer Equity
Market Share	Customer Equity Share
Calculating Product NVP*	Calculating Customer NVP*
Managing Product Lifecycle	Managing Customer Lifecycle
Strategy Driven by Product Organization	Strategy Driven by Customer Segment CEO
Incentives at Product Level	Incentives at Customer Level

*The ***Name Value Pair*** are representation of assigned values for a specific concept.

III. THE IMPORTANCE OF INTERNAL CULTURE

The term organizational culture is a system of common values that are unconditionally accepted and live, as well as the assumptions that lie in their basis, expectations and characteristics that define the organization and its members. It encompasses common expectations, collective memories and different characteristics of people and relationships that are present in the organization. It also gives a sense of identity to employees, gives them unwritten rules on how to behave in the organization and

helps them fit into the social system in which they are. Factors shaping corporate culture can be internal and external. External conditions are: economic system, market development, social and competitiveness trends, technological innovations, regulatory framework. The internal conditions are: the purpose, strategies and technology of the organization, the crisis and the area in which the company operates. The corporate culture in the organization always goes from the top to the bottom. The most important factors are the personal philosophy and behavior of the company's management, such as: leadership style, character traits of managers and employee profile. The process of managing a internal culture represents the processes of defining, developing, implementing, controlling and improving of internal culture.

The significance of the organizational culture can be seen from its influence on the business results of the enterprise. There is a strong belief that the successful work of the company is necessary and the organizational culture of certain characteristics and contents. According to [6], all successful companies have a strong culture, which has certain values and beliefs. Organizational culture in the following ways influences the functioning of the company:

- It is a very important factor in making strategic decisions, significant for the company's operations as a determinant of its ability to adapt to changes.
- It is the mechanism of coordination in the company and an effective mechanism for controlling employee behavior.
- Reduces conflicts in the company and
- Powerful motivator.

Organizational culture has a cognitive and symbolic component. Cognitive elements of culture are in the minds of people, while symbolic elements are visible in the daily life of an organization [6]. It can be said that the organizational culture lies in the basis of collegiality and loyalty to the company. Such a defined organizational culture represents a framework for identifying corporate values.

A. *Competitive Values Framework*

Corporate values shape internal culture and support the mission and the vision in the company. They are the core of the company's identity - principles, beliefs or philosophies of its value. Corporate values are operating philosophies or principles that govern internal relationships in the organization, as well as its relationship with clients, partners and shareholders. Corporate values are a concise declaration of the organizational culture. The most commonly used theoretical framework for the assessment of organizational culture is the competitive values framework. This model considers the existence of four typical organizational culture profiles: collaboration (clan), innovation (adhocracy), market (competitiveness) and control (hierarchy) as it is also shown in Fig. 3. The characteristics of each of them are given in the Table 3. These profiles are viewed through two dimensions - the company's direction to the inside or outside and the degree of control, from firmly controlled to flexible. By crossing these two dimensions, four quadrants are formed, each representing an ideal type of organizational culture [7].

TABLE 3: COMPETITIVE VALUES FRAMEWORK [7]

Culture Type	***Work place, Leaders & Values***	***Benefits & Success***
Collaboration	Friendly place to work. Leaders are mentors, coaches. The organization is held together by loyalty, tradition, and collaboration. The commitment is high.	The organization emphasizes the long-term benefits of individual development with high cohesion and morale being important. Success is defined in terms of internal climate and concern for people. The organization places a premium on teamwork, participation, and consensus.
Innovation	Dynamic and creative workplace. Effective leadership is visionary, innovative, and risk oriented. Commitment to experimentation and innovation.	Readiness for change and meeting new challenges are important. The organization's long term emphasis is on rapid growth and acquiring new resources. Success means producing unique and original products and services
Market	Results-oriented workplace. Leaders are demanding, hard driving producers, directors, and competitors. Emphasis on winning.	The long-term concern is on competitive actions and achieving stretch goals and targets. Success is defined in terms of market share and penetration. Improving faster then competition, escalating share price, and market leadership dominate the success criteria.
Control	Formalized and structured place to work. Procedures and well-defined processes. Effective leaders are good coordinators, organizers, and efficiency experts.	Maintaining a smooth-running organization is important. The long-term concerns of the organization are stability, predictability, and efficiency. Formal rules and policies hold the organization together.

B. *Customer-centric culture*

There is no organization that absolutely reflects only one type of culture. Each of above mentioned types of culture exists in different degrees within each organization. There is no successful company with an exclusive culture type. A certain conflict of different types of culture is necessary for successful business and it needs careful planning. Many organizations make great efforts to achieve quality culture. A quality culture is a system of shared values, beliefs and norms that focuses on delighting customers and continuously improving the quality of products and services. In an organization with a quality culture, quality is deeply embedded in virtually every aspect of organizational life, including hiring and promotion, employee orientation and ongoing training, compensation, management style, decision making, organizational structure, work processes and office layout.

Customer-centric companies strive to introduce customer-centric culture. They empower employees to: make decisions that are for the benefit of the customer; hire people who fit the culture and have personalities that align with the company's core values, mission and vision;

invest a lot of time and money into soft skills training such as customer service and relationship building; develop their people at a level that keeps them engaged and enthusiastic about taking care of the company's customers.

A customer-centric company must have a program for changing the organizational culture of the company, which aims to develop a strong and harmonized organizational culture that can support the successful realization of the strategic goals of the company. The benefits of innovative culture - readiness for change and meeting new challenges are very important. That is the reason why is one of the most important steps in shifting towards becoming a truly customer centric organization, the development of an appropriate innovative internal customer-centric culture. By using of customer-centric innovation, some players are thinking more radically and developing completely new customer value propositions. This requires new business models and competencies but also can generate significant revenue streams, [8].

IV. CASE STUDY – TOWARDS CUSTOMER-CENTRIC INTERNAL CULTURE

A. *Changing organizational culture - necessary steps*

The market in Bosnia and Herzegovina is very specific. It is characterized by the following factors: the three dominant national operators, the only telecommunications market in the region that is not implemented 4G/LTE technology, weak economic development and low ARPU in relation to the average ARPU in EU. Broadband services are increasing, data traffic is growing continuously, and the number of smartphones and over-the-top (OTT) providers and applications are increasingly common in the market. In order to follow the trends of developed telecommunications markets, the B&H market also needs to evolve from a network-centric to customer-centric. In this process, one of the most important steps is the development of appropriate corporate culture in telecommunications companies. This process can be carried out in several sub-processes shown in Figure 2.

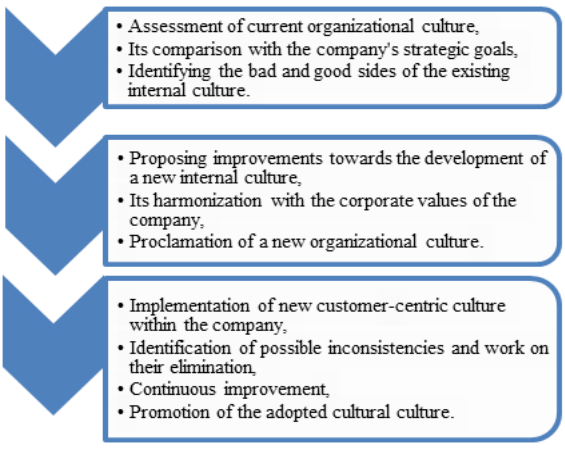

Figure 2. Process of customer-centric culture implementation.

Creating and sustaining a quality culture that facilitates continuous change and improvement is crucial for long-term organizational success. Changing organizational culture is a challenging and time-consuming process as it necessitates changes in the way people think and behave. To ensure success, cultural change efforts must focus on formulating a clear and common vision; securing sustained top management commitment; role modeling of desired behavior by top leaders; promoting employee involvement; conducting appropriate training at all levels to consume the new culture; maintaining open and honest communication; promoting a climate of trust and collaboration; and embedding cultural changes in the organization's structure, systems and policies. It is highly important to ensure that the desired culture is compatible with organizational strategy.

In this paper we gave an example of the directions of change from the current established internal culture to the customer-centric culture for B&H market. This transforming will be challenging for CSPs in B&H due to a lack of relevant skills, organizational inertia and technical complexities. The following steps given in [9] can be used in creating and maintaining customer-centric culture for B&H market:

- Recognizing the need for change (e.g. financial crisis, competitor pressure, changes in customer expectations).
- Assessment of current organizational culture.
- Ensure that the new culture is aligned with organizational vision and strategy.
- Communicating the desired culture to all organizational members.
- Modeling of desired behavior by leaders.
- Conducting appropriate training at all levels to imbibe new culture.
- Harmonizing the dominant future organizational culture through reinforcing the desired behavior and evaluating progress towards desired culture.

To accelerate and sustain the cultural change process, the desired behavior of employees should be reinforced through recognition and reward systems. Continually monitoring and evaluating of the cultural change efforts are enforced to determine if the desired behaviors' were achieved. If the cultural change efforts are not successful, taking corrective actions is necessary.

B. *Research results and findings*

A possible scenario of changing current internal culture towards an innovative customer-centric solution in a realistic environment is given in the survey example. The survey, in the form of an interview, was placed among 20 respondents, employees in the telecom sector in B&H. It was an informal empirical review. The questionnaire is prepared according to the identified and described steps in previous discussion. The participants were asked to assess the organizational culture according to the competitive values framework. They should to draw a current and desired organizational culture, which, in their opinion would help the B&H's companies to follow the trends of modern telecommunications market. The results are presented in Figure 3. The participants agreed that Control is currently the dominant organizational culture of the company, followed by Market and Collaboration and the

least is Innovation. The participants concluded that today's culture needs to be adapted to the strategic development plans and customer-centricity trends. The representatives believe that the greatest measures need to be taken in order to increase Innovation and Collaboration and reduce Control. Reduction does not mean that control is less important. It is necessary, but only to the extent that supports efficiency and competitiveness.

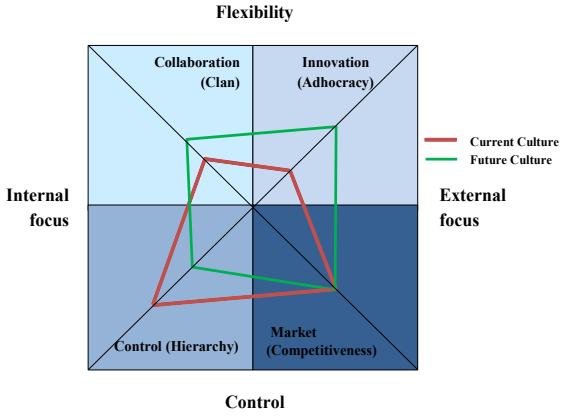

Figure 3. Competitive values framework: Comparing a CSP's current and preferred future culture – a possible scenario.

Basic findings about the direction of change from the current to the desired organizational culture are:

- Successful cultural transformation efforts are focused on clearly defined results and aligning the new culture with organizational vision and strategy.
- Strengthening the culture of Innovation towards customer-centricity is unanimously accepted as the driver of future growth and development of the companies.
- Leadership style propagated in the desired way from top to bottom in the company. Encouraging the style that motivates individualism, creativity, freedom and uniqueness.
- Innovation and creative approaches are welcome in all business segments. It is expected that innovative solutions will be customer-oriented.
- Building a culture that puts the customer at the center and aligns objectives, targets, rewards and recognition with customer needs.
- Encouraging readiness to take responsibility and risk. Revising procedures that impair the efficiency of work processes.
- Maintaining strategic sustainability and stability, with active search for new opportunities.

V. Conclusion

Through digital transformation the customers, CSPs and vendors are connected and influenced to each other. Customers' behavior shapes cultural shifts that can affect both technology and digital transformation. In such an environment, vendors and CSPs are managed by customers, not by technology. To succeed in this fast-changing environment and achieve sustainable growth, CSPs need to focus on redefining customer relationships, transforming business models and introducing an innovative culture in support of strategic decision-making. Internal culture is manifested in different ways and at different levels, affecting the way we live, work and behave.

Through the survey we have concluded that the Innovation is a culture that has to be supported and brought to life from the inside. It should be encouraged and supported by top management in all business areas. Permanent innovation is a key to digital transformation. Continuing research on the measurement and process of changing of organizational culture, consequently, is certainly an important and worthwhile effort.

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Spectrum Sensing from Smart City Perceptive

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Abstract - Frequency availability while developing a city as smart city is a crucial task as the spectrum is scarce resource. We propose the use of cognitive radio for checking spectrum availability via spectrum sensing technique. We propose the use of multiple antenna technique for improving detection probability of the primary users. The detection performance is evaluated using different techniques based on energy detection method. This paper shows the unique way to detect the license user in spite of its fast moving. For performance comparison various parameters like number of sample, signal- to- noise ratio, probability of detection and multipath fading are taken into considerations.

Keywords:smart cities, spectrum sensing,multiple antenna

I. INTRODUCTION

With the fast expansion of the city, an augmented request of resources likes energy,water,good sanitation, education and healthcare needs to be fulfilled. This imposes the necessity to utilize all of these resources in an 'intelligent' / 'smart' way to accomplish the expectations of city residents[1]. The applications like an intelligent-buildings, mobility & transport, water infrastructure, waste management, healthcare and education are based on the frequency availability in the spectrum band. Since the spectrum is scarce resource, it is very difficult to allocate new frequencies for the new applications as mentioned above. Cognitive Radio (CR) can be used to solve the frequency allocation problem of smart cities viz the dynamic allocation of frequency by continuous checking of spectrum utilized by primary/licensed user (PU) and if detected as idle, it is allocated to unlicensed /secondary users (SU) [2][3]-[7].Various applications of CR can be found in [8].

There are various algorithms used to check the presence of licensed primary users viz general likelihood ratio test (GLRT), match filtering (MF), energy detection (ED), cyclostationary, eigenvalue based detection and covariance based detection [2][3]. Each of the methods has advantages and disadvantages. GLRT is the finest method but it entails exact channel information and distribution of noise and source signal. MF based detector necessitates perfect understanding of the channel response from PU to the receiver and precise synchronization.

Multiple antenna techniques i.e. Mutiple Input Multiple Output (MIMO) are presently utilized for consistent signal transmission, effective communication and improvement in bit-error rate. In this paper we have utilized multiple antenna techniques in conjunction with energy detectors (EDs) in order to improve PU detection performance in a CR using single carrier. In [9], improvement in hardware requirement and sensing time is accomplished through 2-stage sensing with multiple antennas. In [10] and [11], the spectrum sensing using ED for unknown deterministic signal and Rayleigh fading has been evaluated. Overall, the multiple antenna method expands system performance and upturns spectrum efficiency. Multiple antennas different techniques with mathematical derivations are described in [12]. GLRT with multiple antennas has been studied and GLRT with multiple antenna outperforms even at SNR=-24dB [13].

The organization of paper is the following: section II briefs about different spectrum sensing techniques based on ED and gives detailed idea about multiple antenna techniques, section III describes proposed system. Section IV evaluates the simulation results. Section V gives conclusion.

Neyman–Pearson (NP) criteria defines that sensing a spectrum is a binary hypothesis problem and given by:

$$H0: \quad Y(n) = w(n) \quad \text{: absence of Signal} \qquad (1)$$
$$H1: \quad Y(n) = x(n)hr(n) + w(n) \quad \text{: presence of signal}$$

where x(n)=input signal,$hr(n)$= gain of the channel, $w(n)$is the white noise with mean zero and variance σ_w^2.Two metrics are used for analysing the perfromance of spectrum sensingalgorithm: P_d is the probability of algorithm accuratelydiscovering the presence of PU andP_{fa}defines the probability of algorithm mistakenly declaring the presence of PU.P_{md} is the probability of missed detection, I.e. 1-P_d.

II. ANALYSIS OF ED AND MIMO BASED TECHNIQUESS

Time Domain ED, Periodogram based ED and Welch periodogram based ED is very well discussed in [6],[7],[14],[15] The energy of received signal in time domain is :

$$\epsilon_{\text{time}} = \sum_{n=1}^{N} |X(n)|^2 \text{ where N=samples} \qquad (2)$$

And finally test static is compared with threshold (τ) to evaluate $H0$ or $H1$

$$\tau \lessgtr \epsilon_{\text{time}} \quad (3)$$

If $\tau > \epsilon_{\text{time}}$, presence of PU otherwise PU is absent. P_d and P_{fa} for ED are given by[6]:

$$P_{fa} = P\left\{Y \middle| \frac{\tau}{H_0}\right\} = Q_m(\sqrt{2y}, \sqrt{\tau}) \quad (4)$$

$$P_d = P\left\{Y \middle| \frac{\tau}{H_1}\right\} = \Gamma(n, \frac{\tau}{2})/\Gamma(n) \quad (5)$$

For Periodogram $\epsilon_{\text{periodogram}}$ is calculated as :

$$X(k) = \sum_{n=1}^{N} X(n) e^{-j2\pi(k-1)(n-1)/N} \quad (6)$$

Where $1 \leq k \leq N$, N point FFT,received signal is $X(n)$

X(k)is applied to ED as :

$$\epsilon_{\text{periodogram}} = \frac{1}{N} \sum_{k=1}^{N} |X(k)|^2 \quad (7)$$

For Welch periodogram ϵ_{welch} is calculated as

$$\boldsymbol{x = [x_1, x_2, \ldots . x_M(l)]} \quad (8)$$

$$\boldsymbol{x_1(\rho) = \sum_{l=1}^{N} x_1(l) e^{-j2(Y-1)(l-1)/N}} \quad (9)$$

$$\epsilon_{welch} = \sum_{Y=1}^{L} \sum_{l=1}^{M} \frac{1}{N} |x_1(\rho)|^2 \quad (10)$$

To provide higher data rates,better sensing result compared to single antenna multiple antenna techniques used. As name suggest-multiple antennas, the communication system will have multiple transmitting and multiple receiving antennas [7][16].Multiple Antenna Techniques i.e.MIMO based on ED are as follows:

A. *Selection Combining*

In this method, channel state information must be known by CR, hence selects the branch with the highest channel gain, receives the data from that antennaand fed to an ED.see figure 1.

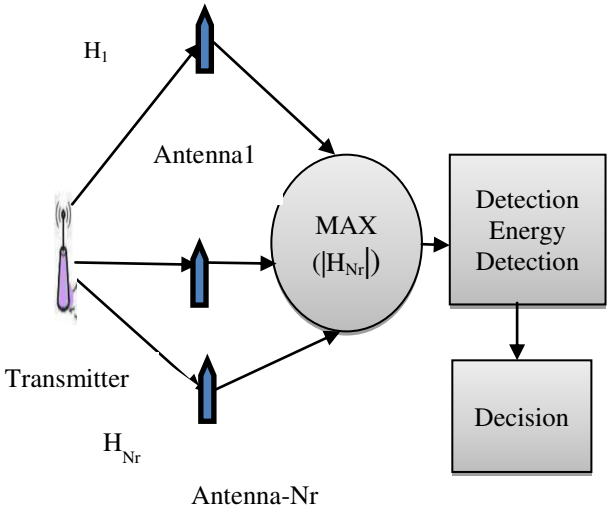

Figure1: Selection Combining

$$s_j(t) = x(t)h_j + w(t) where j = 1,2, \ldots . N_r \quad (11)$$

where N_r is the number of antenna at receiver side, s_j is the received signal at j[th]antenna. h_j is the channel gain at j[th] antenna.

$$j_{max} = \max\ (|h_j|) \quad (12)$$

Then the received signal at Jmaxth antenna is applied to the energy detector equation 13.$P_{fa(SC)}$ is given by equation 14.

$$\epsilon_{sc} = \sum_{l=1}^{N} |s_{jmax}(l)|2 \text{ where N=symbollength} \quad (13)$$

$$P_{fa(SC)} = \frac{\Gamma(N, 2\sigma_w^2)}{\Gamma(N)} \quad (14)$$

B. *Maximum Ratio Combining*

In this method,channel state information must be known by CR.CR receives data from each antenna, multiplies them with the conjugate of each channel gain and summing all the multiplied data which is then applied it to ED .see figure 2.

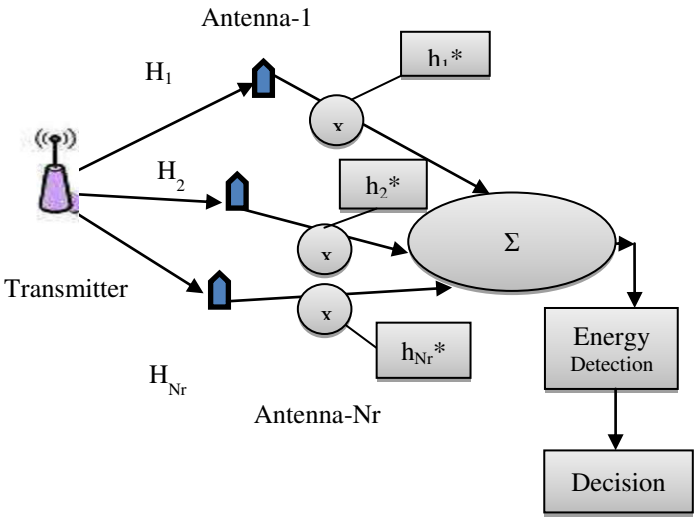

Figure 2:Maximum Ratio Combining

The received data at each antenna is multiplied with the conjugate of the channel gain and summation of all is applied to an energy detector as follows

$$\epsilon_{MRC} = \sum_{l=1}^{N} \sum_{j=1}^{Nr} |s_j(l) * h_j(l)|^2 \quad (15)$$

$P_{fa(MRC)}$ is given by equation 11.

$$P_{fa(MRC)} = \frac{\Gamma\left(\frac{N}{2}, \frac{\tau}{2\sum_{j=1}^{Nr}(h_j^{*2})\sigma_w^2}\right)}{\Gamma\left(\frac{N}{2}\right)} \quad (16)$$

C. *Equal Gain Combining*

In Equal Gain Combining normalized data which is multiplied with the conjugate of the channel gain and then divided by its absolute valueapplied to only one energy detector. See Figure 3.

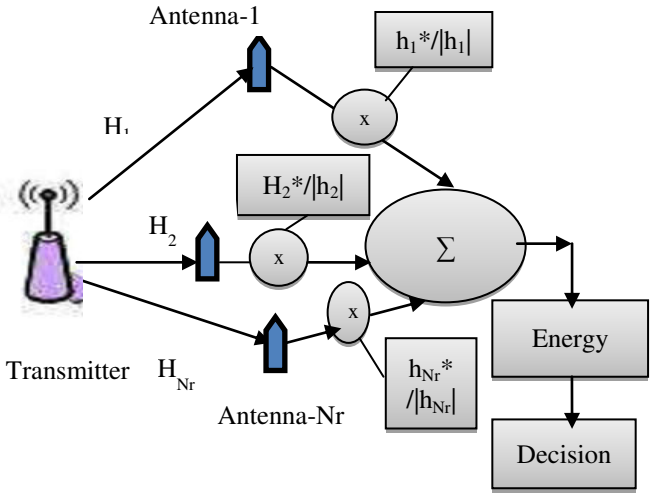

Figure 3:Equal Gain Combining

ϵ_{EGC} is calculated in equation 17 .$P_{fa(EGC)}$is calculated using equation 18.

$$\epsilon_{EGC} = \sum_{l=1}^{N} |(\sum_{j=1}^{Nr} | s_j(l).\frac{h_j^*}{h_j})|^2 \quad (17)$$

$$P_{fa(EGC)} = \frac{r(\frac{N}{2}, \frac{\tau}{2\sum_{j=1}^{Nr}(h_j^{*2}/|h_j^2|\sigma_w^2})}{r(\frac{N}{2})} \quad (18)$$

D. *Square-Law Combining*

The energy detectors' outputs are combined, comparedwith a threshold for $P_{fa(SLC)}$.

$$\epsilon_j = \sum_{n=1}^{N} |Xj(n)|^2 \quad (19)$$

$$\epsilon_{SLC} = \sum_{j=1}^{Nr} \epsilon_j \quad (20)$$

$$P_{fa(SLC)} = \frac{r(Nr.\frac{N}{2}, \frac{\tau}{2\sigma_w^2})}{r(Nr.\frac{N}{2})} \quad (21)$$

III. PROPOSED SYSTEM

In order to make a city as Smart City for various applications as mentioned in section I, the proposed system is as shown in figure 4.

Every person has been given the facility to activate the spectrum sensing on demand basis through his/her smartphone. The spectrum sensing hardware starts seeking for available frequencies within the specified frequency band as per the program embedded in it.so that if the frequency band is found to be free ,it can be utilized for various smart cities related applications as discussed in section I.

The spectrum sensing results are displayed through webserver on Web dashboard and through cloud the user can come to the availability of particular frequency for its own applications. The spectrum sensing hardware consists of National instruments USRP (Universal Software Defined Peripheral Board) with MIMO antennas. Various spectrum sensing algorithms likeED in time domain, periodogram,Welch periodogram and different multiple antenna techniques based on ED are running on USRP board. The detailed explanation of spectrum sensing algorithms is described in section II.

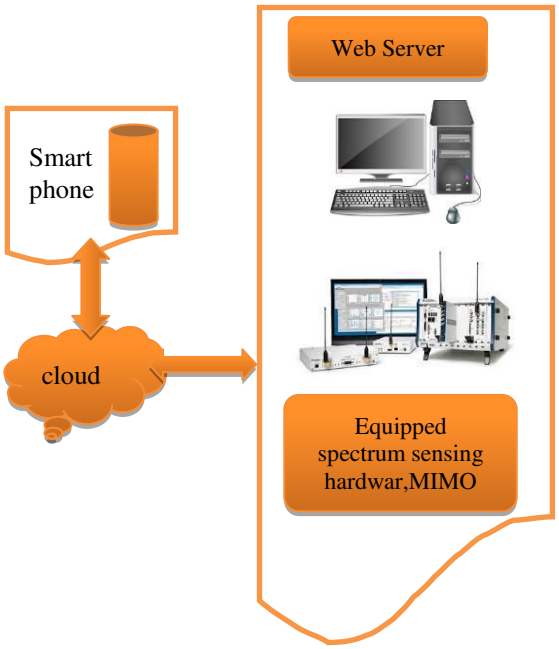

Figure 4:Proposed System

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IV. SIMULATION RESULT

While evaluating performance of MIMO using ED based different techniques, we have considered Binary Phase - shift keying (BPSK) and Quadrature Phase-shift keying (QPSK) modulated wireless voice signal as PU signal and PU signal encountered two types of fading Additive - White Gaussian Noise(AWGN) and Rayleigh fading. The time-varying Jakes model is used in Rayleigh fading. The simulation is carried for time domain ED, periodogram,Welch periodogram and different multiple antenna techniques.

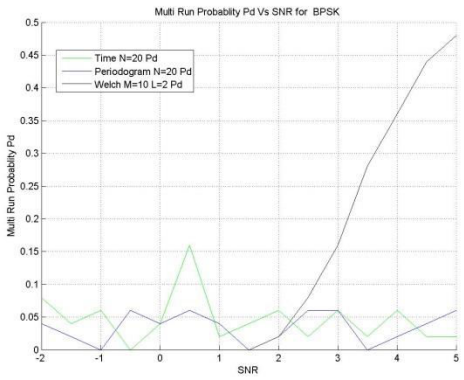

Figure 5 : Probability of detection BPSK versus SNR for P_{fa} =0.01 for N=10

Figure 5 shows that Welch periodogram with M=10,L=2 is performing well compared to time domain ED and periodogram.

Figure 6 shows the probability of detection for QPSK and BPSK signal using ED and periodogram with no. of segments=20 in AWGN channel. Figure 6 shows that periodogram gives betterP_d results as compared to time domain ED even for poor values of SNR.
As SNR increases the P_d also increases.

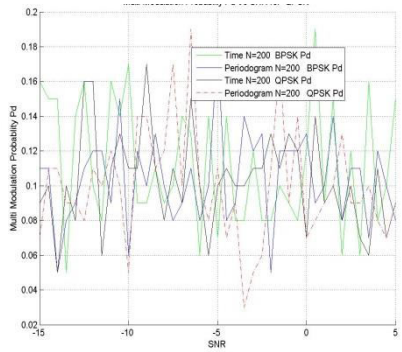

Figure 6:$P_d$for QPSK and BPSK using ED using ED for N=200 using single antenna in AWGN channel keeping Pfa =0.01

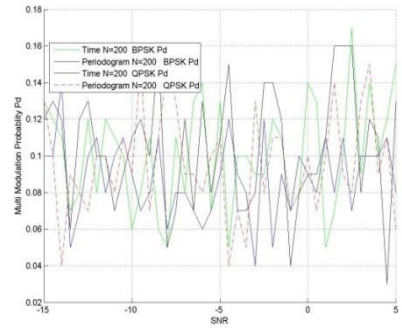

Figure 7:P_d for QPSK and BPSK using ED for N=200 using single antenna in Rayleigh fading channel keeping Pfa =0.01

Figure 7 shows the probability of detection for QPSK and BPSK signal using ED and Periodogram with no. of segments=20 in Rayleigh fading channel. For Rayleigh fading, time varying Jakes model is used. The figure 7 shows that periodogram gives better results as compared to time domain ED even for poor values of SNR.
Performance of BPSK is compared with various MIMO techniques for time domain based ED in figure 8 , periodogram based ED in figure 9 and Welch periodogram based in figure 10 with 0.9800, 0.9700, 0.9000, 0.8700 as antenna channel gains. For selection combining; antenna -01 with channel gain 0.98 has been selected. As shown in Figure 8 , For time domain ED and SNR=0.05dB MRC and EGC gives P_d =1 compared to P_d =0.05 and 0 respectively provided by SC,SLC.

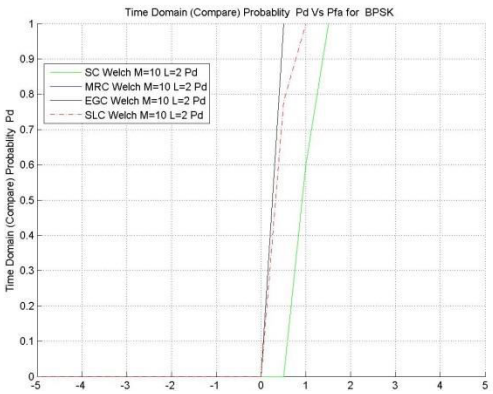

Figure 8: MIMO techniques viz SC, EGC, MRC, SLC using Time domain ED with N=20, M=10 ,L=2 $P_d$vs SNR for BPSK for Pfa=0.01 for various values of SNR

Performance of BPSK is compared with various MIMO techniques for time domain based ED in figure 8 , periodogram based ED in figure 9 and Welch periodogram based in figure 10 with 0.9800, 0.9700, 0.9000, 0.8700 as antenna channel gains. For selection combining; antenna -01 with channel gain 0.98 has been selected.

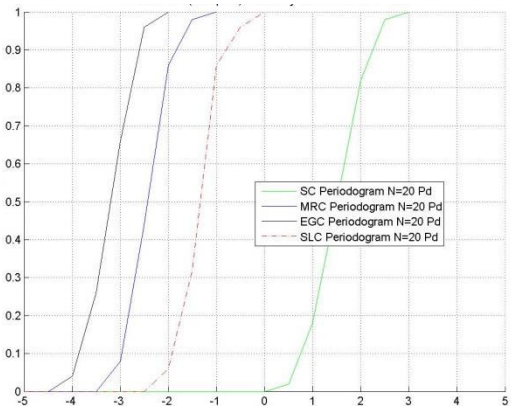

Figure 9:MIMO techniques viz SC, EGC, MRC, SLC using periodogram with N=20, M=10 ,L=2 $P_d$vs SNR for BPSK for Pfa=0.01

As shown in Figure 8 , For time domain ED and SNR=0.05dB MRC and EGC gives P_d =1 compared to P_d =0.05 and 0 respectively provided by SC,SLC.
As shown in Figure 9, For periodogram with SNR= -2dB, N=20 MRC and EGC provides P_d as 1, 0.87 respectively compared to SLC, SC as 0.05and 0 respectively. As

shown in Figure 10, MRC and EGC outperforms the SC and SLC techniques.

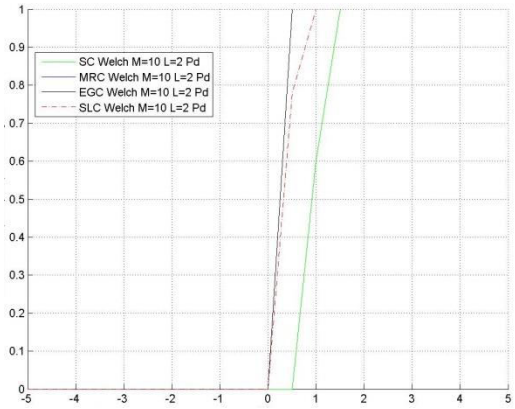

Figure 10:MIMO techniques viz SC, EGC, MRC, SLC using Welch periodogram with N=20, M=10 ,L=2 $P_d$vs SNR for BPSK.

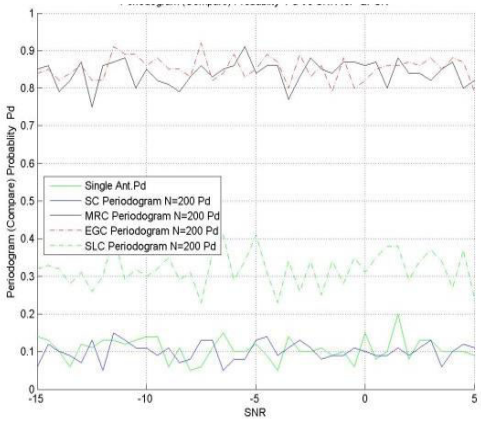

Figure 11: MIMO techniques QPSK viz SC, EGC, MRC, SLC using periodogram with M=20 a) $P_d$vs SNR b) P_d vs SNR with N=200

Figure 11 shows the comparison of P_d vs SNR for QPSK signal among various MIMO techniques viz SC,EGC,MRC,SLC using periodogram with no. of segments with single antenna using periodogram. The simulation is carried for SNR -15dB to 5dB, P_{fa}=0.01, N=200 with 0.9800, 0.9700, 0.9000, 0.8700 as antenna channel gains. For selection combining; antenna -01 with channel gain 0.98 has been selected. For SNR =-15dB MRC, EGC provides P_d as 0.88 and 0.87 respectively when compared to SC and SLC which provides P_d as 0.08 and 0.14 respectively**.** Results show that MRC and EGC outperform the other two methods for poor SNR values. Figure 8 to 11 reflect that as number of samples increases probability of detection also increases.

V. CONCLUSIONS

In this paper dynamic spectrum sensing using cognitive radio for effective utilization of available spectrum for making a city as 'Smart City' have been studied. The performance of various MIMO techniques based on energy detection has been evaluated compared with single antenna. The simulation results shows that in AWGN channel the time domain energy detection and periodogram methods for BPSK and QPSK based PU signal outperforms the Rayleigh channel for single antenna. The simulation results demonstrate considerable detection performance gain for MIMO based techniques compared to single antenna. Even though the signal undergoes through fading the detection performance of MRC and EGC does not deteriorate. Among the multiple antenna techniques the MRC and EGC outperforms the SC and SLC techniques.

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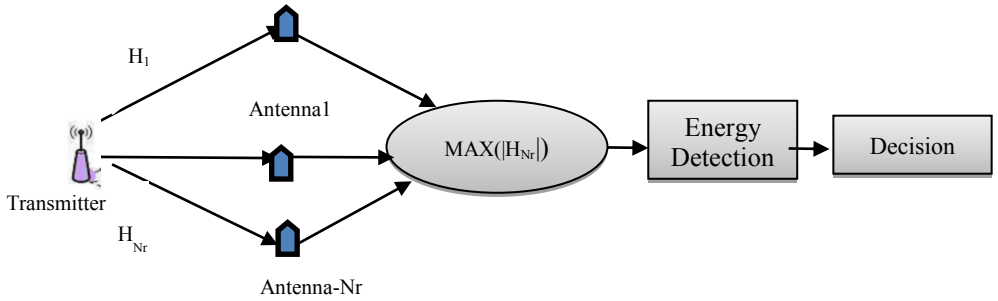

Figure1: Selection Combining

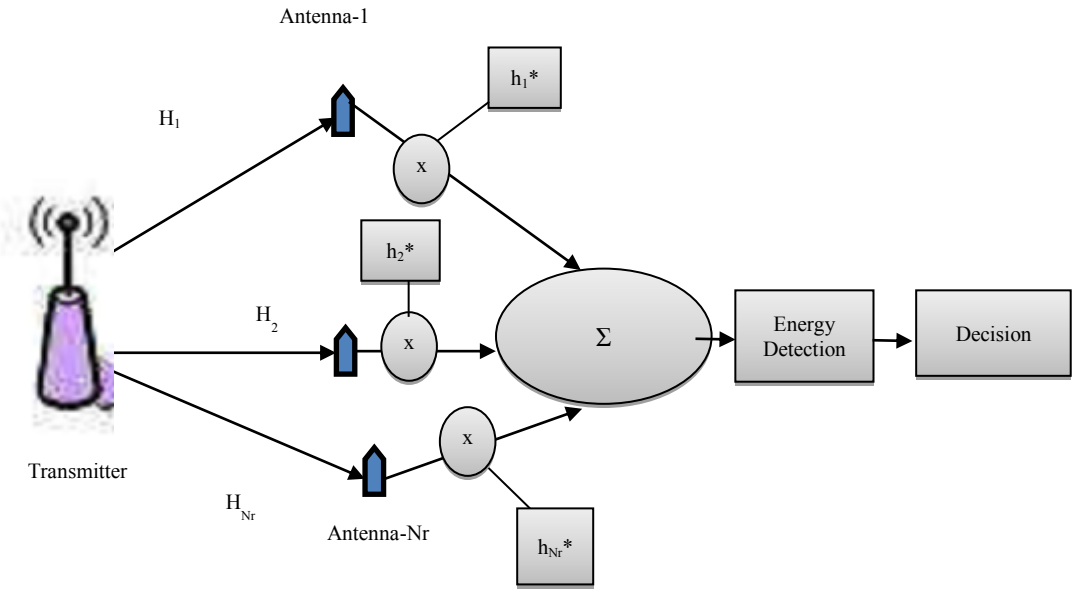

Figure 2:Maximum Ratio Combining

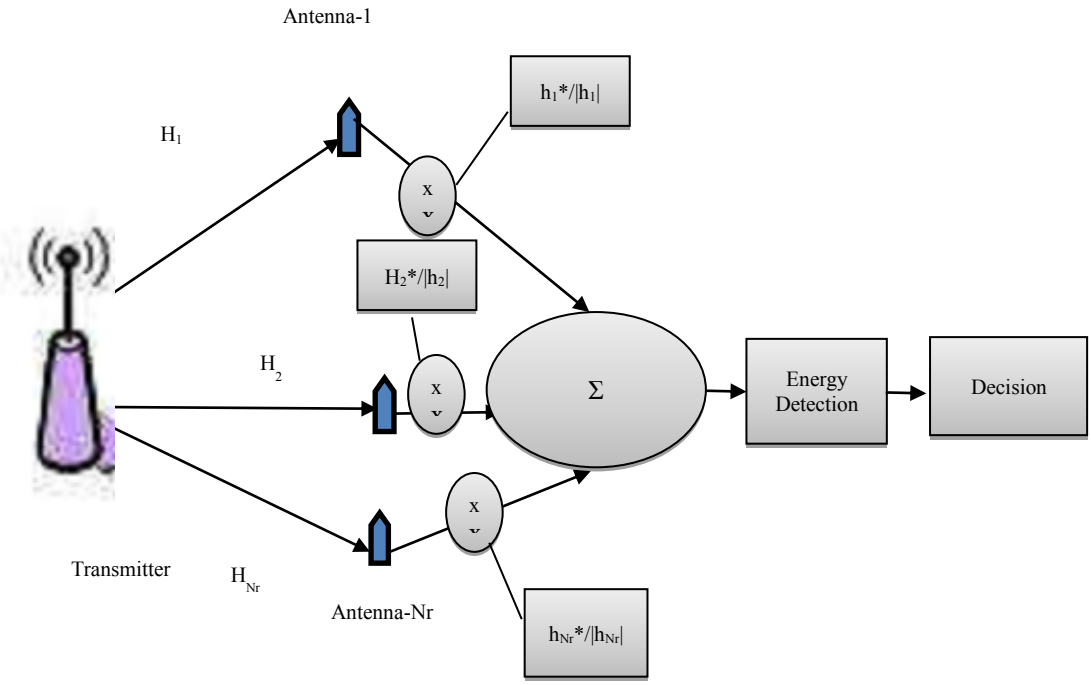

Figure 3:Equal Gain Combining

Artificial intelligence application to design smart portable intensive care unit

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***Abstract* — controlling of vital signs is crucial for patients in an intensive care unit (ICU) who need safe diagnostic and restorative intrusion. The goal of personalized medicine in the ICU is to predict which diagnostic tests, monitoring interventions and treatments are necessary. The devices used in ICU should ensure accuracy, reliability and safety of needed alarms. In this study, we propose an intelligent approach based on fuzzy logic able to automatically learn the features of a patient and consequently send the required alarms. Vital Signs in ICU Patients (Blood Pressure systolic/ diastolic), Heart Rate, Respiration Rate, and Body Temperature are considered in this research work. Multisensor data synthesis (MSDS) is used to collect patient vital signs data. A Fuzzy approach is to used to process the read data and give results in sending alarm about the case, or not to send depending on the processed readings of patient vital signs. The new addressed issue in this research is considering parameters of: Patient age, gender, and previous medical status that could affect the range of normal or accepted readings. This alarm is to be sent and broadcasting, together with patient' readings in case of jeopardy, using wireless communication to neighborhood medical centers or hospitals for back response or sending ambulance. These in turn should broadcast an acknowledgment to others that it got the case.**

Keywords— vital signs; fuzzy logic; wireless communications

I. INTRODUCTION

Health care, especially critical care medicine is complex and expensive both in terms of money and human terms. Great and satisfying medical decision making are done depending on the knowledge of the patient's medical record history and having accurate current clinical information. In a financially restrained environment, the cost of intensive care is expensive and not all the patients' families can afford to pay. In other words, the cost is main idea of making Smart Portable Intensive Care Units (SPICU) inevitable especially with the simplest techniques that can be efficient, understandable, and at the same time affordable to wide range of people. They then can take care of their patients at home, monitoring their biological functions. Vital signs are measurements that provide physiological data indicating the health conditions of the person, demonstrating the functioning and changes in body function. Thus, the vital signs guide the initial diagnosis and the monitoring of patients' clinical evolution. So, their main objective is to help in the health assessment of the person, as well as equip the decision making process related to specific interventions. The most decisive vital signs monitored that help the medical diagnosis are: ***Systolic blood pressure, diastolic blood pressure (mean arterial pressure), heart rate, respiratory rate, and body temperature.*** The accurate measurement of vital signs is enormously essential for the clinical assessment of patients that are, in this work scope, in the ICU.

The importance of idea of maintaining the electronic vital data record is to analyze the individual's trends, range, history and known health issues; overall the record also helps to understand how an individual patient responds to care. This raise the need for a smart portable ICU that has the ability of monitoring the patient's vital signs that can also help in detecting of his biological status and also broadcast his status to medical center, hospital, or his doctor or physician. The less complete the information the greater the potential for error and waste. This is also true of decision making within a health care system. The data should be chosen based upon: reliability, usefulness and feasibility, action enabling, representing a mixture of outcomes, processes and cost, and reflecting present performance. Much research work has been carried on to use artificial intelligence techniques to monitor and process patient's vital signs [1-6]. Much of the work in the ICU revolves around information that is recorded by electronic devices. Such devices typically incorporate simple alarm functions that trigger when a value exceeds or falls down pre-defined limits (normal). The high rate of false alarms is not only a nuisance for patients and caregivers, but can also compromise patient safety and effectiveness of care. The development of alarm systems has lagged behind the technological advances of medical devices over the last years. The idea is that in order for an alarming scheme to be efficient, the definitions of normal, abnormal and intermediate state have to be changed many times on an hour to hour basis, since in ICU the patient state can change dramatically from day to day. In a study 2176 alarms events were recorded, 68% were false, 5.5% were significant, and 26.5% were induced by interventions. Concluded that 94% of alarms events were clinically insignificant (Chambrin: 2001) [13]. The goal of personalized medicine in the ICU is to predict which diagnostic tests, monitoring interventions and treatments

translate to improved outcomes given the variation between patients. The main objective of this research work is to design Smart Portable Intensive intelligent systems techniques combined with technologies that integrate *mobility* and *portability* in accessing processed information Care Unit (SPICU) foreseeable model for medical decision support using. A Fuzzy approach is used to give results in sending alarm about the case, or not to send depending on the processed readings of patient vital signs (blood pressure, heart beats, body temperature, and respiration rate) considering *patient age, gender*, and *previous medical status* (not addressed in previous related work). This alarm is to be sent using wireless communication to medical center or hospital for back response. The effects of this architecture can be significant, allowing a better interface, especially in the aspect of expert knowledge, communication and usability, important features for applications in medicine. Thus, the specification of the application architecture considered environments with heterogeneous architectures and was based on: the acquisition of data from patient's vital signs monitoring; the use of intelligent systems techniques, especially fuzzy logic; information processing; and sending alerts through mobile devices. The monitored environment, entitled Intelligent System for Monitoring Patients.

A. Steps of achievement:

First is to use multisensory devices that read five patient vital signs: *heart rate, blood pressure systolic, blood pressure diastolic, respiration rate, and body temperature*. Fuzzy logic is used for processing these data. This is used to deal with the problem of different physical or normal readings when considering *patient age, gender*, and *previous medical status* (not addressed in previous related work). A fuzzy model is built for each level of ages as well as if the patient is male or female. Upon the previously mentioned steps, such SPICU can alert the hospital or medical center if anything goes wrong or any deviation from normal level happens. The SPICU consists of: acquisition of data through a network of sensors attached to the patient; data processing and classification using fuzzy logic; data post-processing and preparation for sending alerts if any abnormality was detected; the information is sent to mobile devices that are registered in the environment, to support medical staff in decision making and implementation of relevant actions. Also, such SPICU should alert the hospital or medical center if anything goes wrong or any deviation from normal level happens. Examples of patients that can benefits from such devices are: People have heart or blood vessels problem (for example very low very high blood pressure, a heart attack, or unstable heart rhythm). People who have serious infections in their bodies or having imbalance in the level of chemicals, having salt, or minerals in their blood. Such people need continuous reading of their vital signs.

II. VITAL SIGNS

Vital signs are measurements of the body's mainly basic functions. Patient health status can be estimated and determined upon the acquisition of basic physiological vital signs. The four main vital signs monitored consistently include the following: Heart Pulse rate, Blood pressure (Systolic/ Diastolic), Body temperature, and Respiration rate (rate of breathing). Vital signs are essential components of monitoring the patient's progress during hospitalization. Credits to the wide technological advances in data wireless communication systems in the last decade, the claim of wireless-based vital sign monitoring devices for patient monitoring gained an escalating attention in the clinical field. These could be monitored by using wearable medical body sensor devices placed on the patient's body. The vital signs are measured, observed and monitored to check level of physical functioning. Normal vital signs defers and changes with gender, age, weight and overall health [7]. Normal vital sign ranges for the regular healthy adult while resting, implemented in this research paper, are:

- Blood pressure: 90/60 mm/Hg to 120/80 mm/Hg
- Pulse: 60 to 100 beats per minute
- Temperature: 97.8°F to 99.1°F (36.5°C to 37.3°C), average 98.6°F (37°C)
- Breathing: 12 to 18 breaths per minute

A. Blood Pressure

The blood pressure measurement unit is mm Hg (millimetres of mercury). There are two numbers recorded when blood pressure is measured. The higher number present's systolic pressure. This shows the pressure inside the artery when the heart contracts and pumps blood through the body. The lower number or diastolic pressure presents the diastolic pressure which is the pressure inside the artery when the heart is at rest and is filled with blood. Boso-medicus prestige blood pressure monitor is an example of a wireless blood pressure sensor as it is a wireless Bluetooth device and can be used to detect the blood pressure (systolic and diastolic) of the patient [8].

B. Heart rate Sign (resting pulse rate)

The measurement unit of heart pulse rate is: beats per minute. Heart beat rate is one of the vital signs consistently measured in clinical observation [9].

C. Body temperature

The normal body temperature of a person varies depending on sex, food, recent activity, time of day, fluid consumption. In women additionally it varies with the stage of the menstrual cycle. Normal body temperature ranges from 97.8 degrees F (or Fahrenheit, equivalent to 36.5 degrees C, or Celsius) to 99 degrees F (37.2 degrees C) for a healthy adult. G-plus wireless remote body thermometer is a wireless continuous body temperature sensor device that can be used.

D. Respiratory Rate

The respiratory rate is the rate at which breathing occurs. This is usually measured in breaths per minute. The respiratory rate is measured when a person is at rest and involves counting the number of breaths for one minute, thesis done by counting how many times the chest rises. *Pulse oximeter:* Nonin's Onyx II finger clip oximeter is a wireless Bluetooth device which records oxygen saturation and heart rate continuously [10].

III. DESIGN CRITERIA AND CONSTRAINTS

A fuzzy logic model is designed for vital signs monitoring and its process. The model has five main fuzzy input variables: Blood pressure systolic, Blood pressure diastolic, Heart Pulse rate Body temperature, and Respiration rate. These input variables are the readings outputs of multisensor device attached to the patient. The output fuzzy variable would be constancy degree of patient. The following assumptions are made: whether the patient is stable, semi-stable or unstable. The fuzzy controller design steps are:

A Definition of fuzzy medical system

Where vital signs investigation is held, including the consideration of the parameters of ordinariness and the defined fuzzy rules base, inferences in vital signs are made resulting in generating alarms from pre-diagnosis indicating abnormalities.

B Obtain information from one or more specialists

In this step, the role of a specialist in the application is to be modeled and this gives the fundamental importance to collaborate in the construction of membership (relevant) functions for the entries description.

C Fuzzification

This step includes the definition of the fuzzy sets or, membership functions. In this step, each input variable is indentified to which fuzzy set(s) it can belong to by assigning the relevant degree to each fuzzy set. Before the creation of fuzzy system, it is obligatory to assemble the fuzzy sets (relevance functions) to be used in both fuzzification and defuzzification steps.

D. The inference mechanism

The fuzzy logic technology is associated with artificial intelligence. As humans automatically use rules in implementing their actions, the inference process uses a number of rules concurrently. This process is a combination of four sub processes that are: fuzzification, inference, composition, and defuzzification.

E. Reporting the comments to the fuzzy sets – Inference

In this step, the inputs are analyzed to generate the output fuzzy set with its relevant degree of compatibility. In the fuzzy ICU system, the controller model proposed by Mamdani is used [11], where the activation function of each rule is set in and the inference system determines the degree of compatibility with the premise of the rules contained in the rules base. After that, activated rules are determined and the relevance output function is applied, joining all activated output fuzzy sets and their degrees of compatibility in a single output set. This represents all acceptable actions to the input set, each one with their level of compatibility.

IV. FUZZY LOGIC CONTROLLER (FLC)

A. Fuzzy input and output variables

The inputs of fuzzy system here are the main vital signs (Blood Pressure systolic, Blood Pressure diastolic Rate, Body Temperature, Heart Pulse and Respiration Rate). These are shown in Table I. Note that notations are used to shorten these variables.

B. Fuzzification- Membership functions

Fuzzification is a process to match the input variables with the linguistic terms. It converts an input value into degrees of membership for each input variable. Fuzzification works with membership functions (MF) for each input variable used in the fuzzy set. The number of membership functions can be varied from three to more. Each membership function has to be defined in a different category, for example LOW, NORMAL and HIGH. The shape of these functions can be represented in different forms (e.g. triangle, trapezoid etc.) Sometimes Gaussian functions are also used to represent the membership functions. In this research work, the trapezoid shaped membership functions are used in defining the basic concepts of fuzzy logic system and the synthetic data validation.. For the vital signs fuzzy model, there are three membership functions for each of the input and output fuzzy variables. The membership functions for each fuzzy linguistic variable together with its graphical representation is illustrated in Fig. 1, 2, 3, 4, and 5. For the input fuzzy variables the universe of discourse (the x-axis) is the quantized value of each of vital sign. For the output fuzzy variable the universe of discourse is the priority degree of the given approach.

1) Blood Pressure systolic (BP_s) Membership Function: BP_sn normal (BP_sn)=120, considering a domain (95-130), by the linguistic terms low (L), normal (N) and high (H), respectively representing the bands, as illustrated in Fig. 1:

$$\text{high (BPs)} = \begin{cases} 0, & \text{if BPs} < 130, \\ (\text{BPs}-130)/10, & \text{if } 130 <= \text{BPs} <= 140, \\ 1, & \text{if BPs} > 140 \end{cases} \quad (1)$$

Fuzzy set of BPs:

$$\text{F(BPs,85,95,130,140)} = \begin{cases} 0, & \text{BPs} <= 85 \\ (\text{BPs}-85)/(95-85) & 85 < \text{BPs} <= 95 \\ 1, & 95 < \text{BPs} <= 130 \\ (140-\text{BPs})/(140-130) & 130 < \text{BPs} <= 140 \\ 0, & 140 < \text{BPs} \end{cases}$$

2) Mean Blood Pressure diastolic (BP_d) Membership Function: BPd normal (NBPd) considering a domain (60-80), by the linguistic terms low (L), normal (N) and high (H), respectively representing the bands, illustrated in Fig.2:

$$\text{high } (BP_d) = \begin{cases} 0, & \text{if } BP_d < 80, \\ (\text{BPd}-80)/8, & \text{if } 76 <= BP_d <= 84, \\ 1, & \text{if } BP_d > 85 \end{cases} \quad (2)$$

TABLE I. FUZZY VARIABLES INPUTS AND OUTPUTS

Fuzzy Inputs										Fuzzy Output	
BP_s		BP_d		HR		TB		RR		Stability	
Low <85	L	Low <55	L	Low <50	L	Low <36	L	Low <10	L	Low	Unsable_L
LowNormal 85-95	LN	LowNormal 55-60	LN	LowNormal 50-59	LN	LowNormal 36-36.5	LN	LowNormal 10-11	LN	LowNormal	LS
Normal 96-130	N	Normal 61 - 80	N	Normal 60-110	N	Normal 36.6 – 37°	N	Normal 12 to 18	N	Stable	S
HighNormal 131-140	HN	HighNormal 81-85	HN	HighNormal 111-125	HN	HighNormal 37.1-37.3	HN	HighNormal 19-20	HN	HighNormal	HS
High >140	H	High >85	H	High >125	H	High >37.3	H	High >20	H	High	Unsable_H

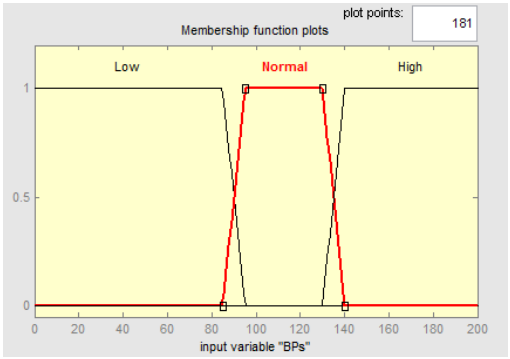

Fig. 1. Membership function of BPs. – the first input of FLC

$$f(BPd,55,60,80,85)=\begin{cases}0, & BPd <=55\\ (BPd-55)/(60-55) & 55 < BPd <= 60\\ 1, & 60< BPd <= 80\\ (85- BPd)/(85-80) & 80 < BPd <= 85\\ 0, & 85 < BPd\end{cases}$$

3) Heart Beats (Pulse rate HR) Membership Function: HR normal (NHR) considering a domain (60-100), by the linguistic terms low (L), normal (N) and high (H), respectively representing the bands, as illustrated in Fig. 3:

$$\text{high (HR)} = \begin{cases}0, & \text{if } HR < 100,\\ (HR-60)/40, & \text{if } 60 <= HR <= 100,\\ 1, & \text{if } HR > 100\end{cases} \quad (3)$$

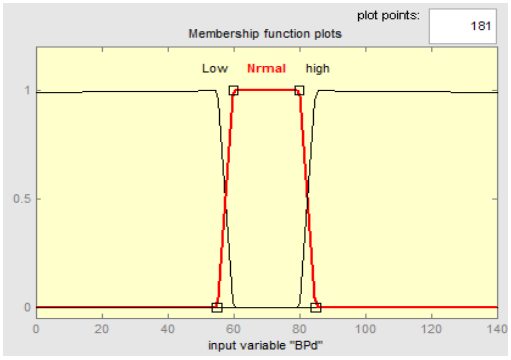

Fig. 2. Membership function of BPd– Second input of FLC

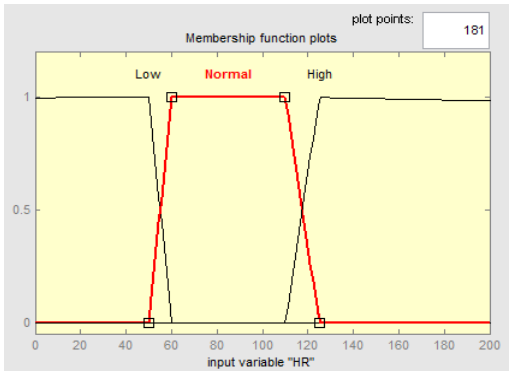

Fig. 3. Membership function of HB. – Third input of FLC

$$f(HR,50,60,110,125)=\begin{cases}0, & HR <= 50\\ (HR-50)/(60-50) & 50 < HR <= 60\\ 1, & 60<HR<= 110\\ (125-HR)/(125-110) & 110<HR<=125\\ 0, & 125 < HR\end{cases}$$

4) Body temperature (TB) Membership Function: TB normal (NTB) considering a domain (36.5°C to 37.3°C), by the linguistic terms low (L), normal (N) and high (H), respectively representing the bands, as illustrated in Fig. 4:

$$\text{high (TB)} = \begin{cases}0, & \text{if } TB < 36.5,\\ (TB-36.5)/0.8, & \text{if } 36.5 <= TB <= 37.3,\\ 1, & \text{if } TB > 37.3\end{cases} \quad (4)$$

$$f(TB,36,36.5,37,37.3)=\begin{cases}0, & HR <= 36\\ (TB-36)/(36.5-36) & 36<TB<= 36.5\\ 1, & 36.5 < TB <= 37\\ (37.3-TB)/(37.3-37) & 37<TB<=37.3\\ 0, & 37.3 < TB\end{cases}$$

5) Respiration rate (RR) Membership Function: RR normal (NRR) considering a domain (12 to 18), by the linguistic terms low (L), normal (N) and high (H), respectively representing the bands, as illustrated in Fig. 5:

$$\text{high (RR)} = \begin{cases}0, & \text{if } RR < 12,\\ (RR-12)/18 & \text{if } 12 <= RR <= 18,\\ 1, & \text{if } RR > 18\end{cases} \quad (5)$$

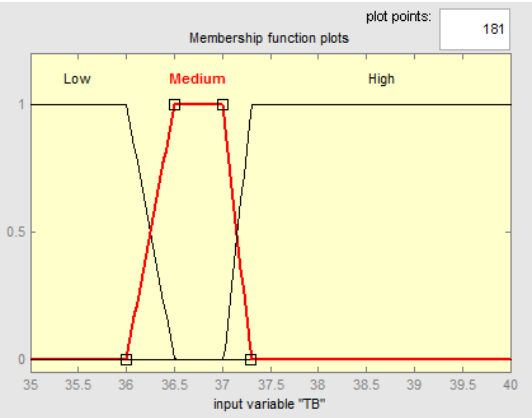

Fig. 4. Membership function of TB.– fourth input of FLC

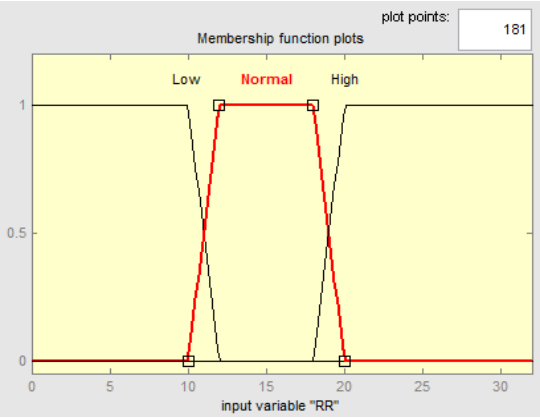

Fig. 5. Membership function of RR. – fifth input of FLC

$$f(RR,10,12,18,20)=\begin{cases} 0, & RR <= 10 \\ (RR-10)/(12-10) & 0< RR <= 12 \\ 1, & 12 < RR <= 18 \\ (20-RR)/(20-18) & 18 < RR <= 20 \\ 0, & 20 < RR \end{cases}$$

5) Fuzzy Output S (Stability) Membership Function: S normal (NS) considering a domain (12 to 18), by the linguistic terms low (L), normal (N) and high (H), respectively representing the bands, as illustrated in Fig. 6:

$$\text{high}(S) = \begin{cases} 0, & \text{if } S < 6, \\ (S-6) & \text{if } 6 <= S <= 7, \\ 1, & \text{if } S > 7 \end{cases} \quad (6)$$

$$f(S,3,4,6,7)=\begin{cases} 0, & S <= 3 \\ (S-3)/(4-3) & 3< S <= 4 \\ 1, & 4 < S <= 6 \\ (7-S)/(7-6) & 6 < S <= 7 \\ 0, & 7 < S \end{cases}$$

The objective here is to classify the patient condition, in real time, for indicating whether a normal (i.e., vital signs with normal values), a semi-stable (i.e., vital signs with values close to normal), or an unstable situation (i.e., vital sign values fairly abnormal).

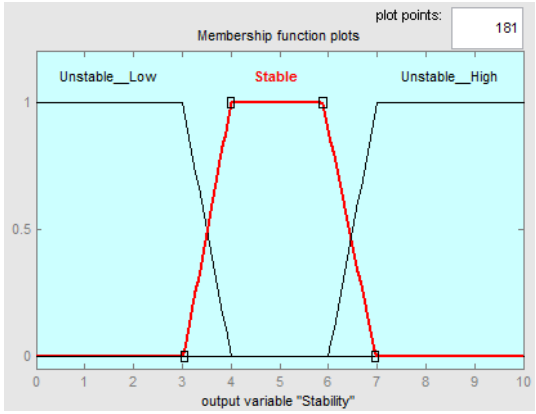

Fig. 6. Membership function of Stability. – Ouput of FLC

A. Rules- Rule Base

Fuzzy rules definition (Rules Base): When the input variables and membership functions are defined, then we next have to establish linguistic rules, which are represented or assembled with the following structure, as

IF < premises or antecedents> THEN <conclusions or statements >

The number of rules increases rapidly with the addition of more variables. If the number of fuzzy input variables is 6 and Number of Terms per Variable is 5 then Number of Rules is 15,625. A part of the Rule base used in this research is shown in Fig. 7.

At this stage it is important that the amount of rules defined can cover all possible combinations of inputs and outputs of the problem proposed and that the consistency of the rules is reviewed to avoid contradictions. The rules base was developed from several meetings, discussions and interviews with the Promoter hospital medical staff.

B. Inference

The input values provided in the fuzzification step have to be processed by these rules to generate an output value. This processing is done by applying inference, using different linguistic rules in the following three steps: Aggregation, activation, and accumulation.

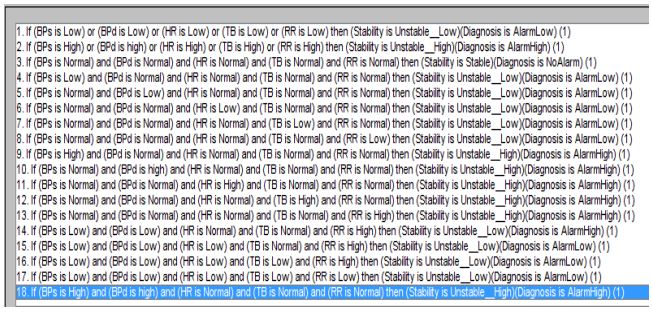

Fig. 7: Part of Rules Base.

1. Aggregation

Aggregation is used to determine the degree of success, which is a single output value combining the degree of membership functions of all the subconditions used in a rule. It considers the degree of membership of each subcondition in a rule. If the condition consists of a combination of more than one subcondition then the degree of accomplishment has to be calculated considering each individual value of each subcondition. Aggregation works with two operators: AND (Minimum of subcondition values) and OR. (Maximum of subcondition values).

2. Activation

Activation is the process which provides the end result of a rule. It determines the degree of membership of the conclusion of a rule on the basis of the degree of accomplishment of the condition which was determined in the previous aggregation step. In general, the MIN and PROD are used for the activation process. The activation process provides the result based on the outcome of the sub conditions. In fact, the activation process is an interpretation step for the components determined in the aggregation step.

3. Accumulation

Accumulation is the process used to obtain the combined result of all the linguistic rules after aggregation and activation have been applied. To complete the accumulation process, we have to use the MAXIMUM operation to find out the overall result (result from the activation step). Therefore, from the accumulation of the above rules, one can determine if the health status is normal or unmoral.

C. Defuzzification and testing

Defuzzification is the final step which maps fuzzy output variables to a crisp numerical value. The inference (i.e. three successive stages of aggregation, activation and accumulation) provides a degree of membership function as the result. This result has to be converted into a crisp numerical value. A crisp numerical value is a precise value in a crisp set. The output value obtained from the membership function should provide the "best possible" result of the values contained in it. The maximum height method is used to find out the best possible solution in the defuzzification method. A test for this fuzzy model is carried on using real data obtained from PhisyoNet [12], where fuzzy variables data is incorporated to see the values for fuzzy output variables (Fig. 8). Alarming techniques is incorporated in this research as described in [13].

V. CONCLUSION

A fuzzy model able to monitor and classify the condition of the vital signs of ill patients, sending information to an alerts system is presented. Monitoring, processing, validation and testing of the fuzzy model were carried out using database with real data. A simulation is presented in order to evaluate its effectiveness, taking into account the pre-adjustment of the relevance functions in the pursuit of reducing false alarms. The use of fuzzy logic in the medical area could be very useful as a tool to assist specialists in this area. Finally, from this study numerous possibilities for future work arise, such as: validation of the model in a real scenario and environment, confronting the real-time alarm generation and reception of messages, an increase of vital signs in the model, inclusion of specific alarms for each patient.

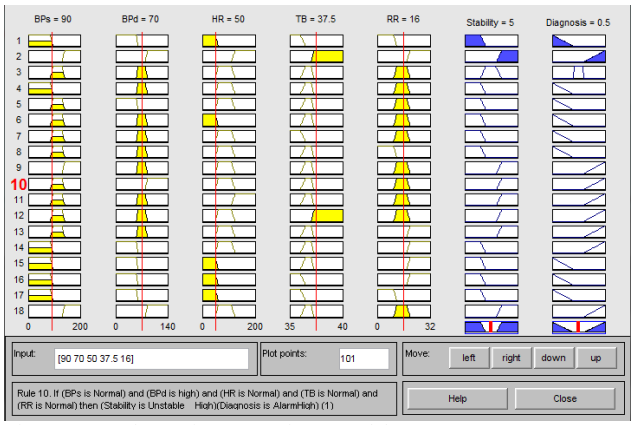

Fig. 8: A sample test for SPICU fuzzy model

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Kibernetički napadi i krizno komuniciranje - izvještavanje novinskih portala

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***Sažetak* – Otkad su mediji proširili svoj informacijski doseg, tj. od stapanja s e-platformom, sve postaje javno dostupno, a najveći publicitet odnose afere i krize. Pojava novih društvenih mreža povećava rizik od kibernetičkog kriminala, lako se dolazi do podataka i kreira kibernetički napad. Treba spomenuti i krađu identiteta, dječju pornografiju, trgovinu drogom i druge nelegalne trgovine na mreži. Informacijska je tehnologija omogućila mrežno ratovanje, a samim time i kibernetički terorizam. Medijsko izvještavanje oblikuje društvenu misao, odnosno javno mnijenje i stvara određene stereotipe. Nepotpuno i neprofesionalno prenošenje vijesti dovodi u pitanje kvalitetu informiranja javnosti. Zato je istraženo na koji način hrvatski mediji izvještavaju o kibernetičkim napadima. Analiza sadržaja članaka na trima najčitanijim hrvatskim novinskim portalima *jutarnji.hr*, *vecernji.hr* i *24sata.hr* od 1. svibnja do 31. listopada 2017. godine pokazala je da se o opasnostima unutar kibernetičkog prostora premalo piše. Nisu zadovoljeni glavni kriteriji vijesti. Rijetko se navodi koje su informacije obuhvaćene kibernetičkim napadom. Također, nedovoljno se piše o preventivnim mjerama zaštite. Što se tiče razdoblja kriznog komuniciranja, članci se najčešće odnose na razdoblje poslije same krize. Ustanovljeno je da informacijskim prazninama mediji daju nedovoljno prostora kibernetičkom prostoru kao oružju i obavještavanju javnosti.**

Ključne riječi - kibernetički napad; krizno komuniciranje; novinski portali; izvještavanje; analiza sadržaja

I. UVOD

Rizik koji kretanje unutar kibernetičkog prostora nosi raste kad se ide kontra zakona i etike, u pozadini su uvijek moć i novac, a velika sloboda u kibernetičkom prostoru onemogućava kažnjavanje. Strateško i krizno komuniciranje dobivaju sve više na važnosti, a mediji oblikuju javno mnijenje. Aktualni naraštaj koji odrasta u tehnološkom i internetskom okviru zapeo je u konstrukciji rizika globalnog informacijskog društva.

Cilj rada bio je doznati na koji način hrvatski mediji izvještavaju o kibernetičkim napadima, točnije o kojim se temama i predmetima najviše izvještava i kako su s autorske strane prikazane teme. Analizom sadržaja obuhvaćena su tri hrvatska novinska portala *jutarnji.hr*, *vecernji.hr* i *24sata.hr* od 1. svibnja do 31. listopada 2017. godine.

II. KIBERNETIČKA TERMINOLOGIJA

Termin „*cyber*“ nerijetko se pojavljuje u medijima, a njegova upotreba postaje dio komuniciranja u sklopu dnevno političkih događanja, ponajviše kroz sigurnost i ekonomiju. Referenca [2] ističe da je „*cyber*“ obično prefiks pojma ili modifikator riječi vezan uz elektroničku obradu informacija, tehnologiju, elektroničku komunikaciju ili informacijske i računalne sustave.

Drugačije perspektive upućuju na nepostojanje zajedničkog konsenzusa oko definiranja kibernetičkih napada. Referenca [2] određuje kibernetički napad kao: „Poduzete mjere za ometanje, uskraćivanje, degradiranje ili uništavanje informacija koje se nalaze u računali i/ili računalnoj mreži ili računalo i/ili računalne mreže“. Razlike ne bi trebale čuditi s obzirom na to da implikacija kibernetičkih napada ima različite ciljeve, kao i rezultate svojeg operativnog djelovanja.

Iako postoje brojne vrste kibernetičkih napada, spomenut će se samo one najpoznatije: zlonamjerni softvere, krađa identiteta, SQL (Structured Query Language) injekcija, skriptiranje na drugom mjestu XSS (Cross-Site Scripting), uskraćivanje usluge DoS (Denial of Service)/DDoS (Distributed Denial of Service), otmica sesije i ponovno korištenje vjerodajnice. Najučestaliji tipovi kibernetičkih napada su zlonamjerni softvare i DDoS. Činjenica da se računalni crvi propagiraju vrlo brzo na mrežama čini ih jednim od najzahtjevnijih zloćudnih softvera za presretanje. Treba spomenuti i kategoriju računalnog virusa koji, za razliku od računalnog crva, nije samostalan program, a aktivira se pokretanjem zaraženog programa.

DDoS napad je karakteriziran eksplicitnim pokušajem napadača da spriječi legitimnu upotrebu usluge. DDoS napadi koriste višestruka računala za postizanje tog cilja. Često se primjenjuje pristup u okviru kojeg napadač šalje pakete žrtvi, troši njezine ključne resurse i time usluge čini nedostupnim.

A. Izloženost kibernetičkog prostora

Referenca [1] u visokorizične zemlje u pogledu porasta kibernetičkog kriminala ubraja SAD, Kinu, Brazil, Njemačku, Indiju, Veliku Britaniju, Rusiju, Poljsku, Italiju i Španjolsku. Kibernetički se napadi koriste i kao sredstvo za postizanje geopolitičkih ciljeva što je vidljivo u slučaju Ukrajine kroz anektiranje Krima, kao i pokušaje utjecanja na izbore. Digitalna je tehnologija donijela za sobom demokraciju sazdanu od prijetnji. Tako [3] upućuje na: „ […] decentralizirajuće učinke novih informacijskih i komunikacijskih tehnologija. Stratezi sada govore o

>>informacijskom ratu<<: zemlje s razmjerno malim zalihama konvencionalnih vojnih sredstava, npr. vojske i oružja, ipak mogu predstavljati ozbiljni prijetnju ako prodru u osjetljive kompjutorske sustave. Dakako, ta prijetnja ne mora potjecati od država nego od nedržavnih aktera, primjerice hakera ili terorističkih organizacija.“.

Informacijska je tehnologija omogućila mrežno ratovanje, a samim time i kibernetički terorizam. Njihov međuodnos su na primjeru bliskoistočnih terorističkih organizacija utvrdili [4]:

„1. Što je viša razina mrežne organiziranosti terorističke organizacije, to je veća vjerojatnost da se informacijska tehnologija koristi za potporu u procesu mrežnoga odlučivanja.

2. Najnoviji napredak informacijske tehnologije pomaže umreženim terorističkim organizacijama s obzirom na brži, jeftiniji i sigurniji protok informacija.

3. Prihvaćanjem informacijske tehnologije za potporu u odlučivanju i u druge organizacijske svrhe, raste vjerojatnost da će se terorističke organizacije koristiti istom tehnologijom kao napadačkim oružjem (u svrhu ometanja normalnoga funkcioniranja ili uništavanja).“.

Također, potvrdili su evoluiranje kibernetičkog terorizma jer će novi pripadnici terorističkih organizacija biti osposobljeniji za korištenje informacijske tehnologije pa će i terorističke organizacije u budućnosti biti umreženije i više koristiti računalnu tehnologiju kao oružje.

III. Strateško komuniciranje

Pojam strateškog komuniciranja integrirao se u državne i nedržavne subjekte te postao nezaobilazan dio sigurnosnog, društveno-političkog i poslovnog komuniciranja. Referenca [5] pod strateškim komuniciranjem podrazumijeva korištenje koordiniranih akcija, poruka, slika i drugih oblika signaliziranja koji su usmjereni informiranju, utjecanju i uvjeravanju radi ostvarivanja nacionalnih ciljeva. U navedenoj je definiciji razvidno kako strateško komuniciranje u cilju koherentnog i učinkovitog izvještavanja koristi jasno definiran metodološki okvir. Referenca [6] govore da je trenutačno pojam sve popularniji u smislu sveobuhvatnog koncepta koji sadrži razne ciljane komunikacijske aktivnosti, a koje obično uključuju odnose s javnošću, marketing i financijske komunikacije, zdravstvene komunikacije, javnu diplomaciju, kampanje i brojne druge discipline.

Među ostalim, strateški komuniciraju i teroristične skupine, radi ciljanog mijenjanja uvjerenja i ponašanja u sklopu kojeg koriste narative kojima se nastoji prisiliti ciljana skupina da usvoji željeno ponašanje ili da se udalji od neželjenog ponašanja. Zbog sve veće dostupnosti tehnologije, dolazi do ubrzane radikalizacije. O pojavi informacijsko-tehničkog terorizma govori i [7]: „Terorizam se počeo širiti putem Interneta, a istodobno i protiv Interneta. Suprotstavljene strane pokušavaju blokirati mrežna mjesta protivnika, onesposobiti baze podataka i uopće spriječiti potencijalne korisnike da se koriste njima neprihvatljivim izvorima na mreži.“.

Ne postoji unisona definicija strateškog komuniciranja, ali je vidljivo da državni i nedržavni subjekti teže informiranju javnosti radi unaprjeđenja stanovitih ciljeva ili ostvarivanja ciljeva, odnosno umirivanja ili senzibiliziranja javnosti tijekom određene krize.

A. Krizno komuniciranje

Referenca [8] krizno komuniciranje povezuju s odnosima s javnošću i potrebom popravljanja loše slike određenog subjekta nakon krize ili katastrofe. U pogledu krize cilj je definitivno vezan uz smirivanje javnosti. Referenca [9] ovdje izdvaja vojno znanje kao uvijek dobrodošlo i upotrebljivo za ishod krizne situacije. Također, naglašava da potreba za rješavanjem međuljudskih odnosa sve više raste i da je već sada riječ o unosnom poslu.

Okvirno, krizno komuniciranje obuhvaća tri razdoblja - razdoblje prije krize (predviđanje i priprema), razdoblje krize (brze i važne odluke, kontrola posljedica i priprema za funkcioniranje nakon krize) i razdoblje poslije krize (uspostavljanje reda, analiza kriznog komuniciranja). Referenca [10] izdvaja opća komunikacijska pravila u kriznim situacijama: manji broj ključnih poruka, samo provjerene poruke, laži ne dolaze u obzir, bez komentara pretpostavki, izraz „bez komentara“ nije dozvoljen, komuniciranje svih loših vijesti u jednom hipu, uvijek moguća povratna informacija.

Referenca [10] naglašava kako mediji mogu pomoći, ali i odmoći u upravljanju krizom te da je zato važna kooperativnost. Referenca [11] dodaje i dva osnovna grijeha u komunikaciji s medijima za vrijeme krize: odbijanje komunikacije i nedostavljanje obećane informacije. Otkad su mediji proširili svoj informacijski doseg, tj. od stapanja s e-platformom, sve postaje javno dostupno, a najveći publicitet odnose afere i krize. Rizik koji kretanje unutar kibernetičkog prostora nosi raste kad se ide kontra zakona i etike, u pozadini su uvijek moć i novac, a velika sloboda u kibernetičkom prostoru onemogućava kažnjavanje. Referenca [9] ovakvu vrstu krize s obzirom na okolinu iz koje potječe svrstava u krizu javnog mnijenja.

IV. Kibernetička tematika u medijskom prostoru

Elektronički mediji, usto novinski portali kojima je obuhvaćen istraživački uzorak ovog rada, također su dio kibernetičkog prostora za koji [12] kažu da je: „ […] informacijski prostor u kojemu su podaci oblikovani tako da onome tko sa njima radi daju privid kontrole, premještanja i pristupanja informacijama, pri čemu on ili ona mogu biti povezani s velikim brojem korisnika uz pomoć marioneti slične simulacije što se odvija u petlji povratne sprege s korisnikom.“. Riječ je o simulaciji okoline koja omogućuje interakciju. Kibernetički prostor se u komunikološkim krugovima zamjenjuje terminom „računalno posredovana komunikacija“.

Mediji svojim izvještavanjem pridonose oblikovanju društvene misli, odnosno javnog mnijenja i stvaranju određenih stereotipa. Referenca [13] s pravom kaže da se nametnula nova kultura - kultura stvarne virtualnosti. Okosnica današnje kulture u kontekstu novih tehnologija i tehnokratskog društva zapravo je računalno posredovana

komunikacija koja se poistovjećuje s virtualnom stvarnošću.

Globalna računalna mreža informacija nosi za sobom i brojne rizike. S pojavom Interneta 1969. godine počinje i računalno hakerstvo. Današnje je globalizacijsko informacijsko društvo dobro upoznato s pojmovima kao što su „*cyber* rat“, „*cyber* kriminal“, „*cyber* fundamentalizam“, „*cyber* špijunaža“, „*cyber* terorizam“, „*cyber* pedofilija“ itd. O kibernetičkom ratu u komunikacijskom kontekstu [1] navodi sljedeće: „Svrha rata je da se uz pomoć ICT-a postigne bilo ekonomska, politička ili vojna moć. Glavni resursi ratovanja su informacije i dezinformacije. To je ratovanje uz pomoć informacije.“. Autor pojma „*cyber* terorizam“ Barry C. Collin naglašava da se navedeni fenomen svodi na informacijsku bombu koja treba nanijeti štetu i proizvesti strah i nesigurnost. Pojava novih društvenih mreža povećava rizik od kibernetičkog kriminala, lako se dolazi do podataka i kreira kibernetički napad. Treba spomenuti i krađu identiteta (bankovni računi, kreditne kartice), dječju pornografiju, trgovinu drogom i druge nelegalne trgovine na mreži (krivotvorenje).

Brzo širenje vijesti povećava publicitet terorizma, a teroristi se hrane publicitetom. Referenca [14] govori o svojevrsnoj simbiozi terorista i medija: „Za masovne medijske organizacije praćenje terorizma, posebice dugotrajnih incidenata poput otmica aviona i talačkih situacija, predstavlja beskonačan izvor senzacija i vizualno privlačnih novosti koje mogu uistinu povećati gledanost/čitanost.“. Referenca [15] pruža pogled i s novinarske strane, govori o medijski oblikovanoj ikonografiji islama koju prati površno i jednostrano izvještavanje te naglašava da curenje informacija o islamskom svijetu, usto i kibernetičkom terorizmu: „ […] u SAD-u definiraju geopolitika i ekonomski interesi […].“. Na neki način možemo govoriti i o novinarskom terorizmu koji vrši psihološki utjecaj na recipijenta.

Doba je moralne panike ili kolektivnog stresa. Novinski naslovi stalno upozoravaju na nove opasnosti, skoro svaka pojava izaziva paniku i svi su spremni igrati na kartu strahova većine. Referenca [9] naglašava važnost medijskog izvještavanja u kriznoj situaciji, oni oblikuju javno mnijenje i stoga djeluju kao, kako ih naziva, „katalizatori krize“. Dodaje kako se radi oblikovanja objektivne slike u javnosti za medije moraju popuniti sve informacijske praznine. Aktualni naraštaj koji odrasta u tehnološkom i internetskom okviru zapeo je u konstrukciji rizika globalnog informacijskog društva. Referenca [1] poziva se na francuskog postmodernističkog filozofa Jeana Baudrillarda: „Globalizacija je isto što i integracija. Svijet se integrira u jedan sustav, misleći kako će biti jači. No, pokazalo s na primjeru 11. rujna 2001. da je tako integriran svijet ili globalni sustav moći zapravo ranjiv […] Suvremeni je kibernetički terorizam odgovor na globalizaciju.“. S druge strane, cilja se na optimizam i tehnologiju koja se razvija kako bi riješila sve ljudske i društvene probleme.

V. IZVJEŠTAVANJE NOVINSKIH PORTALA O KIBERNETIČKIM NAPADIMA

A. Ciljevi istraživanja, metoda i uzorak

Krajnji cilj rada bio je doznati na koji način hrvatski mediji izvještavaju o kibernetičkim napadima, točnije o kojim se temama i predmetima najviše izvještava i kako su s autorske strane prikazane teme.

Analizom sadržaja (istraživačka metoda za prikupljanje podataka iz informacijskog materijala, daje podatke o sadržaju različitih poruka, obilježjima pošiljatelja poruka, obilježjima primatelja poruka i efektima poduzetih akcija) obuhvaćena su tri hrvatska novinska portala *jutarnji.hr*, *vecernji.hr* i *24sata.hr* od 1. svibnja do 31. listopada 2017. godine. Navedeni su portali izabrani zato što su prema podacima GemiusAudience od 1. do 28. veljače 2017. godine, prije nego je Hanza Media (*jutarnji.hr*) napustila spomenutu agenciju specijaliziranu za praćenje čitanosti europskih portala, bili najčitaniji novinski portali. Članci su za analizu određeni pretraživanjem po ključnoj sintagmi (riječi) „*cyber* napad“ i utvrđivanjem povezanosti s navedenom tematikom.

B. Analiza sadržaja članaka novinskih portala jutarnji.hr, vecernji.hr i 24sata.hr – interpretacija rezultata istraživanja

Analizom sadržaja utvrđeno je da je u navedenom razdoblju novinski portal *vecernji.hr* objavio 29 članaka o kibernetičkim napadima, *jutarnji.hr* 21 članak, a *24sata.hr* 16 članaka. Samim time vidljivo je koliko pažnje novinski portali pridaju kibernetičkoj tematici.

Što se tiče najzastupljenije specificirane tematike o kojoj se izvještava u analiziranim člancima, uočljivo je da se na novinskom portalu *jutarnji.hr* najviše izvještava o kibernetičkom kriminalu i nešto manje o kibernetičkom ratu. Na portalima *vecernji.hr* i *24sata.hr* uglavnom se izvještava o temama koje nisu usko vezane za kibernetičku problematiku. Izvještava se o stanju zaštite od kibernetičkog napada u privatnom i javnom sektoru, jačoj suradnji članica Europske unije u borbi protiv kibernetičkog kriminala, općoj sigurnosti na internetu, nesigurnosti elektroničkog glasanja, mogućim kibernetičkim napadima itd. Ipak, na novinskom portalu *vecernji.hr* dosta se izvještava o kibernetičkom napadu kao događaju.

TABLICA I. TEME ČLANAKA

Tema o kojoj se izvještava u članku?	*vecernji.hr*	*jutarnji.hr*	*24sata.hr*
Kibernetički napad	11 (37,93 %)	1 (4,76 %)	0
Kibernetički rat	0	5 (23,81 %)	1 (6,25 %)
Kibernetički kriminal	2 (6,89 %)	12 (57,14 %)	1 (6,25 %)
Kibernetički fundamentalizam	0	0	0
Kibernetička špijunaža	1 (3,45 %)	1 (4,76 %)	0
Kibernetički terorizam	0	0	0
Kibernetička pedofilija	0	0	0
Kibernetičko zlostavljanje (*cyberbullying*)	1 (3,45 %)	0	1 (6,25 %)

Obrana od kibernetičkog napada	0	0	1 (6,25 %)
Ostalo	13 (44,83 %)	2 (9,52 %)	11 (68,75 %)
Ne može se odrediti	1 (3,45 %)	0	1 (6,25 %)

U analiziranim se člancima na svima trima novinskim portalima uglavnom ne navodi tko je izveo kibernetički napad.

TABLICA II. IZVRŠITELJ NAPADA

Navodi li se u članku tko je izveo kibernetički napad?	*vecernji.hr*	*jutarnji.hr*	*24sata.hr*
Pojedinac	0	0	0
Organizacija	0	2 (9,52 %)	1 (6,25 %)
Država	1 (3,45 %)	3 (14,29 %)	0
Ne može se odrediti	28 (96,55 %)	16 (76,19 %)	15 (93,75 %)

Također, što se tiče institucije pogođene kibernetičkim napadom, uglavnom se ne navodi nijedna od zadanih ili se uopće ne navodi koja je institucija pogođena. Na novinskom portalu *jutarnji.hr* u trima se člancima spominje središnja banka kao institucija koja je pogođena kibernetičkim napadom.

TABLICA III. POGOĐENA INSTITUCIJA

Koja je institucija pogođena kibernetičkim napadom u članku?	*vecernji.hr*	*jutarnji.hr*	*24sata.hr*
Središnja banka	0	3 (14,29 %)	1 (6,25 %)
Bolnica	1 (3,45 %)	1 (4,76 %)	0
Sigurnosna služba	1 (3,45 %)	1 (4,76 %)	0
Hidroelektrana	0	0	0
Nuklearno postrojenje	0	1 (4,76 %)	0
Sustav za distribuciju pitke vode	0	0	0
Nijedna od navedenih	27 (93,10 %)	15 (71,43 %)	15 (93,75 %)

U analiziranim se člancima na svima trima novinskim portalima uglavnom ne izvještava o materijalnoj šteti i/ili žrtvama kibernetičkog napada. Ipak, o materijalnoj se šteti najviše izvještava na portalu *vecernji.hr*. Na istom se portalu najviše piše i o žrtvama, tj. pogođenim osobama.

TABLICA IV. MATERIJALNA ŠTETA I/ILI ŽRTVE

Izvještava li se u članku o materijalnoj šteti i/ili žrtvama kibernetičkog napada?	*vecernji.hr*	*jutarnji.hr*	*24sata.hr*
Samo o materijalnoj šteti	9 (31,03 %)	6 (28,57 %)	3 (18,75 %)
Samo o žrtvama	3 (10,34 %)	1 (4,76 %)	1 (6,25 %)
O materijalnoj šteti i žrtvama	1 (3,45 %)	1 (4,76 %)	0
Ne može se odrediti	16 (55,17 %)	13 (61,90 %)	12 (75,00 %)

Usto, na svim se portalima rijetko navode informacije koje su pogođene kibernetičkim napadom, više na portalima *jutarnji.hr* i *24sata.hr*.

TABLICA V. NAPADNUTE INFORMACIJE

Navodi li se u članku koje su točno informacije obuhvaćene kibernetičkim napadom?	*vecernji.hr*	*jutarnji.hr*	*24sata.hr*
Da	0	7 (33,33 %)	7 (43,75 %)
Ne	15 (51,72 %)	9 (42,86 %)	8 (50,00 %)
Ne može se odrediti	14 (48,28 %)	5 (23,81 %)	1 (6,25)

U većini se članaka na svima trima novinskim portalima ne navodi što je pogođena institucija poduzela ili će poduzeti nakon kibernetičkog napada. Navedena se informacija češće iznosi na portalu *jutarnji.hr*.

TABLICA VI. AKCIJE POGOĐENE INSTITUCIJE

Navodi li se u članku što je pogođena institucija poduzela ili će poduzeti nakon kibernetičkog napada?	*vecernji.hr*	*jutarnji.hr*	*24sata.hr*
Da	1 (3,45 %)	4 (19,05 %)	2 (12,50 %)
Ne	15 (51,72 %)	10 (47,62 %)	15 (93,75 %)
Ne može se odrediti	13 (44,83 %)	7 (33,33 %)	1 (6,25 %)

U većini se članaka na svima trima novinskim portalima uglavnom ne navode preventivne mjere zaštite od kibernetičkog napada. Najviše se navode na portalu *vecernji.hr*, nešto manje na portalu *jutarnji.hr*.

TABLICA VII. PREVENTIVNE MJERE ZAŠTITE

Navode li se u članku preventivne mjere zaštite od kibernetičkog napada?	*vecernji.hr*	*jutarnji.hr*	*24sata.hr*
Da	10 (34,48 %)	7 (33,33 %)	3 (18,75 %)
Ne	17 (58,62 %)	9 (42,86 %)	12 (75,00 %)
Ne može se odrediti	2 (6,89 %)	5 (23,81 %)	1 (6,25 %)

Kad je u pitanju razdoblje kriznog komuniciranja koje je obuhvaćeno člankom, sveukupno se uglavnom izvještava o razdoblju poslije krize. O razdoblju prije krize jedino se piše na novinskom portalu *vecernji.hr*.

TABLICA VIII. RAZDOBLJE KRIZNOG KOMUNICIRANJA

Koje razdoblje kriznog komuniciranja obuhvaća članak?	*vecernji.hr*	*jutarnji.hr*	*24sata.hr*
Razdoblje prije krize	4 (13,79 %)	0	0
Razdoblje krize	2 (20,69 %)	0	0
Razdoblje poslije krize	10 (34,48 %)	14 (66,67 %)	8 (50,00 %)
Ne može se odrediti	13 (44,83 %)	7 (33,33 %)	8 (50,00 %)

Što se tiče glavnog predmeta o kojem se najviše izvještava u analiziranim člancima, ako se gleda cjelokupna slika, tj. općenito stanje na novinskim portalima, uglavnom je to događaj. Pogotovo što se tiče portala *jutarnji.hr*. Zanimljivo je da se na portalu *vecernji.hr* često progovara o problematici kao predmetu teme, tj. ukupnosti pitanja koje treba riješiti, a koje se tiču kibernetičkih akcija.

TABLICA IX. PREDMETI ČLANAKA

Koji je glavni predmet članka?	*vecernji.hr*	*jutarnji.hr*	*24sata.hr*
Događaj	8 (27,59 %)	17 (80,95 %)	5 (31,25 %)
Osoba	2 (6,89 %)	2 (9,52 %)	2 (12,50 %)
Proces	2 (6,89 %)	0	2 (12,50 %)
Problematika	9 (31,04 %)	2 (9,52 %)	2 (12,50 %)
Sukob	5 (17,24 %)	0	1 (6,25 %)
Nijedno od navedenog	3 (10,34 %)	0	4 (25,00 %)

U većini se analiziranih članaka na svima trima novinskim portalima koriste izjave osoba.

TABLICA X. IZJAVE OSOBA

Koriste li se izjave osoba u članku?	*vecernji.hr*	*jutarnji.hr*	*24sata.hr*
Da	23 (79,31 %)	20 (95,24 %)	9 (56,25 %)
Ne	6 (20,69 %)	1 (4,76 %)	7 (43,75 %)

Gledano u globalu, što se tiče profila osoba čije se izjave koriste u analiziranim člancima, uglavnom su to znanstvenici i/ili stručnjaci. Navedeno se pogotovo odnosi na portal *vecernji.hr*, dok se na portalu *jutarnji.hr* dosta koriste i izjave glasnogovornika.

TABLICA XI. PROFILI OSOBA

Izjava osobe kojeg profila se koristi u članku?	*vecernji.hr*	*jutarnji.hr*	*24sata.hr*
Glasnogovornika	2 (6,89 %)	7 (33,33 %)	1 (6,25 %)
Političara	2 (6, 89 %)	1 (4,76 %)	0
Državnih službenika / predstavnika	3 (10,34 %)	5 (23,81 %)	1 (6,25 %)
Znanstvenika i / ili stručnjaka	14 (48,28 %)	7 (33,33 %)	4 (25,00 %)
Običnih građana	0	0	0
Ostalo	1 (3,45 %)	0	2 (12,50 %)
Ne koriste se izjave osoba	6 (20,69 %)	1 (4,76 %)	7 (43,75 %)
Ne može se odrediti	1 (3,45 %)	0	1 (6,25 %)

Kad je interpretativni okvir analiziranih članaka u pitanju, na novinskom portalu *vecernji.hr* on je većim dijelom neutralan, na portalu *24sata.hr* negativan, dok je u člancima portala *jutarnji.hr* bilo teško odrediti o kakvom je interpretativnom okviru riječ.

TABLICA XII. INTERPRETATIVNI OKVIR

Kakav interpretativni okvir prevladava u članku?	*vecernji.hr*	*jutarnji.hr*	*24sata.hr*
Pozitivan	1 (3,45 %)	1 (4,76 %)	1 (6,25 %)
Negativan	8 (27,59 %)	3 (14,29 %)	8 (50,00 %)
Neutralan	19 (65,52 %)	4 (19,05 %)	4 (25,00 %)
Ne može se odrediti	1 (3,45 %)	13 (61,90 %)	3 (18,75 %)

U analiziranim se člancima na svima trima novinskim portalima uglavnom ne pojavljuje senzacionalizam, tj. tekstovi se ne temelji na skandaloznosti, preuveličavanju, dramatizaciji, jednostranosti, spajanju informacije i zabave i narušavanju ljudske privatnosti. S druge strane, senzacionalizam se najviše pojavljuje u člancima portala *vecernji.hr*.

TABLICA XIII. SENZACIONALIZAM

Pojavljuje li se senzacionalizam u članku?	*vecernji.hr*	*jutarnji.hr*	*24sata.hr*
Da	6 (20,69 %)	2 (9,52 %)	1 (6,25 %)
Ne	23 (79,31 %)	14 (66,67 %)	9 (56,25 %)
Ne može se odrediti	0	5 (23,81 %)	6 (37,50 %)

Na novinskim portalima *vecernji.hr* i *24sata.hr* većina je članaka s autorske strane prikazana jednostrano, dok je na portalu *jutarnji.hr* obrnuta situacija, tj. autori su teme uglavnom prikazali višestrano.

TABLICA XIV. AUTORSKI PRIKAZ

Kako je autor prikazao temu članka?	*vecernji.hr*	*jutarnji.hr*	*24sata.hr*
Jednostrano	26 (89,66 %)	6 (28,57 %)	7 (43,75 %)
Višestrano	3 (10,34 %)	12 (57,14 %)	5 (43,75 %)
Ne može se odrediti	0	3 (14,29 %)	4 (25,00 %)

Većina članaka na novinskim portalima *vecernji.hr* i *24sata.hr* ne potiče oblikovanje negativnih stereotipa u recipijentovoj svijesti. U člancima portala *jutarnji.hr* bilo je teško odrediti navedeno.

TABLICA XV. OBLIKOVANJE NEGATIVNIH STEREOTIPA

Potiče li članak oblikovanje negativnih stereotipa u recipijentovoj svijesti?	*vecernji.hr*	*jutarnji.hr*	*24sata.hr*
Da	6 (20,69 %)	4 (19,05 %)	3 (18,75 %)
Ne	21 (72,41 %)	2 (9,52 %)	9 (56,25 %)
Ne može se odrediti	2 (6,89 %)	15 (71,43 %)	4 /25,00 %)

Cilj autora članka uglavnom je informiranje. U šest članaka na portalu *vecernji.hr* cilj autora bila je analiza.

TABLICA XVI. AUTORSKI CILJ

Koji je cilj autora članka?	*vecernji.hr*	*jutarnji.hr*	*24sata.hr*
Informirati	16 (55,17 %)	17 (80,95 %)	11 (68,75 %)
Analizirati	6 (20,69 %)	2 (9,52 %)	3 (18,75 %)
Ponuditi rješenja problema	3 (10,34 %)	2 (9,52 %)	2 (12,50 %)
Senzacionalizirati	3 (10,34 %)	0	0
Ostalo	0	0	0
Ne može se odrediti	1 (3,45 %)	0	0

U analiziranim člancima na svima trima novinskim portalima uglavnom nisu prisutni elementi koji potiču stvaranje moralne panike, tj. devijantnost, društveni problemi kao prijetnja općeprihvaćenim vrijednostima, kolektivno ponašanje, reakcija vlasti i pokretanje društvenog otpora. Takvih elemenata najviše ima u člancima na portalu *vecernji.hr*.

TABLICA XVII. POTICANJE MORALNE PANIKE

Jesu li u članku prisutni elementi koji potiču stvaranje moralne panike?	*vecernji.hr*	*jutarnji.hr*	*24sata.hr*
Da	5 (17,24 %)	2 (9,52 %)	2 (12,50 %)
Ne	23 (79,31 %)	15 (71,43 %)	13 (81,25 %)
Ne može se odrediti	1 (3,45 %)	4 (19,05 %)	1 (6,25 %)

Što se naslova analiziranih članaka tiče, na svima trima novinskim portalima pripadajući naslovi odgovaraju tekstovima. U šest članaka na portalu *jutarnji.hr* naslovi ne odgovaraju člancima.

TABLICA XVIII. NASLOVI

Odgovara li naslov pripadajućem članku?	*vecernji.hr*	*jutarnji.hr*	*24sata.hr*
Da	29 (100 %)	15 (71,43 %)	15 (93,75 %)
Ne	0	6 (28,57 %)	1 (6,25 %)
Ne može se odrediti	0	0	0

Isto tako, u većini članaka na svima trima novinskim portalima prateće slike odgovaraju tekstovima. Ipak, zanimljivo je da na portalu *jutarnji.hr* veliki broj analiziranih članaka sadrži neodgovarajuće slike.

TABLICA XIX. SLIKE

Odgovara li prateća slika članku?	*vecernji.hr*	*jutarnji.hr*	*24sata.hr*
Da	27 (93,11 %)	10 (47,62 %)	11 (68,75 %)
Ne	2 (6,89 %)	10 (47,62 %)	3 (18,75 %)
Ne može se odrediti	0	1 (4,76 %)	2 (12,50 %)

I. ZAKLJUČAK

Iako su napredne aplikacije za komuniciranje i usavršeni informacijski sustavi omogućili demokratizaciju misli, širenje idejnih konstrukata i slobodu izražavanja, s druge su strane državnim i nedržavnim subjektima omogućili ostvarivanje probitaka i drugih ciljeva posredstvom kibernetičkog djelovanja. S teorijskog aspekta kibernetički napad može biti usmjeren prema pojedincu, grupi, političkoj organizaciji, bankarskom sektoru, medijskim agencijama i inim nedržavnim subjektima, ali i prema državi i njezinim ekonomskim, gospodarskim, znanstvenim, energetskim, prometnim, vojnim, sigurnosnim i inim sustavima.

Ciljevi kibernetičkog napada mogu biti zastrašivanje određene populacije, izazivanje panike, stvaranje nepovjerenja u sustav nacionalne sigurnosti, ali i pokazivanje nadmoći najčešće prikrivenog izvršitelja napada. Sami napadi mogu biti usmjereni na rušenje informacijskih sustava, ugrožavanje ljudskih života, zlostavljanje, povredu privatnosti i krađu identiteta. Nadalje, posredstvom kibernetičkog napada moguće je doći u posjed klasificiranih podataka od strateškog i vitalnog državnog značaja. Kibernetički prostor postao je adekvatan za plasiranje dezinformacija i idejnih narativa koji su usmjereni prema stjecanju određene prednosti ili postizanju stanovitog vanjskopolitičkog cilja.

Analizom sadržaja članaka triju hrvatskih novinskih portala jutarnji.hr, vecernji.hr i 24sata.hr od 1. svibnja do 31. listopada 2017. godine utvrđeno je, prema broju pronađenih odgovarajućih članaka i njihovom sadržaju, da se nedovoljno i šturo izvještava o kibernetičkim napadima. Određeni konteksti (kriminal, terorizam, pedofilija, obrana i dr.) imaju društveni značaj, tiču se veće skupine ljudi i zato bi se trebali češće naći na medijskom repertoaru.

Članci su uglavnom informativnog karaktera, što donekle i odgovara medijskom karakteru izvještavanja. Naime, medijima nije cilj popravljanje loše slike određenog događaja ili subjekta nakon krize, već privlačenje publike. Smirivanje javnosti ostaje u ingerenciji vladajućih struktura i odgovarajućih sastavnica izvršne vlasti. To je i očekivano jer napadnuti subjekti nastoje zadržati što više informacija u tajnosti i ne izlagati se. Sukladno tome nedostaje višeslojna (višestrana) obrada teksta.

Zanimljivo je što, suprotno postavljenoj hipotezi, negativan interpretativni okvir ne prevladava na svima trima novinskim portalima. Također, senzacionalistički članci koji se temelje na skandaloznosti, preuveličavanju, dramatizaciji, jednostranosti, spajanju informacije i zabave i narušavanju ljudske privatnosti rijetka su pojava. Usto, izostaju elementi koji potiču stvaranje moralne panike, tj. devijantnost, društveni problemi kao prijetnja općeprihvaćenim vrijednostima, kolektivno ponašanje, reakcija vlasti i pokretanje društvenog otpora, a samim time i oblikovanje negativnih stereotipa u recipijentovoj svijesti. Iako je medijima glavni cilj što veći broj recipijenata, izvještavanje o kibernetičkim napadima u ovim okvirima odstupa od učestalog medijskog žutila.

Iako medijsko izvještavanje ponekad može povećati štetu nakon krize, u analiziranim lancima navedeno nije uočeno. S druge strane, ustanovljeno je da informacijskim prazninama mediji daju nedovoljno prostora, kako kibernetičkom prostoru u službi modernog oružja, tako i obavještavanju javnosti. Analizirani članci nemaju koherentan i konzistentan pristup prezentiranju ove tematike. Nameće se potreba za dodatnom edukacijom i stvaranjem eksperata koji bi izvještavali o kibernetičkim napadima iz svih navedenih informativnih kutova. Treba skrenuti pozornost i na sveobuhvatnu slobodu kao nužni preduvjet. Isto tako, ne manje važno, potrebna je snažna podrška građanskog društva i javnosti, kao i stvaranje publike koja će postati svjesna svojih informativnih težnji i početi tražiti kvalitetne medije.

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Socio-Economic Origin-Destination Matrix Derivation Through Contextualization of Material World

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***Abstract* - An origin-destination matrix contains data about individual and group mobility in a certain spatial area. As such, an origin-destination matrix represents an indicator of urban migrations and commuters' volume and can be used in strategic planning of the observed area. However, the origin-destination matrix does not contain information about the context of the migrations. In this paper we present an approach of expanding the origin-destination matrix data with the spatial data attributes containing information about the socio-economic context of activity's source and target derived from the material world. Origin-destination matrix enriched with such context can be used to gain a better understanding of socio-economic activities in an observed area, providing an insight to their nature and cause. Knowing the reason behind urban migrations can be useful for various socio-economic purposes. We describe developed information fusion algorithm, deploy the proposed concept, and present the graphical representation of the contextualized origin-destination matrix.**

Keywords – origin-destination matrix; ODM; socio-economic activities; contextualization; contextualized OD matrix

I. INTRODUCTION

An origin-destination (OD) matrix provides an objective and independent indication of mobility, related to both an individual and a group, in an observed area. It is often used in transport science as an information source for activity patterns assessment, and a tool for urban migration analysis and strategic planning. Traditionally, the OD matrix estimation is conducted by counting movement of individuals using human observers, video surveillance or other means. In recent developments, the utilization of various available datasets in the process of OD matrix estimation has been introduced. An example of such dataset is Charging Data Record (CDR) [1] used by telecommunication service providers. CDR is a collection of information about chargeable telecommunication events, e.g. performed phone calls, Short Messaging Services (SMS) and internet usage, used for billing purposes.

Here we propose a method for OD matrix estimation based on information extracted from CDRs and additional spatial data attributes extracted from OpenStreetMap [2], providing a novel framework for identification and estimation of the urban migrations due to socio-economic activities. OpenStreetMap (OSM) project is a collaborative initiative for creating a publicly available and editable map of the world. It provides information about spatial objects and relationships between them, following a topological data structure. Examples of object-related data obtainable from OSM include object's geographical position and type, i.e. object category. Object categories are related to the purpose of the object and include examples such as education (schools, universities), health (hospitals and other facilities providing healthcare services), work (company buildings, offices), and other religious, commercial, residential, and cultural facilities. Providing the information about the purpose of the origin and destination of a migration derives its socio-economic context. Hence, using this approach, it becomes possible to better understand daily and weekly urban migrations driven by socio-economic activity, which can be meaningful in identification of local regions of socio-economic attractions and urban strategic planning.

The remainder of this paper is organized as follows. Section 2 outlines the related work on the OD matrix estimation with the focus on estimations based on telecommunication activities datasets. Section 3 describes the methodology of our work. Results and the graphical representation of contextualized OD matrices can be found in Section 4, followed by conclusion and future work in Section 5.

II. RELATED WORK

The concept of enriching position (i.e. coordinates in a positioning system) with additional information, thus creating its context and transforming the position information into the location, has been described in [3]. One of recent commonly used approaches in creating information context is to utilize telecommunication activity data combined with other information sources for various purposes, such as emergency detection and management [4], estimation of human dynamics [5], regional delineation [6], or urban planning [7].

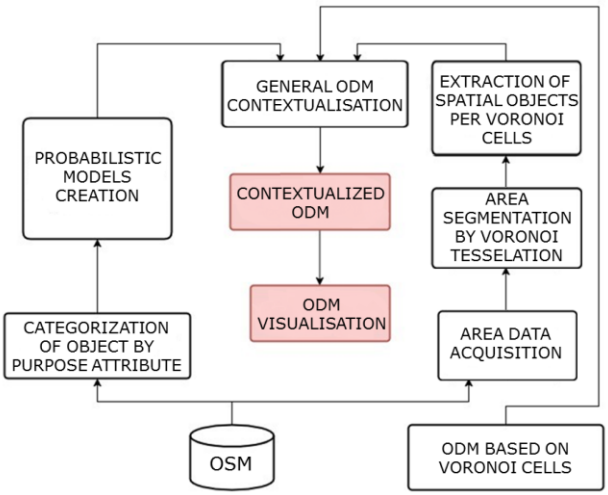

Fig. 1 ODM contextualization workflow

Several studies [4][8][9] introduce approaches of estimating OD matrices based on activities performed in a telecommunication network. Telecommunication network operators use data about chargeable user actions such as phone calls, SMS and internet usage, stored in a CDR. Based on CDR data, origins and destinations of an OD matrix can be determined such that areas of user activities are properly rendered [10] [11] [12].

As a base of our work we use OD matrix derived from telecommunications activity data as described in [13]. Authors of [13] use telecommunication activity data available in CDRs and match them with the spatial data to identify the origins and destinations in the process of OD matrix estimation, using the method of space partitioning based on Voronoi diagram called Voronoi tessellation. In our work, we expand the telecom-based OD matrix derivation described in [13] by providing the context of socio-economic activities derived from the OSM data, hence enabling better understanding of the socio-economic activity types in the observed region and the motivation behind them.

Fig. 2 OSM data and Voronoi tesellation -Shenzhen, China

III. Origin-Destination Matrix Contextualization

The proposed method of OD matrix contextualization described in this paper comprises the following tasks: acquisition of the area data and OD matrices derived from structured CDR subsets, area segmentation, spatial objects categorization and extraction, probabilistic model for migration flow contextualisation and graphical presentation, as outlined in Fig. 1.

A. Area Data Acquisition

In this work, we use an OD matrix estimated using structured CDR subset data collected in a mobile network in the Shenzhen metropolitan area [13]. The same CDR subset has been used for acquiring locations of base stations in the observed area. Every OD matrix is related to the predefined time-window. In this work we use OD matrices based on 3-hour time-window. The daily time span has been split into 8 time-windows: 0-3 h, 3-6 h, 6-9 h, 9-12 h, 12-15 h, 15-18 h, 18-21 h, 21-24 h thus estimating 8 OD matrices per day.

The area data acquisition necessarily precedes matrix contextualization algorithm development and deployment. The process consists of acquiring locations of base stations for area of interest and deriving spatial object data from the OSM database.

The set of base station locations used in this project originates from the CDR subset used for the OD matrix estimation which has been stripped off from the unnecessary data and stored in a Comma Separated Vale (CSV) format file. For each instance of a telecom activity in CDR data, an ordinal number of the activity was recorded, as well as latitude and longitude of the base station that detected activity. These records were also used for extraction of base station unique locations.

The OSM data describes spatial objects following a topological data structure, with four core elements defined as *nodes*, *ways*, *relations*, and *tags*. *Nodes* represent points with geographic position and are used to describe points of interest. *Tags* are key-value pairs which are used to store metadata about map objects (type, name, physical properties) and are always tied to a *node*, *way*, or *relation*. *Nodes*, *ways*, and *relations* are ranked hierarchically in the manner where *ways* consist of *nodes*, and *relations* consist of *ways* and *nodes*. In our work, *tags* assigned to *nodes* and *ways* were used to categorize objects described by *nodes* in purpose-based categories (described in detail in subsection *Purpose-Based Object Categorization*).

Due to the large area of interest (Shenzhen metropolitan area) and high number of objects in it, the spatial object data could not have been exported directly from the OSM database [14]. An algorithm was deployed with the purpose of extracting data related to smaller areas more convenient for data acquisition, eventually merging them into set of objects covering entire area of interest. A list of *nodes*, *ways* and *relations* was assigned to each area part, branched into specific purpose-based categories (e.g. home, education, health, etc.). *Nodes* were represented as a list of attributes (node ID, time of tagging, user, geolocation) and *tags*. Data from all area parts were

gathered and merged into single dataset representing all the OSM objects for the area of interest. In this step, we also acquired geolocations of base stations in the area of interest by retrieving them from the Open Cell ID database [15].

B. Area Segmentation

The OD matrices derived from CDR use space partition based on Voronoi cells that define base station areas of coverage [13]. This approach allows for accurate mapping of the contextual information from telecommunication network into spatial domain of socio-economic activities in the physical world. The purpose of this step is to determine which *nodes* lay in each of the cells, since nodes are the elements of the OSM data related to a single geolocation.

A data frame of spatial points was generated from the node geolocations, consisting of latitudes, longitudes, and nodes IDs. Such representation of *nodes* allowed separation of spatial data into smaller sets. We implemented spatial sub-setting using R [16] [17]. For each subset of spatial points, the corresponding *nodes* were retrieved from the initial set of data based on matching node IDs. This action results in the initial OSM-extracted dataset being split into a list of datasets matching the Voronoi cells. Results of the area segmentation for the city of Shenzhen are depicted in Fig. 2, containing both OSM objects and the Voronoi cells based on the tessellation method.

C. Purpose-Based Object Categorization

In *Area Data Acquisition* subsection, we presented the structure of data collected from OSM. The *tags* assigned to *nodes* and *ways* are used for the object categorization, along with geolocation of nodes. Objects are categorized by their purpose into six initial categories: *home*, *education*, *leisure*, *health*, *work* and *other*. The categories listed are also referred to as attributes. The category *other* comprises the objects whose purpose does not fall into any of the preceding categories but are still meaningful for the estimation of socio-economic activities (e.g. supermarkets, shops, amenities). Based on observation of tagging system used by OSM, each category is given a tag value that is used for filtering and categorization. Some categories (work, other) are given tag keys to categorize objects more specifically.

An additional method of object detection was deployed for *home* category due to an inconsistency of the OSM data tagging system. During the study of OSM data we observed that the tag *residential* is commonly used with *ways* that describe streets in residential suburbs. Since *ways* are used for representing linear features but do not have geographic position, they are represented with a list of *nodes* whose coordinates describe polyline of a *way*. The *nodes* parented by *ways* tagged *residential* were not tagged themselves, thus making them undetectable with method based on tags attached exclusively to *nodes*. For this category, a method of detecting nodes based on *tags* attached to their parent *ways* was deployed so that untagged *nodes* related to *ways* tagged *residential* were categorized as *home* objects.

D. Spatial Object Filtration Algorithm

As described in *Area Segmentation* subsection, the area of interest and OSM data are segmented per Voronoi cells, thus allowing for further categorization of objects by purpose. The following methods for filtering desirable nodes are applied on each Voronoi cell data: detection based on *tags* attached to *nodes* and detection of *nodes* based on *tag* values attached to their parent *way*.

The set of OSM data for each Voronoi cell is scanned for *nodes* whose *tags* correspond to specified category of purpose, as a part of detection based on *tags* attached to *nodes*. These *nodes* are counted and stored separately into list representing *nodes* distributed per purpose attributes for each Voronoi cell. Once counted in a specific category, nodes are removed from set of OSM data for the area to avoid the assignment of a single *node* to multiple categories, which was important for the process of probabilistic model creation.

Detection of *nodes* based on *tag* values attached to their parent *way* is only used for the *home* category, due to previously described specifics of tagging residential areas. The set of the OSM data for the current Voronoi cell is processed for ways matching tag *residential*. Given the method of OSM data distribution per Voronoi cell, there is a possibility of a single *way* appearing in two or more cells. Hence children *nodes* of residential *ways* are compared with *nodes* in OSM dataset for the current area and only *nodes* existing in the current Voronoi cell were taken as *nodes* belonging to *home* category.

Resulting from the application of the two methods presented, an attribute matrix is assembled describing objects distribution per Voronoi cell and object purpose. For n (where n is a natural number) Voronoi cells, the matrix contains n rows. The attributes, i.e. purpose categories, are represented by columns. The (i, j) element of attribute matrix defined in such manner represents number of objects in i^{th} Voronoi cell whose purpose is from j^{th} category. The attribute matrix servers as an input for the next step, probabilistic model creation.

E. Probabilistic Model Creation

In this section, the development of the probabilistic model for describing targeted objects within a Voronoi cell is presented, as well as its algorithmic representation.

Probability of migration flow segmentation on objects based on their purpose is determined by a number of objects for each category within a cell and time-window during which migrations occur. Time-windows have been chosen accordingly to OD matrices and following common practice of splitting daily span onto 8 time-windows of a 3 hours-duration. Considering each time-window, the attributes have been assigned the appropriate weight values, depending on the influence that the categories have on a socio-economic motivation of migrations. Weight values in a form of natural numbers on scale 1 to 10 have been assigned in naive manner, based on the identification of a nature of socio-economic movement thorough various time slots (e.g. at 6-9 h time-window people are more likely to visit health institutions than at 18-21 h time-slot, while the 15-18 h time-slot holds an increased likelihood of home objects being

destinations rather than workplaces). Using weight values and number of objects per cell for each category allows for deployment of weighted distribution of migration flow in a specific time-slot.

Let O be the origin cell and D destination cell. Furthermore, let $a_1,\ldots,a_6$ be the purpose attributes defined in previous subsection, and w_{ai} weight value assigned to attribute a_i.

For every attribute a_i the probability for a single migration being directed to object belonging to a_i is calculated and multiplied with weight value assigned to attribute a_i as expressed in (1):

$$f_{a_i} = \frac{n_{a_i}}{n} w_{a_i} \tag{1}$$

where n is the number of all objects in cell and n_{ai} is the number of objects in category a_i.

Weighted distribution of a migration flow from origin area O to destination area D is given as in (2):

$$P \sim \begin{pmatrix} a_1 & a_2 & a_3 & a_4 & a_5 & a_6 \\ p_{a_1} & p_{a_2} & p_{a_3} & p_{a_4} & p_{a_5} & p_{a_6} \end{pmatrix} \tag{2}$$

where p_{a1} is described with (3).

$$p_{a_1} = \frac{f_{a_i}}{\sum_{k=1}^{6} f_{a_k}} \tag{3}$$

The contextualization has been conducted for each original OD matrix separately. Every migration flow (stored in OD matrix cell at i^{th} row and j^{th} column) was distributed according to above mentioned distribution and stored as vector. Novel contextualized origin-destination matrix (COD matrix) is assembled as 3-dimensional array, where the first and the second dimensions are origin and destination from the original OD matrix respectively, and the third dimension is an attribute to which the migration flow is segmented. The algorithm for probabilistic model development described in this section was deployed as algorithm in an R-based script.

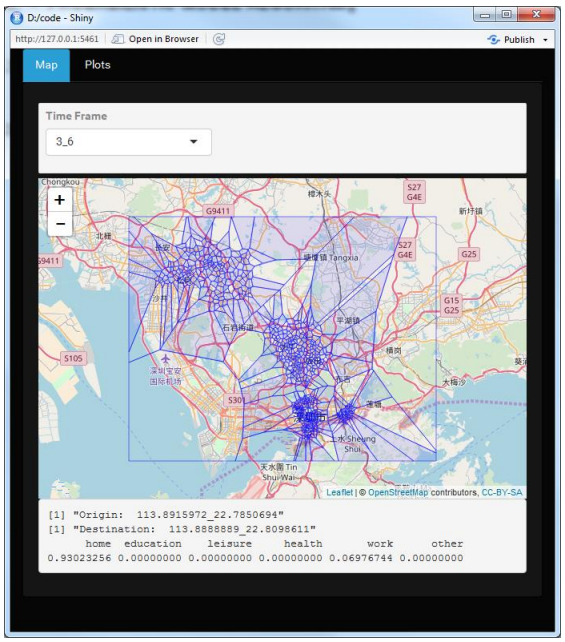

Fig. 3 Interactive map

IV. GRAPHICAL REPRESENTATION OF RESULTS

As a graphical representation of OD matrix contextualization, we use several plots and diagrams. An interactive map (Fig. 3) was designed to show Voronoi cells on top of the OSM foundation layer. The map allows selection of the time-slot and the origin cell of interest, and displays possible destination cells based on the selection. After destination cell has been chosen, the spatial analysis results are displayed bellow map showing distribution of the initial migration flow.

Probability distribution of the incoming migration flow to a destination Voronoi cells was graphically represented in a bar plot (Fig. 4) depicting probabilities of a selected category being migrated to destination Voronoi cells. The bars represent Voronoi cells with every color corresponding to a specific attribute (i.e., purpose category). Probabilities of a migration flow being appointed to an object of certain category are shown on y-axis.

The OD matrix graphical presentation method we used in this work was inherited from [18]. The authors describe methodology for OD matrix graphical presentation, in which they represent the intensity of migration through the color gradient rather than numerically. In addition to the two-dimensional heat-map we introduce a surface plot (Fig. 5) where bar height represents the number of migrations. The intensity of color red reflects the number of migrations from i^{th} to j^{th} area of observation.

Both two-dimensional heat-maps and surface plots were generated for selected time window through the following procedure. We loaded the OD matrix and probabilities matrix for the selected time window and performed OD matrix contextualization according to the method described in Section 3, *Probabilistic Model Creation*. As the contextualized OD matrix contains category-related probability distributions, the two-dimensional heat-maps and surface plots were generated for each category of the contextualized OD matrix.

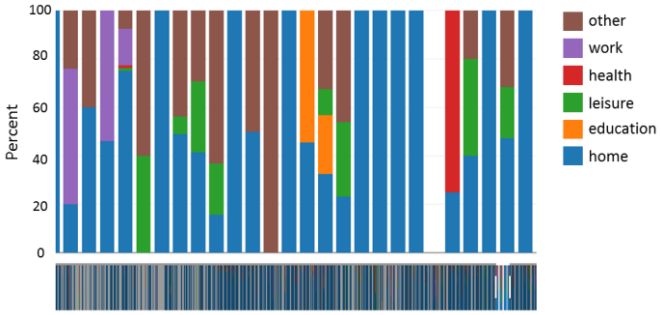

Fig. 4 Bar plot for probabilities in 9 to 12h time-window

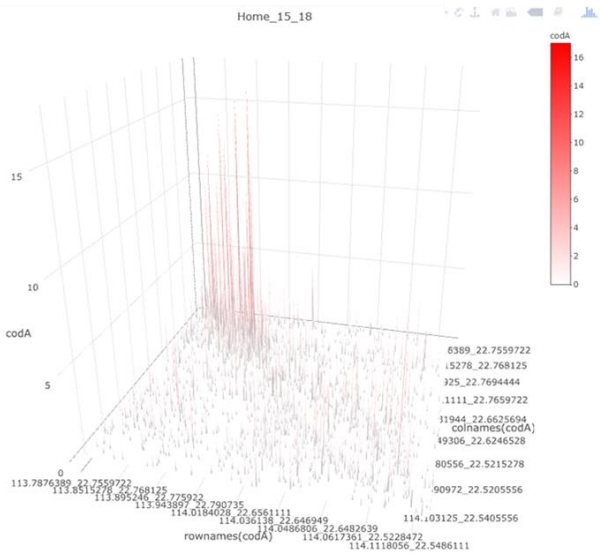

Fig. 5 Surface plot of *Home* OD matrix for 15 to 18h time-window

V. CONCLUSION AND FUTURE WORK

In this paper we present an approach of providing socio-economic context to traditionally created OD matrices. We expanded CRD data used for OD matrix estimation with the spatial data attributes available from OpenStreetMap initiative, resulting in gaining more insight on the socio-economic motivation of the migration flows. Using this approach, it becomes possible to better understand reasons behind daily and weekly urban migrations driven by socio-economic activity, which can be meaningful in identification of local socio-economic attractions and urban strategic planning.

Further research will focus on relating additional data to the process of OD matrix derivation, as well as optimization of presented contextualized migration flow probabilistic model.

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DEVELOPMENT OF ICT SYSTEMS

Design of helix antenna for 2.4GHz applicable in FSO/RF hybrid system

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Abstract - Nowadays demand on communication between people in private life, work or industry area to reached incredible size. All of us need to communicate and share information with each other. The number of information is growing day to day and we have to secure transmission of these informations between nodes (people, companies, devices ...) in real time. Requirements on connection are high transmissions speed, stability, availability, security and last but not least price. The majority of communication systems based on different transmission methods are designed on the basis of above mentioned requirements. One of those systems is FSO (Free Space Optics) system. FSO system is based on principle of standard optical fibers. Atmospheric channel is used in FSO system as transmission channel. Inhomogenities in atmosphere depend on type of weather because inhomogenities represent water particles in atmosphere. Optical beam spread through atmosphere reacts with water particles. This process creates attenuation of received optical power. Implementation of RF(Radio Frequency) backup line, which will be used when the weather conditions are bad, increases availability of FSO system. The aim of this paper is design and analyse of helix antenna, working in non-licensed frequency range of about 2.4GHz, as potential candidate for our backup RF line.

Key words – FEKO, FSO/RF hybrid system, helix antenna, RF antenna

I. INTRODUCTION

The point of this paper is to investigate possibilities for design and analysis of our designed helix antenna which will be considered as potential candidate for backup RF line for hybrid FSO/RF system. FSO system offer high speed of transmission comparable with standard optical fibers. In recent years, there were confirmed cases when values of speed of transmission reached10Gbps.

Optical fiber was a breakthrough invention in the area of communications. Transmission number of data and informations for long distances was possible for many users. Data Centers were possible to be placed far from customer without loss of connection. Increasing number of users were not problem because optical fibers offer wide frequency band. Their limitation is only for case when theoretical physical maximum of optical fiber is reached.

Optical fibers have one big drawback and it is a high start investition. Building of physical optical topology contains from optical components (for example: optical splitter, optical amplifiers, and other), opto-electronical components (for example: opto-electronical converters, and other) and physical optical fibers which are costly. In several cases is noneffective build physical architecture. FSO systems are available for these cases.

Increasing availability of FSO system is possible by using RF backup line. This implementation increases independence of weather changes to FSO system. This upgraded system was named as FSO/RF hybrid system because of combination of FSO optical system with radio frequency system implemented in backup line.

Transmission is in full duplex regime Secondary communication link contains from one pair of RF antennas. Efficiency of this backup RF link is what we want to increase. This is actually aim of our paper. We analyzed impact of weather changes on quality of received optical power before. Method of switching between primary and secondary link is in phase of solution. We analyzed hard switching and we are working on its improving. Some types of antennas were analyzed and obtained results have been published. Our results are published in [1-5].

II. EXPERIMENTAL MODEL OF FSO/RF HYBRID SYSTEM

We have experimental FSO system realized in the area of TUKE (Technical university of Košice). The proposed FSO/RF system is possible to see in the Fig.1. System is able to reach speed of transmission in range of several Gbps.

Type of used optical terminal installed on buildings is Flightstrata 155E. Terminal Flightstrata 155E contains four optical lasers working on 850nm wavelength. The number of used lasers increases reliability compared to optical system which uses one optical laser.

TABLE I. PARAMETERS OF FSO TERMINAL

Lightpointe Flightstrata 155E	
Parameters	**Values**
Wavelength	850nm
TX Power	160mW
RX Power (Sensitivity)	-30dBm
Diameter of receiving lens	8cm
Directivity	2mrad

TABLE I shows parameters of terminal used in experimental model of FSO system. Design of experimental FSO model installed on TUKE is shown on Fig.1 [1].

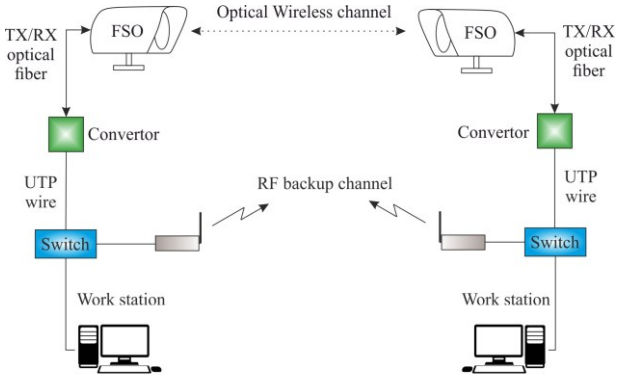

Fig. 1 Experimental model of FSO system

Our experimental model connect two subnets. One optical head is placed in Vysokoškolska 4 and the second optical head is placed in Letná 9. Distance between these optical heads is approximately 500m.

III. HELIX ANTENNA

Decision of using helix antenna as active part of backup link preceded analysis of appropriate type of RF antennas available for our case. Requirements of antennas were directed on high level of gain and directivity of transmitted waves. Potential appropriate candidate for our system is helix antenna. Helix antenna is characterized by high level of gain (around 9dB) and helix antennas are categorized by antennas with high directivity. Polarization of this helix antenna is circularly polarized.

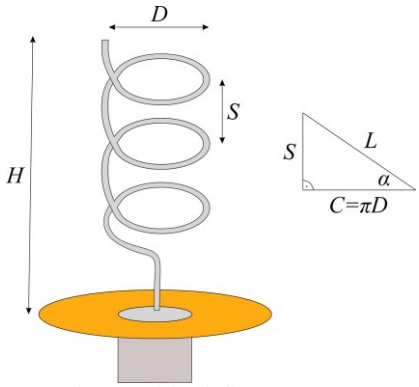

Fig. 2 Model of helix antenna

Model of helix antenna with parameter is shown in the Fig. 2. Where variable D represents diameter of turn on the helix antenna, C correspond with circumference of a turn on the helix and circumference is possible to express by equation:

$$C = \pi D, \tag{1}$$

and variable S is given as vertical separation between turns of antenna, α is pitch angle which determines maximal length of antenna in z-axis. Pitch angle α is given by equation:

$$\alpha = \tan^{-1}\frac{S}{C}, \tag{2}$$

variable N determine number of turns on helix antenna and H represents total height of antenna given by:

$$H = NS, \tag{3}$$

angle of inclination ψ between diameter of turn and vertica separation between turns is given by:

$$\tan\psi = \frac{S}{\pi D}. \tag{4}$$

In the Fig. 2, it is possible to see left hand polarized helix antenna, because direction of helix is left. This antenna is able to receive signal with LHCP (Left Hand Circularly Polarization). Direction of retraction determines type of polarization of spreaded signal. The second type of circularly polarization is the RHCP (Right Hand Circularly Polarization) [6-9].

VSWR (Voltage Standing Wave Ratio) is possible to minimize by implementation of two additional conical threads in the end of helix. These conical threads attenuate reflected currents. Critical frequency is in case when circumference of helix is 0.75λ [10-12].

The typically value of α pitch angle for helix antenna is 13 degrees. Impedance Z_{in} of helix antenna can be approximated in Ohm by:

$$Z_{in} = 140\frac{C}{\lambda}. \tag{5}$$

HPBW (Half Power BandWidth) in degrees is represented by θ and given by equation:

$$\theta = \frac{52}{\frac{C}{\lambda}\sqrt{\frac{NS}{\lambda}}}, \tag{6}$$

all of the used variables were defined further in this chapter [13-15].

Radiation pattern of E-field in Volt to square meter is possible to approximate by:

$$E = A\left[\cos\theta\frac{\sin\left(\frac{N\psi}{2}\right)}{in\left(\frac{\psi}{2}\right)}\right], \tag{7}$$

where A represents factor of normalization of plane $sin(\pi/2N)$.

Axial ratio of helix antennas as the number of loops N can be approximated by:

$$AR = \frac{2N+1}{2N}. \tag{8}$$

The gain of helix antenna can be approximated by:

$$G = \frac{6 \cdot 2C^2 NS}{\lambda^3} = \frac{6 \cdot 2C^2 NSf^3}{c^3}, \tag{9}$$

where f represents operating frequency and c is speed of light in vacuum[16-19].

IV. Design of Helix Antenna

On the base of theoretical knowledge we designed helix antenna appropriate for our application. One of the conditions for our design was using non-licensed frequency range. Then we made decision of using operating frequency at 2.4GHz. This frequency belongs to frequency range for Wi-fi service. Structure of designed antenna is possible to see in Fig. 3.

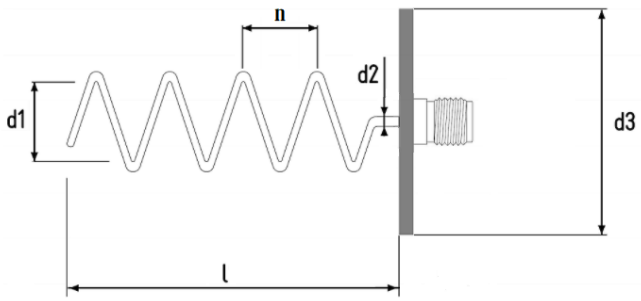

Fig. 3 Parameters of our helix antenna

Parameters of helix antenna shown in Fig. 3 are expressed by labels. Each of them are characterized by value which determines properties of this antenna. Through these parameters it is possible to reach required properties. Gain of antenna is based on these parameters. For our case we consider to approximate gain of this helix antenna around 12dB. Parameters of helix antenna are show in TABLE. II.

TABLE II. Parameters of Designed Helix Antenna

Label	Parameter	Values
f	***Frequency***	2.4GHz
N	***Number of turns***	5
d1	***Diameter of helix***	22mm
d2	***Diameter of conductor of helix***	0.06mm
d3	***Diameter of reflector***	60mm
l	***Length of helix***	102mm

Model of designed helix antenna in program suite CAD FEKO (from German: FEldberechnung für Körper mit beliebiger Oberfläche) in three dimensional space is illustrated in Fig. 4.

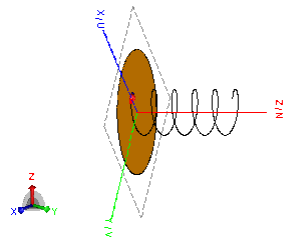

Fig. 4 Model of our designed helix antenna

Radiation characteristic of designed antenna could be seen in Fig. 5. Helix antennas are characteristic by high level of directivity and high level of reached gain.

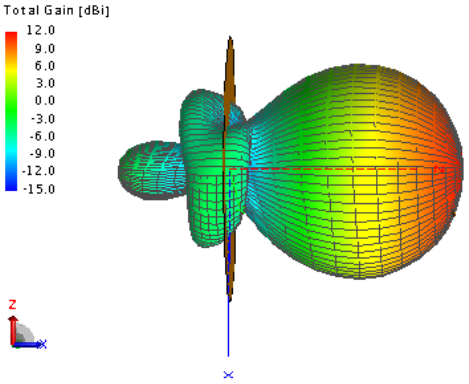

Fig. 5 Radiation of designed helix antenna

Value of reached gain is 11.2439dBi in direction of main lobe by angle ϕ = 0°. Level of side lobes is low in comparison with radiation in main beam. Total gain of helix antenna is in Fig. 6.

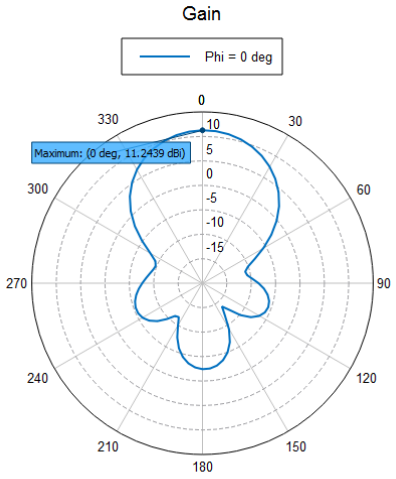

Fig. 6 Reached total gain of designed antenna

Change of radiation angle could be seen in Fig. 7 at half power. At half power for ϕ = 90° reach angle of radiation value is 51.8514° and for ϕ = 0° reach angle of radiation value is 50.261°.

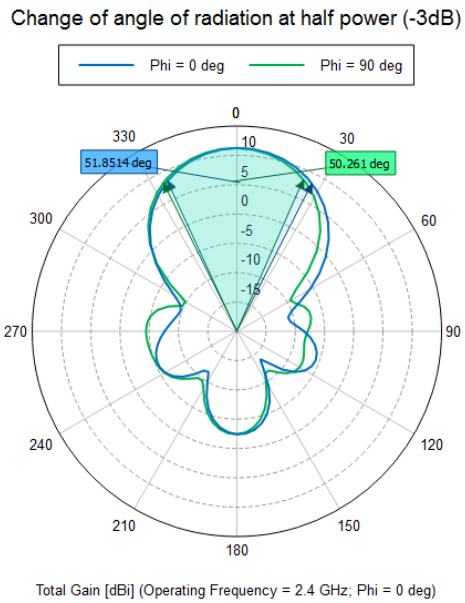

Fig. 7 Change of angle of radiation at half power

Characteristic of reflection coefficient for analyzed helix antenna could be seen in Fig. 8. Value of this coefficient is -9.70945dB for operating frequency around 2.26667GHz.

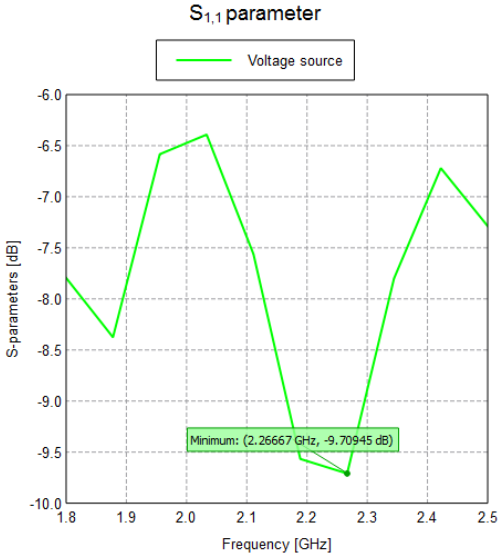

Fig. 8 $S_{1,1}$ parameter of helix antenna

V. Conclusion

In this paper we wanted to show the possibility of application of helix antenna for 2.4GHz in FSO/RF hybrid system with regards on required features. Through the analysis of designed antenna were reached effective properties which allowed its realization in the future and application in our system. Transmission of electromagnetic waves on frequency around 2.4GHz offers high level independence of weather changes. This is very important for stable connection for FSO/RF hybrid system. Approximate value of gain is more than 12dBi which is sufficient for our application.

Acknowledgment

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On the impact of the dropping function on the packet queueing performance

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***Abstract*—To eliminate the bufferbloat phenomenon from the Internet, it is recommended to apply the active queue management in network nodes – for instance, by dropping packets with a probability that is a function of the queue size (dropping function). The positive effects of this mechanism on the queue sizes, queueing delays, TCP flow desynchronization and inter-flow fairness, have been studied in many papers. They did not deal, however, with the statistical structure of packet losses caused by the application of the dropping function. This structure is especially important when real-time time multimedia transmissions are considered – such transmissions are very sensitive to consecutive packet losses. In this paper, we study the impact of the dropping function on the burst ratio, a formally-defined measure of the tendency of packet losses to occur in long series. We also check the tradeoff between the burst ratio and the overall packet loss ratio, using the cost function proposed for voice transmissions. Finally, taking this tradeoff into account, we draw conclusions about best shapes of the dropping function.**

***Index Terms*—active queue management, dropping function, burst ratio, loss ratio, multimedia transmissions, impairment factor**

I. Introduction

A growing concern among researchers working on the development of the Internet is caused by the phenomenon called bufferbloat, [1], [2], [3], which manifests itself by frequent overfilling large buffers located in modern routers, and, as a consequence, causing the significant increase of the latency and other negative side effects. The solution to this problem is the use of the active queue management for packets in routers, i.e. dropping packets before the queue becomes long, for preventive reasons (see e.g. [4]). To avoid synchronization of TCP flows, it is recommended to use random dropping of packets. For instance, incoming packets may be dropped with the probability that is a function of the queue size (so called dropping function, see e.g. [5]).

Up to date, many active queue management algorithms have been proposed. Some of them, like RED [6], REM [7], PI [8], AVQ [9], are already considered classic. Their capabilities of the reduction of the queueing latency, while preserving the high link utilization, have been shown in the original papers, as well as in several independent studies (e.g. [10]). Other algorithms are proposed in e.g. in papers [11], [12], [13], [14], [15], [16], [17].

Most of the proposed active queue management algorithms can be divided into two groups. In the first group, very advanced algorithms can be placed, whose probability of packet dropping is a complex function of many variables, such as the current and past packet arrival intensity, the current and past queue size, the history of packet drops, the history of buffer overflow events, etc. The resulting dropping probability is obtained often by using the fuzzy logic (eg. [18], [19]), artificial neural networks (eg. [20], [21]) or genetic algorithms (eg. [22], [23]). In simulations, the algorithms of the first group are able to realize very well the assumed queue management objectives, but their implementation in real networking devices may be difficult, due to high computational complexities on one hand, and increasing requirements on the number of switched packets per second in modern devices, on the other.

To the second group the algorithms in which the probability of the packet rejection is a function of the length of the queue (dropping function) can be assigned. These algorithms are computationally less complex than the algorithms of the first group. Therefore, they can be easily implemented in routers and are able to operate effectively at full speed of contemporary interfaces. In the first algorithm of this type, the aforementioned RED [6], a linear dependence of the dropping probability on the queue size was assumed. Then other types of dropping functions have been studied, including the doubly linear function [11], the exponential function [7], the quadratic function [12], the cubic function [24], the function based on orthogonal polynomials [25], and other. In this paper, we do not assume any particular form of this function – we rather study its possible different shapes and parameterizations.

As was already mentioned, the effects of the application of dropping functions on queue sizes, queueing delays, TCP flow desynchronization and inter-flow fairness, have been studied in many papers. We are not aware, however, of any study on the statistical structure of packet losses caused by the dropping function. This structure is important, especially when real-time multimedia transmissions are considered – such transmissions are very sensitive to consecutive packet losses. In other words, for a real-time time multimedia transmission it makes a difference, whether 1 packet is lost after every 50 delivered packets, or 4 packets are lost in a row after every 200 delivered packets. Due to human perception characteristics and design of modern multimedia codecs, an occasional packet loss is not a problem, while losing a series of packets one after another may have a serious impact on the user's quality of experience.

The best way to describe the tendency of losses to occur in

series is computing the burst ratio parameter, denoted herein by B. Its formal definition will be given in the next section. Roughly speaking, the burst ratio is equal to the observed average length of series of packets lost one after another, divided by the theoretical average length of series of losses in the case of independent packet loss. If $B = 1$, then we can conclude that every packet loss is purely random and independent. If $B > 1$, then the packet losses have a tendency to appear in groups. The larger the value of B is, the stronger is this tendency. Finally, if $B < 1$, then the losses have a tendency to occur separately.

Network traffic engineers know well, that in TCP/IP networks with the standard drop-tail FIFO queueing implemented in the routers, the packet losses have a bursty character, i.e. high values of B can be expected. The main reason of this is that the losses occur when the FIFO buffer is full (overflowed), and this overflow state may last some time. Naturally, all the packets arriving during this state are lost in a row.

Intuitively, we may expect that application of the dropping function reduces the value of B. When packets are deleted randomly, at any buffer occupancy level, then the losses should not be grouped together. This is the main purpose of this paper – to test the hypothesis, that the dropping function makes B smaller. If this hypothesis was confirmed, then another positive effect of the dropping function would be added to previously shown reduction of the queue size, flows' desynchronization etc.

Our second purpose is to check, if the additional cost connected with the application of the dropping function, which is a higher loss ratio L, does not ruin the positive effect of the decreased B, on the overall multimedia transmission quality. To check this, we use the cost function, which presents the combined impairment of the transmission quality, as a function of L and B.

Thirdly, we will look for good shapes of dropping functions, in terms of providing a small B value and a reasonable impairment factor at the same time. To achieve this goal, we will exploit 20 different dropping functions, from 4 classes (linear, convex, concave and other).

The rest of the paper is organized in the following manner. In Section 2, the formal definitions of the performance characteristics of interest are recalled. These include the packet loss ratio, the packet burst ratio and the transmission impairment factor. In Section 3, a detailed description of the queueing model as well as some of its analytical solutions are given. Then, in Section 4, the resulting loss ratios, burst ratios and impairment factors are presented and discussed. Finally, in Section 5, the concluding remarks are gathered.

II. Loss characteristics

The main characteristic of the loss process is obviously the loss ratio, L. Consider a stream of packets passing trough a network node. L is defined as the number of packets lost at the node, divided by the total number of packets that arrived at the node, both measured in a long time interval. Thus L is equivalent to the loss probability – both concepts are interchangeable. The loss ratio for buffer overflows in queueing systems without the dropping function has been studied in [26], [27] for different traffic models. The loss ratio for the system with the dropping function is given in formula (25) of [5]. As for the experimental measurements of the loss ratio in the Internet, we refer the reader to [28], [29], [30].

The second important characteristic of the loss process is the burst ratio, B, proposed in [31]. It is equal to the average observed length of series of lost packets, $\overline{G}$, divided by, $\overline{K}$, the theoretical average length of series of lost packets, expected for independent, random loss (i.e. in the Bernoulli process) $B = \frac{\overline{G}}{\overline{K}}$. Of course, the same packet loss probability, L, is assumed in both the nominator and denominator. Note that, even if L is small, $\overline{G}$ can be arbitrary large, due to possible strong dependencies in the loss process. This is not the case of the denominator – in the Bernoulli process we can easily derive that $\overline{K} = \frac{1}{1-L}$, which converges quickly to 1 when $L \to 0$. Using the latter formula, we can also rewrite the formula for B into $B = \overline{G}(1 - L)$.

So far, there are no published papers with analytical formulas for the burst ratio in queueing models, no matter with or without the dropping function. Some preliminary work on the structure of packet losses in finite-buffer queueing models can be found in [32], but they are far from any direct calculation of B. Therefore, B will be obtained herein using simulations performed in Omnet++ environment, [33].

Thirdly, we need a cost function, combining both L and B, which could tell us, whether it is better to have, for instance $L = 1\%$ and $B = 2$, rather than $L = 2\%$ and $B = 1$, or vice versa. One of the best candidates for such cost function is the impairment factor for voice transmissions, I, defined in [34] to be:

$$I = I_e + (95 - I_e)\frac{100L}{100L/B + R}, \tag{1}$$

where I_e and R are some constants, with default values $I_e = 0$ and $R = 4.3$. Playing with formula (1), we can easily find examples in which the impairment gets worse due to deterioration of B, even though L is improved. For instance, the impairment for $L = 2\%$ and $B = 2$, is worse than for $L = 3\%$ and $B = 1$.

Finally, in addition to the loss ratio, the burst ratio and the impairment factor, it is worth presenting the basic queueing characteristics, i.e. the average queue size and its standard deviation. The appropriate formulas for the system without the dropping function and a general arrival process can be found in e.g. [35], while for the system with the dropping function - in [5].

III. Queueing model

The arrival process is modeled herein by the Poisson process, where the interarrival times are exponentially distributed with parameter λ. The arriving packets form a queue in the buffer. The packet service time distribution is general, given by some distribution function $F(t)$. The buffer space for arriving packets is limited, i.e. no more than N packets can be stored

in total, including the one being serviced. If on the arrival of a packet the buffer is full, the arriving packet is dropped.

Moreover, if not stated otherwise, the dropping function, $d(n)$, is used in the system. This means that even a packet which arrives when the buffer is not full, can be dropped with probability $d(n)$, where n denotes the queue size at the time of arrival of this packet. Obviously, $d(n)$ must fulfill the conditions: $d(n) = 1$ for $n \geq N$ and $0 \leq d(n) \leq 1$ for $n < N$.

We are interested in values of the loss ratio, burst ratio and impairment factor, defined in the previous section, for the packet losses caused by the dropping function and the finite buffer mechanisms. Additionally, we will check the average queue size and the standard deviation of the queue size.

Analytical solutions

Some of the aforementioned characteristics of interest can be computed using the solution of the queueing model with the dropping function and general Markov-modulated Poisson arrivals, shown in [5]. In particular, we can compute the loss ratio, the average queue size and the standard deviation of the queue size, for both models, with and without the dropping function. (Note that in the model without the dropping function, we can simply use a trivial dropping function in the form $d(n) = 0$ for $n < N$ and $d(n) = 1$ otherwise, which enable us to use the formulas proved for dropping functions). Namely, we have the following theorem.

Theorem. *The Laplace transform of the distribution of the queue size at time t of the system with Markov-modulated Poisson arrivals and the dropping function is:*

$$\overline{\phi}(s,l) = \mathbf{G}^{-1}(s)R(s,l), \tag{2}$$

where $\mathbf{G}(s)$ is the square matrix:

$$\mathbf{G}(s) = \left[\mathbf{G}_{ij}(s)\right]_{i=0\ldots N, j=0\ldots,N},$$

$$\mathbf{G}_{ij}(s) = \begin{cases} \tilde{\mathbf{A}}_{i,j-i+1}(s), & \textit{if} \quad 1 \leq i \leq N-2, i < j \leq N-1, \\ \tilde{\mathbf{A}}_{i,1}(s) - \mathbf{I}, & \textit{if} \quad i = j, 1 \leq i \leq N-1, \\ \tilde{\mathbf{A}}_{i,0}(s), & \textit{if} \quad i = j+1, \\ \mathbf{U}_0(s) - \mathbf{I}, & \textit{if} \quad i = 0, j = 0, \\ \mathbf{V}_0(s), & \textit{if} \quad i = 0, j = 1, \\ -\mathbf{I}, & \textit{if} \quad i = N, j = N, \\ \mathbf{0}, & \textit{otherwise,} \end{cases}$$

with

$$\tilde{\mathbf{A}}_{n,k}(s) = \left[\tilde{a}_{n,k,i,j}(s)\right]_{i,j}, \tag{3}$$

$$\tilde{a}_{n,k,i,j}(s) = \int_0^\infty e^{-st} A_{n,k,i,j}(t) dF(t), \tag{4}$$

$$\mathbf{U}_n(s) = \left[\frac{(\lambda_i - \mathbf{Q}_{ii})p_{ij} + d(n)\mathbf{\Lambda}_{ij}}{s + \lambda_i - \mathbf{Q}_{ii}}\right]_{i,j}, \tag{5}$$

$$\mathbf{V}_n(s) = \left[\frac{(1 - d(n))\mathbf{\Lambda}_{ij}}{s + \lambda_i - \mathbf{Q}_{ii}}\right]_{i,j}, \tag{6}$$

$$p_{ij} = \begin{cases} 0 & \textit{if} \quad i = j, \\ \frac{\mathbf{Q}_{ij}}{\lambda_i - \mathbf{Q}_{ii}} & \textit{if} \quad i \neq j, \end{cases}$$

$\mathbf{Q}$, $\mathbf{\Lambda} = \mathbf{diag}[\lambda_\mathbf{1}, \ldots, \lambda_\mathbf{m}]$ are the generating matrices for the Markov-modulated Poisson process, while $R_i(s,l)$ is the following column vector:

$$R(s,l) = \left[R_0(s,l), \ldots, R_N(s,l)\right]^T, \tag{7}$$

$$R_i(s,l) = \begin{cases} -\delta_{0l} z(s), & \textit{if} \quad i = 0, \\ -r_i(s,l), & \textit{if} \quad 1 \leq i \leq N, \end{cases}$$

$$z(s) = \left[\frac{1}{s + \lambda_1 - \mathbf{Q}_{11}}, \ \cdots \ , \frac{1}{s + \lambda_m - \mathbf{Q}_{mm}}\right]^T, \tag{8}$$

$$r_n(s,l) = \begin{cases} \mathbf{0} \cdot \mathbf{1}, & \textit{if} \quad l < n, \\ \overline{\mathbf{D}}_{n,l-n}(s) \cdot \mathbf{1}, & \textit{if} \quad n \leq l \leq N, \end{cases} \tag{9}$$

$$\overline{\mathbf{D}}_{n,k}(s) = \left[\overline{d}_{n,k,i,j}(s)\right]_{i,j}, \tag{10}$$

$$\overline{d}_{n,k,i,j}(s) = \int_0^\infty e^{-st} A_{n,k,i,j}(t)(1 - F(t))dt,$$

where all $[\cdot]_{i,j}$ matrices are of $m \times m$ size.

In this notation, m is the number of states of the modulating Markov chain, $\mathbf{I}$ is the unit matrix of size $m \times m$, $\mathbf{0}$ is the square matrix of zeroes, $\mathbf{1}$ is the vector of 1's, δ_{ij} is the Kronecker symbol.

Function $A_{n,k,i,j}(u)$ is the counting function of the arrival process filtered by the dropping mechanism, defined as the probability that k packets would be accepted into the buffer in time interval $(0, u]$, if the service process was suspended in this interval. Denoting

$$\overline{\mathbf{A}}_{n,k}(s) = \left[\overline{a}_{n,k,i,j}(s)\right]_{i,j}, \tag{11}$$

$$\overline{a}_{n,k,i,j}(s) = \int_0^\infty e^{-st} A_{n,k,i,j}(u) du, \tag{12}$$

and

$$\mathbf{Z}(s) = \mathrm{diag}(z(s)), \tag{13}$$

$$\mathbf{C}_n(s) = (\mathbf{I} - \mathbf{U}_n(s))^{-1}\mathbf{V}_n(s), \tag{14}$$

$$\mathbf{E}_n(s) = (\mathbf{I} - \mathbf{U}_n(s))^{-1}\mathbf{Z}(s), \tag{15}$$

we can compute the transform of this counting function using the following formulae:

$$\overline{\mathbf{A}}_{n,k}(s) = \mathbf{C}_n(s)\mathbf{C}_{n+1}(s)\ldots\mathbf{C}_{n+k-1}(s)\mathbf{E}_{n+k}(s), \quad k \geq 1, \tag{16}$$

$$\overline{\mathbf{A}}_{n,0}(s) = \mathbf{E}_n(s). \tag{17}$$

Finally, to compute the probability P_l that the queue size is l in the steady state, we can use properties of the Laplace transform and the recalled theorem. We have

$$P_l = \lim_{s \to 0+} s\left[\mathbf{G}^{-1}(s)R(s,l)\right]_1, \tag{18}$$

where $[\cdot]_1$ is the first element of a vector. Using (18), we can obtain the full distribution of the queue size, its standard deviation and the loss ratio, which equals:

$$L = 1 - \frac{1 - P_0}{\rho}, \tag{19}$$

where ρ is the load of the system.

IV. Results

We assumed that the queue of packets is served by a 1Gb/s link. The size of a packet arriving to the queue was uniformly distributed in interval $[40, 1500]$bytes, what, given the 1Gb/s link speed, translated into uniform packet service time in interval $[0.32, 12]\mu$s.

It was assumed, that 1.03Gb/s traffic was offered, i.e. the system was slightly congested. In total, 21 scenarios were checked – one scenario without the dropping function and 20 scenarios with dropping functions, grouped in the following four classes:

- linear dropping functions:

$$d_1(n) = 0.00005n, \quad d_2(n) = 0.0001n,$$
$$d_3(n) = 0.0005n, \quad d_4(n) = 0.001n,$$
$$d_5(n) = \begin{cases} 0, & \text{if} \quad n < 100, \\ 0.01n - 1, & \text{otherwise}, \end{cases}$$
$$d_6(n) = \begin{cases} 0, & \text{if} \quad n < 150, \\ 0.02n - 3, & \text{otherwise}, \end{cases}$$
$$d_7(n) = \begin{cases} 0, & \text{if} \quad n < 175, \\ 0.04n - 7, & \text{otherwise}, \end{cases}$$
$$d_8(n) = \begin{cases} 0, & \text{if} \quad n < 190, \\ 0.1n - 19, & \text{otherwise}, \end{cases}$$

- convex dropping functions:

$$d_9(n) = e^{\frac{n-200}{40}}, \quad d_{10}(n) = e^{\frac{n-200}{20}},$$
$$d_{11}(n) = e^{\frac{n-200}{10}}, \quad d_{12}(n) = e^{\frac{n-200}{5}},$$

- concave dropping functions:

$$d_{13}(n) = \begin{cases} 0, & \text{if} \quad n < 100, \\ \sqrt{\frac{n-100}{100}}, & \text{otherwise}, \end{cases}$$
$$d_{14}(n) = \begin{cases} 0, & \text{if} \quad n < 150, \\ \sqrt[4]{\frac{n-150}{300}}, & \text{otherwise}, \end{cases}$$
$$d_{15}(n) = \begin{cases} 0, & \text{if} \quad n < 175, \\ \sqrt[8]{\frac{n-175}{100}}, & \text{otherwise}, \end{cases}$$
$$d_{16}(n) = \begin{cases} 0, & \text{if} \quad n < 190, \\ \sqrt{\frac{n-190}{100}}, & \text{otherwise}, \end{cases}$$

- other dropping functions:

$$d_{17}(n) = 0.203 + 0.13 \arctan(n - 100),$$
$$d_{18}(n) = 0.327 + 0.21 \arctan[(n - 125)/2],$$
$$d_{19}(n) = 0.401 + 0.26 \arctan[(n - 170)/5],$$
$$d_{20}(n) = 0.501 + 0.16[\arctan(n-140) + \arctan(n-180)].$$

(These dropping functions are depicted in Figs. 1-4). Finally, the size of the buffer was 200, including the service position. Therefore, in every case it was $d(n) = 1$ for $n \geq 200$, even if, to preserve space, not stated directly in the above formulas.

The resulting loss ratios, burst ratios and impairment factors are shown in Tab. I.

As expected, the best loss ratio, 0.0291, was obtained in the scenario without the dropping function. Several dropping functions, however, provided only slightly higher loss ratio of 0.0292 (see d_1, d_2, d_{10}, d_{14}, d_{15}).

As for the burst ratio, in the scenario without the dropping function, a high value of 1.50 was obtained. This means that the average length of series of packets lost one after another was fifty percent larger than in the case of the random loss. This value illustrates well the tendency of packets to group together when the classic, FIFO-drop-tail queueing is used.

Now, in every scenario with the dropping function, a significant reduction of B could be observed. In several cases (e.g. d_3, d_4, d_9, d_{10}, d_{19}), the resulting B was very close to 1. The best B was obtained for d_3, d_4 and d_9, for which we got an excellent $B = 1.01$.

Even without looking at the last column of Tab. I, we can guess, that a significant reduction of the burst ratio, together with the slight increase of the loss ratio, should provide an overall improvement of the multimedia transmission quality. Indeed, this is confirmed by the last column of Tab. I. As we can see, the impairment factor, which in the scenario without the dropping function equals 44.3, is also reduced in all the considered scenarios with the dropping function.

The best reduction of the impairment factor, to 38.9, was obtained for the function d_{10}, which balanced well L and B according to the cost function in formula (1). Function d_{10} almost does not drop packets in range 0-130, but then the dropping probability increases exponentially to 1. The former property makes possible to use effectively the majority of the buffering space and to keep the loss ratio low. The latter property makes possible to drop the packets when necessary (forthcoming buffer overflow), but randomly, instead in series.

Finally, the average queue size and its standard deviation is presented in Tab. II for each considered scenario. As we can see, the queue size was always reduced when the dropping function was used, but the reduction factor varied from negligible values, to as high as 500 percent (see d_4).

V. Conclusions

We showed that the application of the dropping function causes a significant improvement of the burst ratio, a characteristic of the tendency of packet losses to occur in long series. We showed also, that properly chosen dropping function is at the same time able to maintain a low loss ratio. Both of these cause an overall improvement of the transmission impairment factor.

This improvement is especially important for real-time multimedia transmissions, whose volumes are rapidly growing in the contemporary Internet.

Having tested several shapes and parameters of the dropping function, we found that the best tradeoff between the loss ratio and the burst ratio was achieved for a convex, exponential

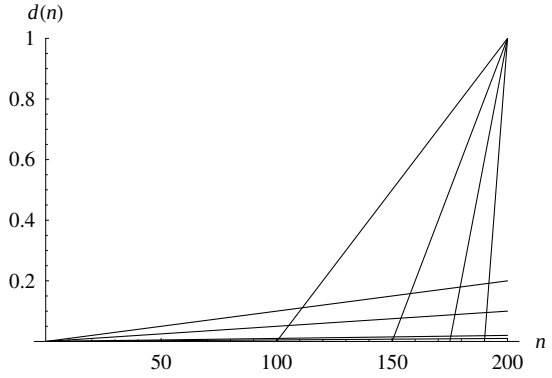

Fig. 1. Linear dropping functions, d_1–d_8.

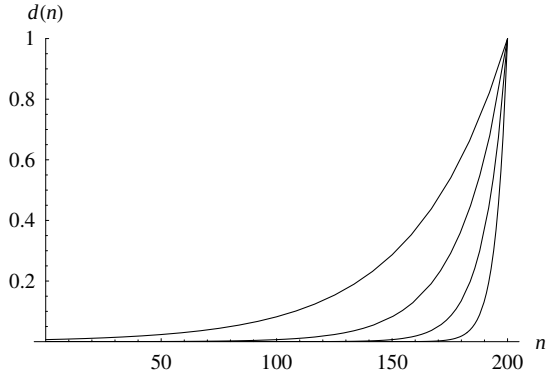

Fig. 2. Convex dropping functions, d_9–d_{12}.

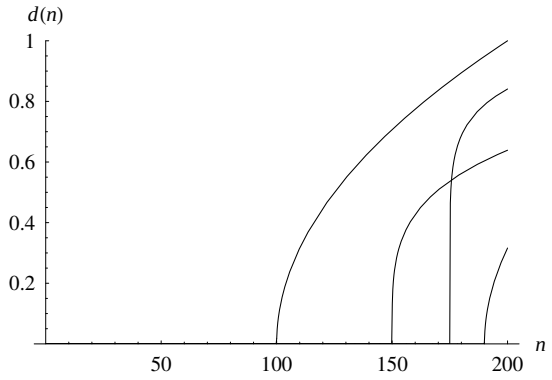

Fig. 3. Concave dropping functions, d_{13}–d_{16}.

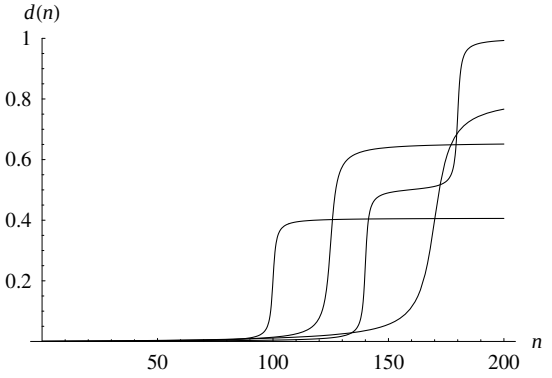

Fig. 4. Other dropping functions, d_{17}–d_{20}.

dropping function	loss ratio, L	burst ratio, B	impairment factor, I
none	**0.0291**	1.50	44.3
d_1	0.0292	1.31	42.5
d_2	0.0292	1.18	40.9
d_3	0.0311	**1.01**	40.0
d_4	0.0355	**1.01**	43.2
d_5	0.0294	1.08	39.8
d_6	0.0293	1.12	40.2
d_7	0.0294	1.17	41.0
d_8	0.0294	1.25	42.0
d_9	0.0318	**1.01**	40.6
d_{10}	0.0292	1.03	**38.9**
d_{11}	0.0294	1.05	39.5
d_{12}	0.0294	1.10	40.2
d_{13}	0.0295	1.16	40.9
d_{14}	0.0292	1.23	41.5
d_{15}	0.0292	1.39	43.2
d_{16}	0.0295	1.17	41.1
d_{17}	0.0295	1.15	40.8
d_{18}	0.0295	1.08	39.9
d_{19}	0.0293	1.03	39.0
d_{20}	0.0293	1.14	40.4

TABLE I
LOSS RATIO, BURST RATIO AND IMPAIRMENT FACTOR FOR DIFFERENT DROPPING FUNCTIONS.

function d_{10}, which was almost zero at two-thirds of the buffering space, but then increased quickly to 1.

This does not mean, however, that such shape is "the best" in general. For instance, far shorter average queue sizes were obtained for other dropping functions, at the cost of high loss ratios. Therefore, these other shapes can be used when a short queueing delay is of the greatest importance, instead of low loss and burst ratios.

An interesting future work would be proposing and testing a good cost function, incorporating in one formula all important queueing characteristics, i.e. the queueing delay, its standard deviation (jitter), the loss ratio and the burst ratio. We are not aware of any such function in the literature.

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dropping function	average queue size	std. dev. of the queue size
none	178.2	21.9
d_1	171.0	27.5
d_2	160.1	33.6
d_3	62.1	31.8
d_4	**35.5**	20.8
d_5	89.9	21.2
d_6	136.2	21.4
d_7	158.8	21.3
d_8	171.7	21.6
d_9	53.8	25.8
d_{10}	117.0	26.5
d_{11}	150.8	23.4
d_{12}	166.9	21.9
d_{13}	83.4	**20.0**
d_{14}	131.1	21.5
d_{15}	154.7	21.7
d_{16}	172.9	21.7
d_{17}	77.4	20.4
d_{18}	93.5	23.7
d_{19}	117.9	29.5
d_{20}	113.5	23.6

TABLE II
AVERAGE QUEUE SIZE AND ITS STANDARD DEVIATION FOR DIFFERENT DROPPING FUNCTIONS.

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Prosumer flexibility management in smart grids

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Abstract— **Diverse electricity consumption and distributed production present serious challenges in future smart grids. Smart grid end users can have a role of a consumer and a producer at the same time. So-called prosumers are considered to play a major role in the future grid operation, management and maintenance. One of main concepts supporting this novel role is prosumer flexibility, namely an ability of the prosumers to adapt their consumption or production according to the smart grid needs. Understanding, managing and utilizing the prosumers flexibility remains a serious research challenge that needs to be evaluated and proved in practice.**

In this paper we will present a synergy of two research projects addressing the area of prosumer flexibility management. First one is a horizon project Flex4Grid, which aims at prosumer flexibility management by using advanced information technology solutions, while the second one is a national Critical Peak Tariff project in Slovenia, that enables distribution system operators to test novel prosumer flexibility management incentives in real life operation. The projects' cooperation allows to utilize modern smart grid infrastructure, boost its usage with advanced IT, and evaluate prosumer flexibility management in practice. We introduce the conceptual model and implementation of our technical solution, as well as some preliminary evaluation results of a large-scale pilot.

Keywords— prosumer; flexibility management; smart grid; large scale pilot; information technologies

I. INTRODUCTION

Electricity demand in households is increasing with the expansion of smart electronic devices. Technology for harvesting energy from alternative sources, whether solar, wind, geothermal or biomass, is also becoming more accessible and in demand. Integration of alternatives into the grid is on the rise, which causes some operational issues in the power system [1]. One such problem concerns the overload of energy production from alternatives and also a critical demand for energy consumption at certain time intervals in the day.

Traditional supply-side flexibility (from centralized power plants) is not enough to manage new smart grid overloads, thus additional flexibility is needed from a range of generators, storage, and demand. In this paper we present and overview two projects addressing demand-side flexibility with a prosumer flexibility management scheme [2]. Our solution allows the end users to actively participate in managing consumption overloads, as well as production overloads from alternative sources connected to their local network. Preliminary results from the project pilot show there is an active response from participants in the pilot, which contributes to reducing peak consumption in households.

Flex4Grid (F4G) [3] is a European project with a focus on creation and provision of an open data and service framework, that enables prosumer flexibility management in households. Project F4G aims to provide a holistic data management solution with a secure and private data exchange between the distribution system operators (DSOs) and their customers, which in turn manages flexibility of prosumer demand and generation to the benefit of all stakeholders. Project F4G will be concluded at end of March 2018.

Primary goal of the F4G project is to build a system with an ability to balance the demand by reducing the peak loads (so called peak clipping). Secondary goal is to allow the system to match an excessive supply from alternative sources by shifting the load. Tertiary goal is to understand how the incentives for participation affect the project solution. And lastly, we are interested in the nature of the flexibility achieved by analysing environmental, technology, and human factors affecting the utility of the proposed solution [4].

Testing and validation of F4G management system is conducted via pilots in three real electricity networks with different characteristics. One pilot site is in Slovenia, where there are smart meters already integrated in households. Two sites are placed in Germany and are of smaller scale, due to necessity and complexity of introducing and installing extended kits to pilot users, as there are no smart meters installed. Extended kits consist of a Flex4Grid gateway, five smart plugs, and optional electricity meters to measure household consumption in real-time, [5]. Preliminary results presented here will be from the Slovenian pilot.

Simultaneously, there is a national Pilot Critical Peak Tariff Project (PCPT) [6] in Slovenia, where dynamic pricing is introduced and tested as a form of demand response regulation [7]. Besides a standard fee, which is a bit lower than current fixed fee, it features a special high network fee, which DSOs can charge during the peak load periods. The intent is to provide incentive for the prosumers to dynamically respond and redistribute their consumption in order to avoid network overload, which can occur with additional production from alternative sources or very high consumption demand. This overload is considered as a critical peak. In the PCPT project it

is possible to use dynamic tariff on real prosumers for 50 hours per year. While PCPT project provides incentive for users to participate in F4G pilot, the F4G solution offers means to measure and evaluate the demand response for each predicted critical peak.

In the following section we introduce the main elements of the F4G solution and its implementation to a real power system environment. The data and testing events are presented in the third section. In the fourth section we present the preliminary results gathered from four events. Corresponding challenges discovered during evaluation are discussed in the fifth section. We end the paper with main conclusions.

Related work

Operational flexibility in power systems is a known and researched subject since the integration of alternative sources in bulk, see [8] and [9]. Demand response programs with multi-hour peak loads have been effectively implemented in past years, but were used as a limited resource. Due to advances in communications and controls in smart grids, the demand response is now being used as an ancillary service to the power system [10]. There are several approaches to regulate demand response, such as time-of-use rates, real-time pricing, and critical peak pricing [11], which were tested on small-scaled grids with different success rates, see [12] and [13].

Demand response refers to a procedure of motivating users to change their power consumption habits as a response to the electricity price. Five large-scale cases studies [14] in USA researched pricing incentives for peak reduction and response sustainability. All employed some form of dynamic pricing and found peak reduction substantially greater with the use of enabling technologies. However, the real-world impact is still limited by the lack of an IP-based network architecture that is reliable, safe, and efficient in managing the complexity of a smart grid communication infrastructure [15].

Another analysis of consumer engagement in Europe [16] revealed that money incentive alone may not be strong enough to get a noticeable consumer response. It is also necessary to have a reliable solution of communicating and informing the costumers, as well as developing social marketing strategies to help increase active response and help change the perception of electricity as a commodity.

Here we present prosumer flexibility management as a service and the effect of dynamic pricing on customer response in a real large-scale pilot. Promising results of the later, will help propose and implement necessary regulatory changes, which are needed in the smart power systems, while the former provides a marketable technical solution to manage the demand response in case of such regulatory changes. Complementary nature of F4G and PCTP projects allows for large-scale pilot testing in a real smart power system environment.

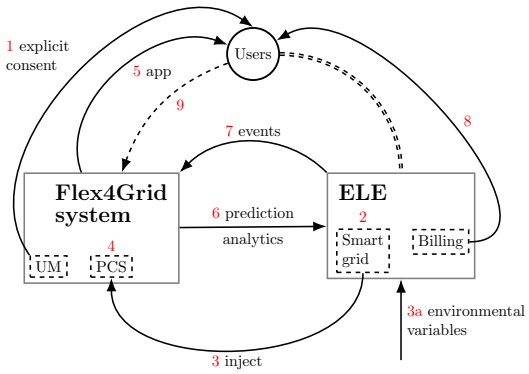

Fig 1. Conceptual model of F4G system implementation.

II. IMPLEMENTATION

The implementation of F4G solution and information flows are presented in Fig 1. The F4G solution uses an existing smart grid metering system. A billing system at Elektro Celje d.d. (ELE) has been adapted to support PCPT billing at one-hour granularity. Users connected to the smart grid interact with F4G system through a mobile application, with which they can monitor their consumption and receive notifications about the test events.

Implementation process flow between F4G system and ELEs smart grid with end users (presented with double dashed line) is as follows:

1. Explicit consent for the use of consumption data, gained during participation in the project, is obtained for each user via user management (UM) module.
2. At ELE, smart grid consumption data from each end user is aggregated at substation level. Household consumption is read at 15-minute interval from smart meters.
3. The aggregated data and corresponding environmental data (3a) are then injected into F4G system. Hourly predicted values of environmental variables (3a) for 3-days in advance are added to the historical data and sent to the F4G system.
4. At Prosumer Cloud Service (PCS) module the data is then pre-processed and inputted into the prediction model.
5. F4G provides a mobile application for a 2-way communication with the user.
6. Prediction for the time and the magnitude of the peak is sent back to ELE.
7. Based on the prediction, an event is organised and notifications are sent to the participants via mobile application.
8. Taking all of the events into account and using the PCTP pilot tariff scheme, corresponding billing is made and sent to the participants.
9. User feedback is sent to F4G system via user satisfaction questionnaires.

TABLE I. DESCRIPTIVE STATISTICS FOR ALL ENVIRONMENTAL VARIABLES AND TOTAL CONSUMPTION ACROSS ALL YEARS (2013 – 2017) AND EACH INDIVIDUAL YEAR

	Temperature [°C]				Radiation [W/m^2]				Precipitation [mm]				Consumption (total) [kW]			
	mean	**std**	**min**	**max**	**mean**	**std**	**min**	**max**	**Mean**	**Std**	**min**	**max**	**mean**	**std**	**min**	**max**
All	11.22	9.08	-20	39	148.15	239.79	0	1068	11.88	74.50	0	3014	**10267.26**	3275.19	141.96	**23303.93**
2013	10.66	9.19	-14	39	141.03	235.99	0	1052	12.06	68.31	0	2503	**8409.55**	2867.39	2886.73	**18353.84**
2014	11.81	7.77	-20	34	135.54	226.20	0	1068	14.92	83.54	0	1773	**9490.51**	2794.56	4483.64	**20062.62**
2015	11.04	9.16	-15	36	147.49	238.46	0	1020	10.47	67.50	0	2029	**10298.71**	2992.97	4760.01	**19972.50**
2016	10.70	8.96	-14	33	142.61	233.74	0	1050	11.77	73.00	0	2636	**10731.79**	3171.64	4998.16	**21969.40**
2017	12.17	10.53	-19	38	186.01	269.68	0	1034	9.44	80.58	0	3014	**12405.74**	4191.45	141.96	**23303.93**

III. EVALUATION

Slovenian pilot is conducted at ELE in the municipality of Celje. Since households in Slovenia are equipped with smart meters, the users do not need the kits to participate in the pilot. The number of participants is thus larger (748 in preliminary phase gathered from 10956 invitations). All participants are consumers who are connected to one of 209 different local transformer substations (TP).

Eligible candidates for the pilot are the household consumers with two-tariff billing, who are connected to the distribution network of ELE. They must have an electricity meter, which can remotely read the load profile in 15-minute intervals, and reliable communication between the electrical meter and the data centre. Participation is formalized with the explicit consent for participation, which was signed by each participant [5].

Candidates were invited to the project with an invitation letter, which contained basic project information and a registration code. Incentives for the participants are: 1) dynamic pricing as defined in the PCTP project, 2) a lottery with material prizes (electrical scooters and bicycles) conducted by ELE, and 3) detailed insight into their electricity consumption via Flex4Grid mobile application.

Flex4Grid system provides a way for the consumer to actively adjust their consumption, when prompted by their DSO. In the case of Slovenian pilot, the prompt is a scheduled event with a 24-hour advance notice. Event represents one hour in a day, for which dynamic pricing applies. Main goal during each event is for users to actively reduce their consumption. For each event a prediction of overall consumption and peak load of that day was made using a prediction model.

For experimental testing the population of consumers was divided into a pilot and a control group. The pilot group represents the pilot participants, who receive event notifications, while the control group is the rest of the population considered by the project.

A. Data

All smart meter measurements are aggregated at substation level. Analysis and prediction are then done on the sum of consumption values across substations. In addition, environmental variables such as temperature, radiation, and precipitation are recorded at every hour and attached to the measurement data by corresponding timestamps.

Historical data from January 2013 until November 2017 is available for all four variables. Descriptive statistics for these variables is presented in Table I. The yearly mean consumption is increasing at a minimum 4% rate. Similar trend can be noticed for yearly maximum consumption.

Since we are also involved in the PCPT project, where defining yearly critical peaks is the primary goal, we explored the daily peak distributions in different seasons, as shown in Fig 2. Daily peak is the highest consumption value of the day. All four distributions are bimodal, with one extreme in the morning to midday and the other in the evening. There is a noticeable shift of an hour between evening peaks in cooler months of shorter days (autumn and winter) and warmer months with longer days (spring and summer). On weekdays the highest peaks occur in the evening, while on weekends and holidays they occur at midday.

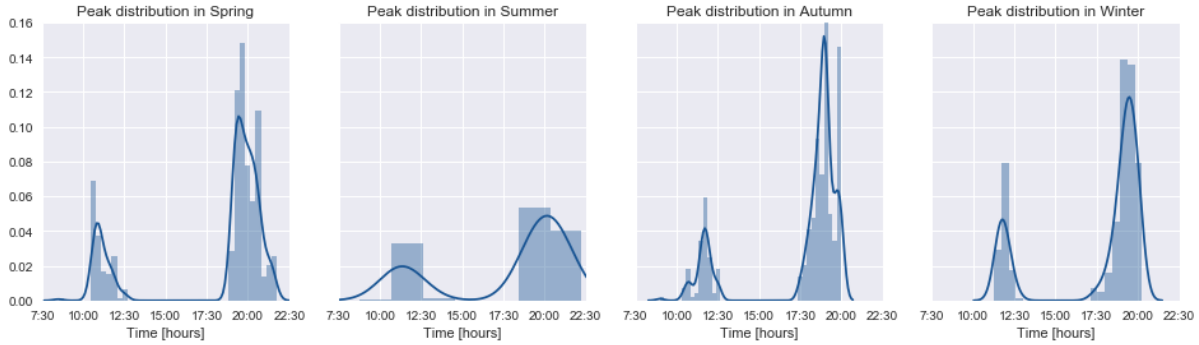

Fig 2. Daily peak distributions (in percentages [%]) for all four seasons.

B. *Prediction model*

In order to predict the highest daily peak, a prediction model was build using artificial neural networks (ANN), specifically Long Short-Term Memory (LSTM) networks. Using ANN as a tool for energy consumption prediction showed promising results in previous studies [17]. A machine learning approach was made possible due to a large amount of historical data. Because there are several periodical patterns in the consumption data (yearly, weekly, and daily), we wanted to use this information when making the predictions. The LSTM networks were shown to successfully model long term and short-term intervals of a time series and were therefore considered for the prediction model [18]. We build a network with two hidden layers with 200 hidden neutrons per layer.

The input vector contains the consumption values (of one week previous the prediction day), values of three environmental variables, and time depended variables, such as season, day of the week (weekend or weekday), and time of the day (separated into eight three-hour intervals) corresponding to each consumption measurement. The output variable is the consumption. Optimization of the weights on edges between layers was done through supervised learning with an Adamax optimizer [19].

IV. RESULTS

Preliminary results of the project presented here were collected from four events. For each event, the critical peak interval was predicted 48 hours in advance. After the event, consumption distributions were analysed and visualised for the pilot group and the control group. We also evaluated the percentage of pilot users, who actively participated in the event. Event summary is presented with Table II.

A. *Consumption profiles*

Two examples of an event day are shown in figures Fig 4 and Fig 3. The distributions of mean consumption for the pilot and the control group are coloured blue and green, respectively. The event interval is shaded with dark grey. In October the event interval was from 7:15 pm until 8:15 pm with real peak occurring at 8 pm. In December the event started at 7 pm and the peak occurred at 8 pm. In both cases, the distribution of the mean consumption was, on average, higher in the pilot group than the control group throughout the day.

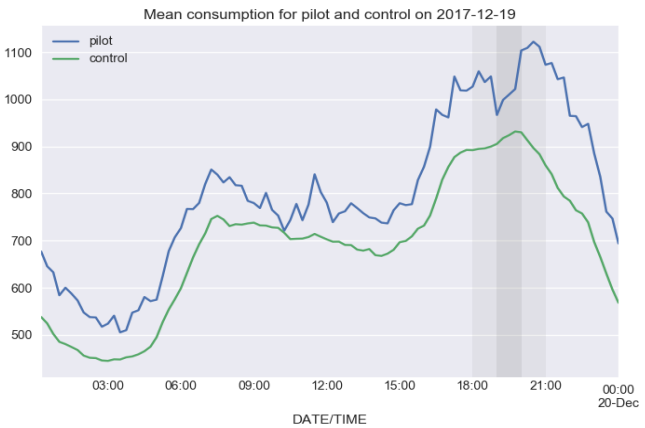

Fig 4. Mean consumption (in watts [W]) for pilot and control groups (December event).

At each timestamp, the consumption distribution is approximately normal for both groups, because the sample sizes are large enough. However, the difference between the interval means of distributions for pilot and control groups is statistically significant at α=0.05 for a paired *t*-test. The discrepancy is more noticeable at the 1-hour interval before and 1-hour interval after the event, as can be seen in Fig 3. There was also a noticeable reduction of consumption in the pilot group, as the pilot mean consumption drops at the start of the event. In the case of the October event, the drop in mean consumption is below the control group mean consumption during the event.

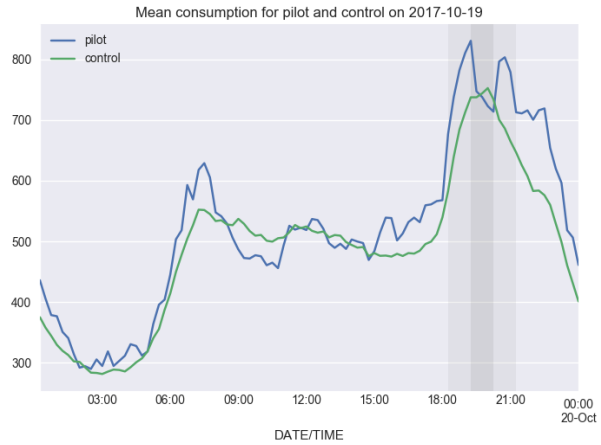

Fig 3. Mean consumption (in watts [W]) for pilot and control groups (October event).

B. *User activity*

Besides the difference in consumption levels for the time of the event, we are further interested in the percentage of active users. The classifier was built on the comparison between overall energy demand (all consumption per time interval) of the user and the mean consumption of the control. Three 1-hour intervals were considered: before the event, event hour, and after event. When a user has lower energy demand than the demand of the control means during the event interval, then the user is classified as good. If their overall demand is higher for all three intervals, then the user is classified as high. Otherwise, the user was considered bad in terms of the demand response. We consider that the user was active, if their demand was lower during the event compared to their demand of one hour before; regardless of their label. A good user with a higher demand during the event than before the event was regarded as a neutral participant (not responding, but not contributing to the peak).

Otherwise we consider the user inactive. Percentages and summary of the events are available in Table II.

Any dispersion in control and pilot sizes is due to either errors in measurement (missing data), or errors in collection. Maximum percentage of active users was 28 % in December, while minimum percentage of inactive users (35 %) was in November.

V. DISCUSSION

At weekdays the highest peaks mostly happen between 5:30 pm and 10 pm, with the mode shifting from 7 pm, in autumn-winter seasons, to 8 pm, in spring and summer. However, all four of our events had their peak around 8 pm. This could be due to a small sample number of events or some external circumstances. This discrepancy will be evaluated further, when more events are considered.

Our prediction model gives acceptable results, as the predicted daily peak was realized in the chosen event time interval in three events presented. The average error rate for peak time predictions is 30 minutes. Difference between predicted and real peak values is on average 24% of the real peak value. The prediction error for consumption does not yet include the prediction error of environment variables, as these predictions are outsourced.

Our pilot group has on average higher consumption during the day than the control group. The difference between the interval means of distributions for pilot and control is statistically significant at $\alpha = 0.05$ for a paired t-test. Therefore, consumption profiles and user profiles are needed to explain this discrepancy between the pilot and control groups' mean consumption distributions.

For the pilot group, there can be a noticeable rise in consumption after the event, as shown in Fig 4. In the October event there was also a rise in consumption before the event, see Fig 3. These steep rises in consumption imply that a percentage of users are active and are shifting their consumption, which we further confirmed by classifying the users into active, neutral, and inactive, and calculating their frequencies. Although user activity gives promising results, it exposes the problem of peak shifting, or even increasing consumption after or before the event. How to regulate such responses needs further study and trials, in order to avoid undesired shift in consumption with a peak higher than predicted.

Future work and challenges

Prediction model can be improved in terms of peak value prediction. In addition, the width of the peak should be considered separately, since the consumption can shift as we saw from preliminary results, which in turn affects the duration of critical peak time. One of the steps towards improving the prediction model, is to optimize the data flow in terms of detecting missing data and pre-processing the data set for prediction.

Since the pilot group has a different consumption profile than the control group, a classification method is needed in order to help generalize the expected consumption profile with a flexibility management tool on the whole network (and not just certain substations).

Prosumer flexibility fluctuates during the day and it is influenced by season. There may be also external unknown variables with influence on the degree of prosumer flexibility. One of such influences are the user socio-demographic profiles, as well as their usage of electronic household devices. Those will be additionally explored through a survey.

As the concept of flexibility management of demand response in power systems is quite novel in terms of integration, there is no standard definition of prosumer flexibility yet available. Flexibility measures in these cases also vary, as there are case specific. A flexibility measure has to be properly defined, in order to measure the change (increase/decrease) of flexibility in the pilot group and compare test result of different flexibility management schemes.

Beside comparing pilot mean consumption to the control group mean during the event, we are also interested in the

TABLE II. EVENT SUMMARY AND USER ACTIVITY PERCENTAGES.

Event summary	**2017-09-20, Wednesday**	**2017-10-19, Thursday**	**2017-11-23, Thursday**	**2017-12-19, Tuesday**
Control size	14737	14533	14341	13990
Pilot size	748	731	737	721
Event time	19:00:00 - 20:00:00	19:15:00 - 20:15:00	18:30:00 - 19:30:00	19:00:00 – 20:00:00
Peak time (real)	**20:00:00**	**20:00:00**	**19:45:00**	**20:00:00**
Active (%)	**25**	**23**	**27**	**28**
Neutral (%)	36	33	38	36
Inactive (%)	39	44	35	36
t-test (*p*-value) [a]	**< 0.05**	**< 0.05**	**< 0.05**	**< 0.05**

[a] paired *t*-test at α=0.05

alternative; i.e. what would be the pilot mean consumption if no event was considered. Possible consumption will be simulated with an adaptation of our prediction model, which was developed for peak prediction.

Finally, we will run a simulation based on the distribution of active users, where we explore peak shifts to an interval before or after the event, as we increase the number of active users. Specifically, we will explore the direction and magnitude of the shifted peak in comparison with the event real peak value.

VI. CONCLUSSION

Flex4Grid project offers a technical tool to help DSOs manage demand response in their local smart grids. Since flexibility as a service is a novel approach, there are still challenges of defining a measure for prosumer flexibility and knowing, which incentives are effectively managing the demand response. Depending on the situation, we want to achieve either peak clipping (reduction of peak consumption) or peak shifting (to match the peak production from alternative sources). One such incentive in the form of dynamic pricing is considered in the PTCP project, which makes the evaluation of the F4G solution possible in a real large-scale environment.

Preliminary results show some promise in gaining additional flexibility in the smart grid from responsive consumers. On the other hand, additional challenges, like peak shifting before or after the event, possible peak increase, as well as differences in consumer profiles at different environmental and seasonal conditions, need to be addressed in further research.

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Dynamic tariff is possible due to Slovenian regulation and consequent financing by SODO agency.

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WLAN Planning and Performance Evaluation

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***Abstract* - In the past, WLAN planning was coverage driven to ensure that the signal quality is satisfied in all covered areas. As the number of users with more high-throughput applications, supported by sophisticated mobile computing devices, continues to grow rapidly on the one hand and on the other hand the new high-speed IEEE802.11 based WLANs continue to have a significant wireless communication market spread, it has been recognized that capacity is equally important as coverage for the WLAN planning. In this paper WLANs capacity based planning and performance evaluation focusing on the impact of the applications throughput requirements, high-speed IEEE802.11 WLAN standards and user terminal capabilities are discussed. Performance evaluation is carried out by means of measurements, using IEEE 802.11ac and IEEE 802.11n standards.**

Key words:* *Wireless Local Area Networks, WLAN planning, frequency bands, channel planning, user terminals capabilities.

I. INTRODUCTION

Wireless Local Area Networks (WLANs) planning in the past, aimed to ensure that S/N (Signal to Noise and Interference ratio) and RSSI (Received Signal Strength Indicator) are satisfied in all targeted areas. However, as the number of users with more bandwidth hungry applications, supported by sophisticated mobile computing devices such as smartphones, tablets, PDAs, laptops, continues to grow rapidly on the one hand and on the other hand high-speed IEEE802.11n and IEEE802.11ac based WLANs continue to mark a huge wireless communication market spread, it has been recognized that capacity is equally important as coverage for current and future WLAN planning [1-6].

In this paper WLANs capacity based planning and performance evaluation focusing on the impact of the applications throughput requirements, high-speed IEEE 802.11ac standard with 40MHz and 80MHz channels, IEEE 802.11n standard with 40 MHz channel, and user terminal capabilities are discussed.

The basic steps of the WLAN Planning are presented in the next section. In Section 3, we describe the channel planning in the 2.4GHz ISM (Industrial Scientific Medical) and in the 5GHz UNII (Unlicensed National Information Infrastructure) frequency bands. Calculation of the capacity planning, in terms of the needed number of the APs, taking into consideration different user device capabilities and user applications throughput are given in Section 4. In Section 5 we have presented the measurement environment and performance evaluation analysis. Conclusions are drawn in the last section.

II. BASIC STEPS FOR WLAN PLANNING

In general WLAN planning is carried out in several steps as shown in Figure 1. The starting step is the survey on WLAN communication requirements, which includes users and communication environment survey for the targeted area. The next step is the channel planning development. For channel planning we have to take into consideration available WLAN frequency bands and channels, IEEE802.11 standards, and communication environment. Having provided data for WLAN requirements and developed channel planning, the next step is the WLAN dimensioning. Dimensioning of the WLANs encounters determining the needed APs to ensure that capacity, S/N (Signal to Noise and Interference ratio) and RSSI (Received Signal Strength Indicator) are satisfied, taking into consideration applications throughput, number and type of user devices. In addition, the vendor's recommendation and planner's experience should be considered. In the network layout and optimization phase, the floor plan with APs location and assigned channels should be specified [2].

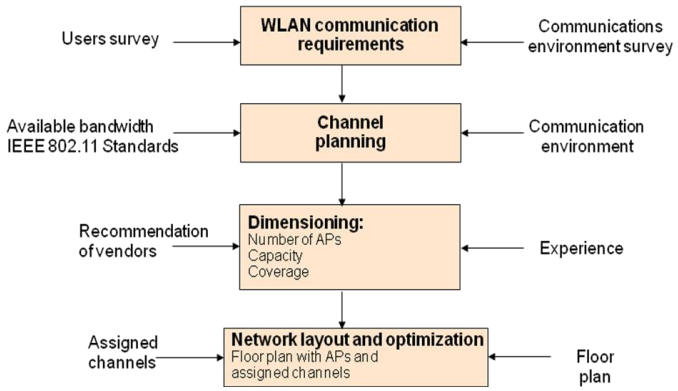

Figure 1. Basic steps for WLAN planning

User survey

The user survey consists of collecting data such as: number of users and their category, user density in each targeted area, user device capabilities, and type of the demanded applications as well as their throughput requirements. QoS (Quality of Service) is critical for multimedia applications, such as IPTV (video, audio and data) and needs to provide quality and Security in IP based networks [12-27].

Communication environment survey

In addition to the user survey, for successful WLAN planning, data about the size of the coverage area, type of the communication environment (closed, open, mobile), buildings architecture (one or more floors, offices spread out in two buildings) also are crucial. Furthermore, it is important to have some inputs about existing communication infrastructure (LAN network and connection to the Internet) in the targeted area.

III. CHANNEL PLANNING IN 2.4 GHZ ISM AND 5 GHZ UNII FREQUENCY BANDS

In this section, we will explore the channel planning in the 2.4GHz and in the 5GHz band. In IEEE802.11 standards, there are defined fourteen channels in the 2.4GHz band, each 22MHz wide. The availability of these channels is governed from local authorities of different Countries. In Europe, there are 13 channels allowed for use, whereas in the United States 11 channels are allowed. Furthermore, in the 2.4GHz band, there are only three non-overlapping channels, for example channels 1, 6 and 11, as shown in Fig 2. It is clearly seen that most of the channels in the 2.4GHz band overlap. Limited available bandwidth and channel overlapping results in the low number of the available channels in 2.4GHz. Hence, implementation of highspeed IEEE 802.11 standards in the 2.4GHz band is not suitable in high user density areas [7].

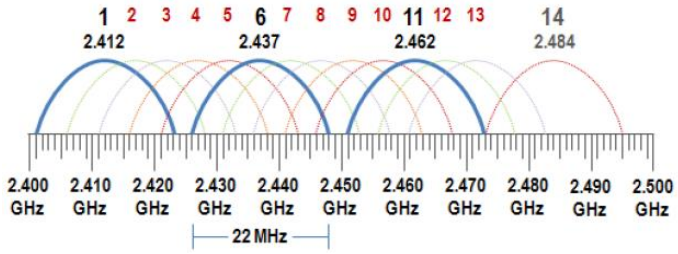

Figure 2. WLAN channels in 2.4GHz band [7]

Different from 2.4GHz band, IEEE802.11 standard defines 23 channels in the 5GHz band, each 20MHz (Fig 3). As seen from the Fig 3, channels are spaced 20MHz apart and separated in three UNII bands.

The most critical issue in channel planning is interference avoidance. There are two types of channel interferences in WLAN environment: Co-Channel Contention (CCC) and adjacent channel interference. The CCC (also called co-channel interference-CCI) is when APs operate on the same frequency and interfere with each other. It is about contention between all users for a wireless channel on the same frequency (Carrier Sense Multiple Access with Collision Avoidance - CSMA/CA) and it is not like other RF (Radio Frequency) interference. CCC is a crucial factor for the capacity planning. Note that adding more APS on the same frequency can lead to opposite effect, in the increase of the number of user contention and consequently in the decrease of the throughput. Adjacent channel interference is when APs operate on the different channels and still interfere with each other. This type of interference is also an important factor to consider in WLAN planning.

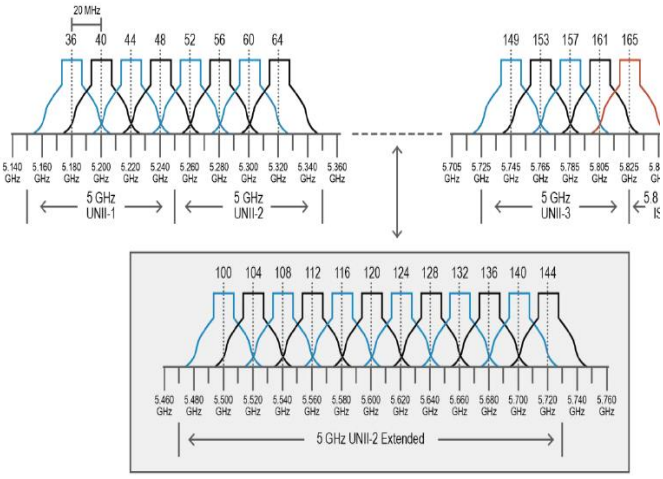

Figure 3. WLAN channels in 5GHz band [7]

In capacity based WLAN planning, network administrators should design Wi-Fi cells (Fig 4) with associated range (adjacent channel interference) between -65dBm to -67dBm. At the same time they should develop a channel plan that ensures that co-channel interference remains below -85dBm to avoid CCC, considering the noise floor to be < -85dBm, whereas S/N: 25 to 30 dB. For coverage based WLAN planning received signal strength is usually limited to > -72 dBm [8].

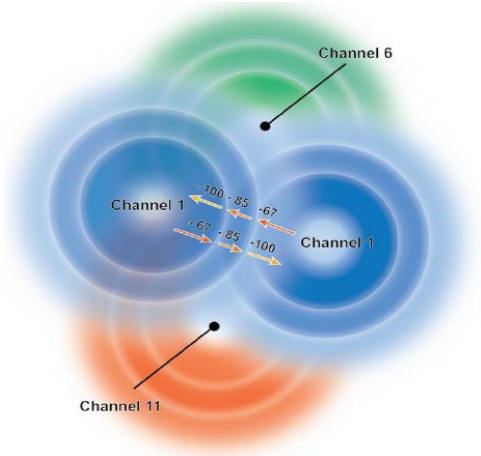

Figure 4. Contention and association range [8]

IV. CAPACITY PLANNING

The WLAN planning in the past was mainly coverage driven to ensure that signal quality (S/N and RSSI) is satisfied in all covered areas. However, as users demands for high-throughput applications supported by mobile computing devices such as smartphones, tablets, PDAs, laptops, continue to grow rapidly, it has been recognized that providing coverage does not mean enough capacity. Hence, capacity is equally important as coverage for the WLAN planning to meet the user requirements. Capacity planning in terms of the needed number of the APs is based on airtime utilization of the shared wireless link. By airtime utilization we understand the time an

application occupies on wireless link, which depends on throughput of the application and on the user device capabilities. For example, a 2Mbps application generated by a laptop with 100 Mbps TCP throughput needs 2% airtime utilization of the wireless channel. In the following paragraphs, we will present two examples to show how the airtime utilization is calculated i.e. number of needed APs is determined for the given application throughput and the given device capability.

Example1: We will assume that we have 50 Laptops with 2x2:2 MIMO, 300Mbps raw data rate (Table I), TCP throughput of 150Mbps (50% of the raw data rate), and 40MHz channel width. Whereas E-Learning applications with 2Mbps throughput [8]. The airtime utilization is calculated as follows: (2/150) x 100 = 1.33%, for a single laptop. For 50 laptops airtime utilization would be: 50 x 1.33% = 66.7%. Furthermore, taking into consideration practical case of the AP channel saturation at 80%, (66.7/80) = 0.83, i.e. 1 AP is needed to satisfy capacity requirements.

TABLE I. SELECTED RAW DATA RATES IN MBPS FOR IEEE802.11 N AND AC STANDARDS [10]

MCS	Modulation & Rate	20 MHz 1x S	20 MHz 2x S	40 MHz 1x S	40 MHz 2x S	80 MHz 1x S	80 MHz 2x S
0	BPSK ½	7.2	14.4	15	30	32.5	65
1	QPSK ½	14.4	28.9	30	60	65	130
2	QPSK ¾	21.7	43.3	45	90	97.5	195
3	16-QAM ½	28.9	57.8	60	120	130	260
4	16-QAM ¾	43.3	86.7	90	180	195	390
5	64-QAM 2/3	57.8	115.6	120	240	260	520
6	64-QAM ¾	65	130	135	270	292.5	585
7	64-QAM 5/6	72.2	144.4	150	300	325	650
8	256 QAM ¾	86.7	173.3	180	360	390	780
9	256-QAM 5/6	-	-	200	400	433.3	866.7

Example 2: This example is an extension of the example 1 with 30 more tablets 1x1:1, with 135Mbps raw data rate (Table I), and 70Mbps TCP throughput. Airtime utilization for each added tablet would be: (2/70) x 100 = 2.85%, whereas for 30 tablets, 30 x 2.85% = 85.7%. Adding this airtime utilization to the one of the example 1, airtime utilization in total will be 152.4%. Assuming again practical case of the AP channel saturation at 80%, we will come up with (152.4/80) = 1.9, i.e. 2 APs are needed.

Based on the above examples, Fig 5 illustrates the impact of the applications throughput and the user devices capabilities on the number of the needed APs for different scenarios. Note the difference between raw data rate and TCP throughput due to WLAN overhead, which is usually between 40-60 %.

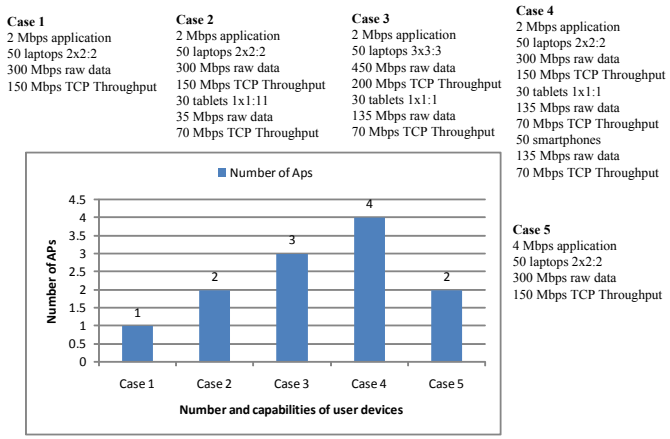

Figure 5. Number of needed APs

From Fig. 5 it can be seen that:

- Applications with higher throughput require more APs (case 1, 5)
- Devices with better capabilities need less APs (case 2,3)
- Increasing the number of devices more APs are needed (case 3,4)

V. MEASUREMENTS AND PERFORMANCE EVALUATION

Performance evaluation in terms of the channel throughput is carried out theoretically and by means of measurements.

V.1. MEASUREMENTS ENVIRONMENT

To model a real WLAN environment is not an easy task because of different IEEE802.11 WLAN types and user devices encountered. For our goal of the investigation, we have set up an experimental network with one IEEE 802.11 n, ac AP and several different user devices, as shown in Fig 6.

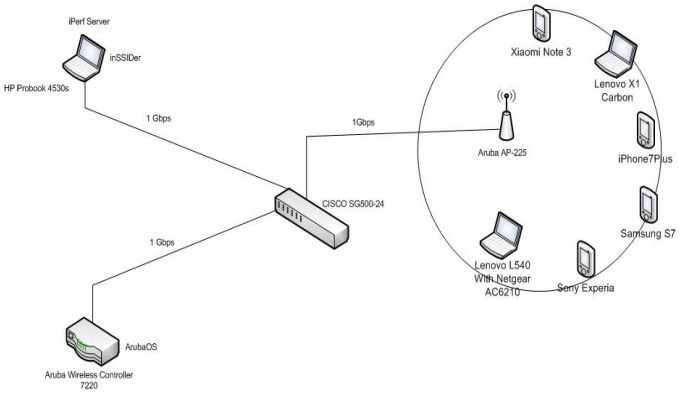

Figure 6. Experimental network

In the experimental network we have used the following software tools and devices:

- **Software tools**

– Aruba OS 6.4, inSSider, iperf 3

- **Devices**
  - Access Point Aruba 225
  - Aruba wireless controller 7220
  - Type of the user devices and their capabilities are shown in table II.

TABLE II. USER DEVICES CAPABILITIES

User Device Type	WiFi Radio Type	MIMO	Channel Width
iPhone 7	802.11a/b/g/n/ac	2x2	40MHz/80MHz
Samsung S7	802.11a/b/g/n/ac	2x2	40MHz/80MHz
Xiaomi Note 3	802.11a/b/g/n/ac	1x1	40MHz/80MHz
Lenovo X1 Carbon with Intel® Dual Band Wireless-AC 7260	802.11a/b/g/n/ac	2x2	40MHz/80MHz
Lenovo L540 with Netgear 6210AC	802.11a/b/g/n/ac	2x2	40MHz/80MHz
Sony xPeria	802.11a/b/g/n/ac	1x1	40MHz/80MHz
Lenovo Ideapad, Intel Dual Band Wireless-AC(1x1) 3165	802.11a/b/g/n/ac	1x1	40MHz/80MHz
Server Device type			
HP Probook 4530s with Gigabit LAN Card			

For the fact that we have used "dummy" access point, known in the technology as thin access points, the wireless controller provides the basic configuration to the access point and all the necessary data inputs for the radio part of the network, such as radio channel, channel bandwidth, frequency band, as well as the client information such as raw data rate, signal level, signal strength etc.

V.2 PERFORMANCE EVALUATION

To investigate the impact of the high-speed IEEE 802.11 n and ac WLAN standards and user terminal capabilities on the network throughput, we have carried out thoroughly measurements in our experimental network. We considered only TCP throughput on Uplink. In addition, we have carried out theoretical throughput calculations and compared to measured throughput results.

A. Theoretical calculation of the Channel throughput

In this paragraph, we will show how is usually throughput estimated accounting device capabilities and number of different devices. Results are shown in Figure 7.

Case 1: Throughput with one client device

Samsung Galaxy: MCS 27 64 QAM, 5/6; 2x2 MIMO, channel width 40 MHz; 300 Mbps raw data rate (Table I), assuming theoretical TCP throughput 150 Mbps. Because Samsung it is the only device using APs channel, throughput is 150 Mbps.

Case 2: Throughput with one client device – iPhone 7

Because the iPhone 7 has the same characteristics as Samsung Galaxy and it is the only device using APs channel, throughput is again 150 Mbps.

Case 3: Throughput with two client device, Samsung and iPhone 7.

Assuming both devices share channel equally i.e. 50 %, each Samsung and iPhone get through 75 Mbps, Adding both throughput we end up with 150 Mbps, which is the same as in the case of having only one device because the two devices have the same capabilities.

Case 4: Throughput with two client device, iPhone 7 and Sony: MCS 7, 64-QAM 5/6, 1x1, channel width 40 MHz, 150 Mbps, raw data rate (Table I), TCP throughput 70 Mbps

Assuming both devices share channel equally i.e. 50 %, each, iPhone gets through 75 Mbps, whereas Sony 35Mbps. Adding both throughput we end up with 110 Mbps, which is less than in the case of having two 2x2 devices (case 3).

Case 5: Throughput with three client device, iPhone 7, Samsung and Sony

Assuming again that all three devices share channel equally (1/3), iPhone gets through 50 Mbps, Samsung also 50 Mbps, whereas Sony gets through 35 Mbps. Hence, channel throughput in total will be 135 Mbps.

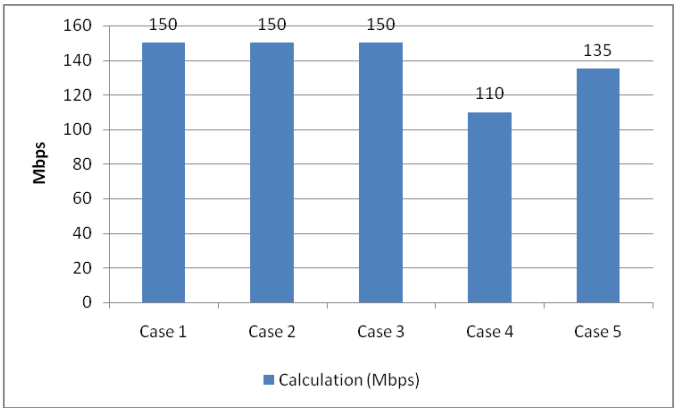

Figure 7. Theoritical throughput in terms user devices capabilities

Figure 7 shows that by adding user devices with lower capabilities channel throughput drops.

Note that sharing the channel linearly to the device capabilities, leads to more efficient use of the channel capacity, i.e. to higher throughput.

B. Throughput measurements

In this subsection we will present performance evaluation, in terms of wireless channel throughput, based on measurements for different scenarios.

Case 1

- Throughput with one client device in the Dual-Band (2.4GHz & 5GHz) and Single-Band (5GHz) mode with 40MHz channel width.
- Used devices:
  - Server: HP Probook 4530s with Gigabit LAN Card
  - Client: iPhone 7 Plus, 2x2 Samsung Galaxy S7 2x2, Lenovo L540 2x2 with Netgear 6210AC adapter
  - WiFi AP Mode: Aruba AP-225 n

Measurement results for this case are shown in Figure 8.

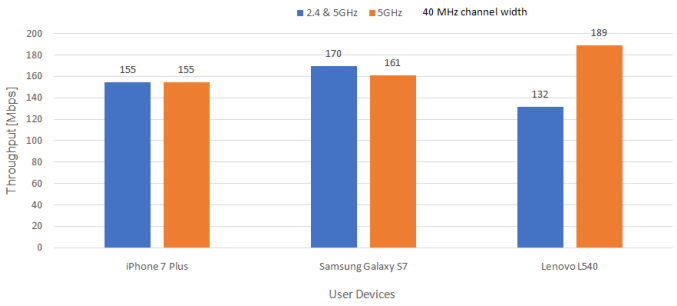

Figure 8. Throughput with one client device

As it can be seen from Fig 8, dual-band mode operation of the AP has no impact on performances, in terms of the network throughput, of the user devices operating only in the 5GHz band. Whereas, dual-band Lenovo L540 with Netgear 6210AC adapter when operating in the 5GHz band performs better (results in higher network throughput) compared to 2.4GHz band. This outcome is due to the higher channel overlapping and Co-Channel Contention interference in the 2.4GHz band.

The measured TCP throughput, due to WLAN overhead, for the Samsung Galaxy is 54 % (161/300) of the raw data rate, whereas 52% (155/300) in the case of iPhone 7. For both devices is within 40-60 % range, which is a usual range in practice.

Case 2

- Throughput with one client device with default and 1Mbyte window size.
- Used devices:
  - Server: HP Probook 4530s with Gigabit LAN Card
  - Clients: iPhone 7 Plus 2x2 & Samsung Galaxy S7 2x2
  - WiFi AP Mode: Aruba AP-225 n/ac

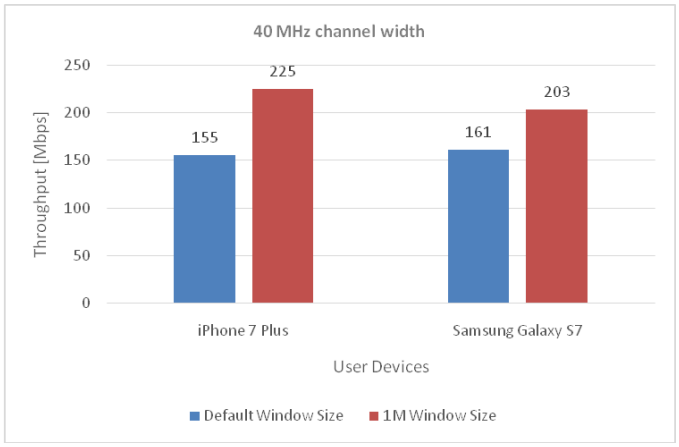

Figure 9. Throughput with one client device with default and 1M Window Size

Measurement results (Fig. 9) for this case show that TCP window size of 1Mbyte results in higher throughput compared to the default window size of 64Kbytes (iperf implementation dependent). An explanation is that default window size is obviously far too small to make full use of the end-to-end wireless link capacity. Having send 64kbytes of data, the sending process must wait for a window update from the receiver (sliding window flow control principle) before putting any more data on the wireless link.

Case 3

- Throughput for individual and combined devices with 40MHz channel width.
- Used devices:
  - Server: HP Probook 4530s with Gigabit LAN Card
  - Clients: iPhone 7 Plus, Samsung Galaxy S7 and Lenovo X1 Carbon with Intel® Dual Band Wireless-AC 7260
  - WiFi AP Mode: Aruba AP-225 n/ac

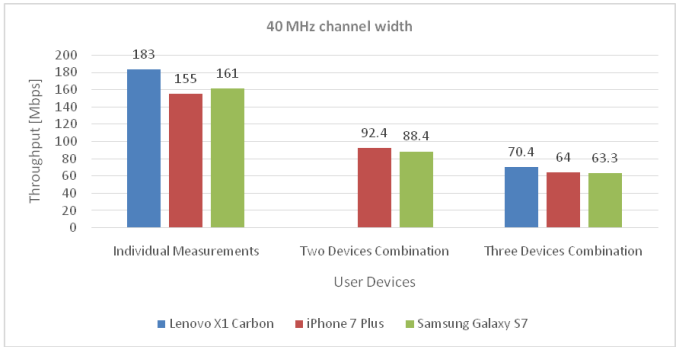

Figure 10. Throughput for individual and combined devices with 40MHz channel width

From the measurements results shown in Fig 10, we notice that the overall throughput 180,8Mbps, with two clients, iPhone and Samsung Galaxy, is higher than in the case of the single client iPhone (155Mbps) or Samsung (161 Mbps). The overall throughput (197,7Mbps) with three clients iPhone, Samsung and Lenovo X1 Carbon, is higher than the overall

throughput with two clients. An explanation is that in the high-bandwidth, high-latency environments (bandwidth delay product), TCP communications are often limited by the amount of data on the way at any given time. Using two or more user devices simultaneously, i.e. two or more TCP connections in our case, overall link (network) throughput is increased because the bandwidth delay product applies to each user device connection individually.

The measured total TCP throughput for iPhone 7 and Galaxy is 60% of the raw data rate (92.4+88.4 =180.8/300). Whereas, the measured total TCP throughput for iPhone 7, Galaxy and Sony is 54 % of the raw data rate (148,7/275). Note that 275 Mbps is the average raw data rate for the three devices. In both cases, the total throughput is within 40-60 %.

Case 4

- Throughput for individual and combined devices with 40MHz and 80MHz channel width.
- Used devices:
  - Server: HP Probook 4530s with Gigabit LAN Card
  - Clients: iPhone 7 Plus and Samsung Galaxy S7
  - WiFi AP Mode: Aruba AP-225 n/ac

Measurements results for this case are shown in Figure 10.

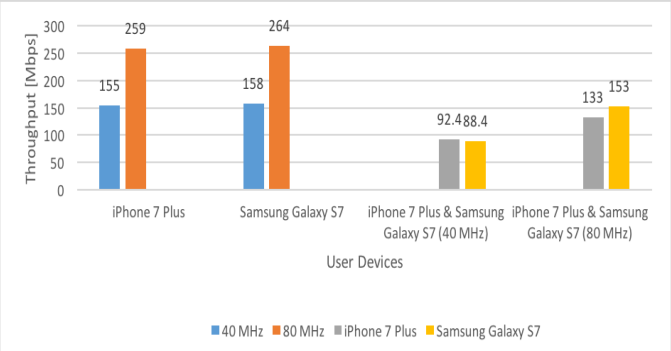

Figure 11. Throughput for individual and combined devices with 40MHz and 80MHz channels

As it can be seen from Fig. 11, operating with wider channels throughput increases significantly. However, doubling channel width does not lead to a doubling of measured throughput as it applies for raw data rate. Comparing raw data rates of 40MHz (MCS 7) with 80MHz (MCS 9) channels (Table I), it can be seen that for devices with the same capabilities, the raw data rate of 80MHz channels is more than twice higher compared to 40MHz channels [Table III], or as per calculations 188% higher.

TABLE III. USER DEVICES CAPABILITIES

User Device Type	Raw Datarate		Throughput	
	40MHz	80MHz	40MHz	80MHz
iPhone 7 Plus	300Mbps	866Mbps	155Mbps	259Mbps
Samsung S7	300Mbps	866Mbps	161Mbps	264Mbps
Xiaomi	155Mbps	433Mbps	73Mbps	221Mbps
Lenovo L540	300Mbps	866Mbps	132Mbps	230Mbps

Whereas, our measurement results, shown in Fig 10, in the case of single device, show an increase of 67% of the throughput with 80 MHz channel compared to throughput with 40 MHz channel. Further on, in the case of the two devices sharing the wireless link, the measurement results show an increase of the throughput of about 58% with 80MHz channel compared to 40MHz channel.

The measured TCP throughput, due to WLAN overhead, with 80 MHz channel width, for the single device e.x. iPhone 7 is 30% (259/866) of the raw data rate. Whereas, the measured total throughput with 80MHz channel for combined iPhone 7 and Galaxy is 37% of the raw data rate (133+153 =286/866). In both cases measured results show lower values than 40-60% usual range in practice. This leads to the conclusion that increasing the channel width to 80MHz the ratio TCP throughput raw data rate drops compared to 40 MHz channel. Hence, the 40-60 % range does not apply for 80MHz channel width.

In Figure 12, we have compared theoretically calculated throughput (subsection A) and measured throughput with 40MHz channel width (subsection B), for different cases described earlier in this section.

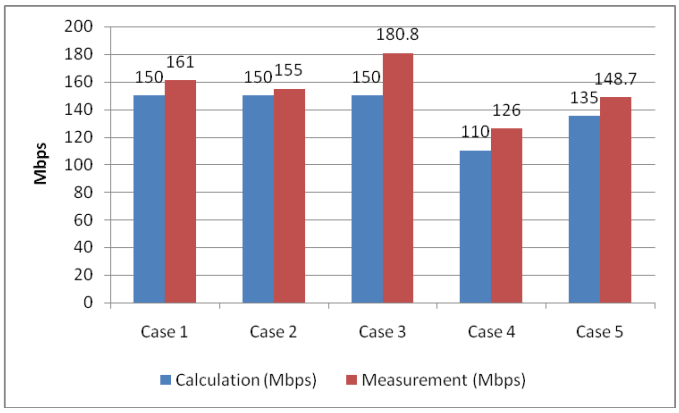

Figure 12. Theoritical throughput and measurements throughput in terms user devices capabilities.

From the Figure 12 it can be seen that our assumption of the TCP throughput value as 50 % of the raw data rate for 40MHz channel is reasonable.

VI. CONCLUSION

We have investigated WLAN capacity planning and performances evaluation focusing on the impact of the applications throughput requirements, high-speed IEEE802.11 standards, and user terminal capabilities. In the past WLAN planning was mainly coverage driven, ensuring that S/N ratio and RSSI are satisfied in all covered area. Today with the massive increase of the wideband applications and high capability user devices, capacity is a crucial issue in WLAN planning to meet users' requirements. For WLAN planning driven by capacity, airtime utilization of the shared wireless link is the main parameter in determining the needed number of the APs. Presented calculations show that applications with higher throughput require more APs, whereas devices with

better capabilities need less APs (Figure 5). Measurement results show that dual-band mode operation of the AP has no impact on performances, in terms of network throughput, of the user devices operating only in the 5GHz band. Whereas, devices that can operate in both modes perform better in the 5GHz band (Fig 8). Furthermore, the TCP window size of 1Mbyte results in higher throughput compared to default window size of 64Kbytes (Fig 9), because the default window size is obviously too small to make full use of the end-to-end wireless link capacity. Measurements also show (Fig 10) that the overall throughput with two client devices is higher than with a single client device, overall throughput with three clients is higher than overall throughput with two clients. An explanation is that in the high-bandwidth links TCP communications are often limited by the amount of data on the way. Using two or more user devices simultaneously i.e. two or more TCP connections, overall wireless link throughput is increased because the bandwidth delay product applies to each user device connection individually. Operating with wider channels, throughput increases significantly. However, doubling channel width does not lead to a doubling of throughput as it applies for raw data rate. Comparing raw data rates of 40MHz (MCS 7) with 80MHz (MCS 9) channels (Table I), we notice that for devices with the same capabilities, the raw data rate of 80MHz channels is more than twice higher compared to 40MHz channels [Table III], or as per calculations 188% higher. Whereas, our measurement results, shown in Fig 11, in the case of single device, show an increase of 67% of the throughput with 80 MHz channel width compared to throughput with 40 MHz channel. In the case of the two devices sharing the wireless link, measurement results show an increase of about 58% of the throughput with 80MHz channel compared to 40MHz channel.

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An Approach for More Effective Use of the Radio-Frequency Spectrum in DVB-T Single Frequency Networks

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***Abstract* - In this paper we investigate the DVB-T SFN networks in Bulgaria. In digital terrestrial television broadcasting, the effects of multipath reception were largely suppressed by choosing of sophisticated modulation methods. In a SFN, multiple transmitters share one frequency, and therefore, the service coverage is determined based on those transmitters. Currently, two types of SFN are available: 1) the single-input single-output SFN (SISO-SFN); 2) the multiple-input single-output SFN (MISO-SFN) based on the modified Alamouti code.**

Keywords – DVB; SFN; multipath;

I. INTRODUCTION

The roots of transition to digital television broadcasting lie in more effective use of the radio-frequency spectrum. Digital technology enables us to use advanced compression algorithms to compress audio and video signals. Consequently, we can use one frequency channel to transmit more than one service (usually three to ten and even more TV channels), and we can build a network of transmitters operating at the same frequency, thus significantly lowering a number of frequencies (channels) needed to cover a territory. The idea is that in certain geographically- difficult areas broadcasters will have better success if they can fill coverage voids by utilizing smaller, usually-less-powerful satellite towers in addition to their main tower.

In digital terrestrial television broadcasting, the effects of multipath reception were largely suppressed by choosing of sophisticated modulation methods. One of many advantages of the emerging terrestrial digital video broadcast standards DVB-T (Digital Video Broadcasting - Terestrial), DVB-H (Digital Video Broadcasting - Handheld), but also next services - e.g. DAB (Digital Audio Broadcasting) or DRM (Digital Radio Mondial) is apart from mobile reception support, the suppression of multipath reception impacts. In the all mentioned standards, digital modulation method (C)OFDM (Coded Orthogonal Frequency Division Multiplex) is used. [1]

Digital broadcasting in the above mentioned standards can be performed in so-called single frequency network SFN (Single Frequency Network). Reception of more delayed signals from several transmitters working in the single frequency network can be utilized even for improvement of the power efficiency of transmitters.

In a multiple frequency network (MFN), each transmitter occupies a specific frequency, and the service coverage is determined by the specific transmitter. Coverage prediction in MFNs is mainly carried out by calculating the path loss between the transmitter and the receiving point, and the coverage contour is obtained by lining the points where the receive field strength (in dBm or dBμ/m) is equal to the minimum required field strength. Consequently, applying an appropriate path loss model is important for an accurate prediction of service coverage.

In a single frequency network (SFN), multiple transmitters share one frequency, and therefore, the service coverage is determined based on those transmitters [2]. The field strength and service coverage in the overlapping area of the received signal in the SFN increase owing to the SFN gain (SFNG) as shown in Fig. 1. Therefore, accurately estimating the SFNG is necessary to predict and determine the SFN service coverage.

Currently, two types of SFN are available: 1. The single-input single-output SFN (SISO-SFN), which is typically used in the first-generation broadcasting systems [3] such as DVB-T; 2. The multiple-input single-output SFN (MISO-SFN) based on the modified Alamouti code, which is newly introduced in the second-generation broadcasting system such DVB-T2. Compared to the conventional SISO-SFN, MISO-SFN provides a higher SFN gain owing to the transmit diversity in overlapping service coverage areas. [4, 5]

On Fig.1 is shown the two equal power SFNs improve the service coverage by means of SFN gain.

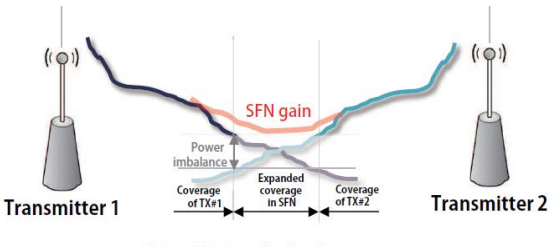

Figure 1. Field strengh of SFN

Fig. 1. Two equal power SFNs improve the service coverage by means of SFN gain.

II. PRINCIPLE OF SFN AND TIME SYNCHRONIZATION

A. Principle of SFN

In SFN, all transmitters are modulated with the same signal and radiate same frequency. The limiting effect of SFN technique is self interference of the network. If signals from far distant transmitters are delayed more than allowed by the guard interval they behave as noise-like interfering signals rather than wanted signals. The self interference of SFN for a given transmitter spacing is reduced by selecting a large guard interval. The network generated self interference of an SFN can be kept sufficiently low by a careful choice of the system parameters and transmitter powers. [6]

There are two main methods of building a single frequency network. The first is through the use of on channel boosters. On-channel boosters quickly receive the OTA (Over-The-Air) signal from the main tower and retransmit the signal at the same frequency. The problem is that there is no error correction. So, any errors in receptions are simply retransmitted along with the slight echo caused by the booster itself. With distributed transmission, the signal is delivered to each of its transmitters via fixed channels. Then through the use GPS (Global Positioning System) based reference clocks at each tower (for both time and frequency), the signals are synced so each can emit a perfect copy of both the signal and the symbol data. To get each transmitter synchronized in both the time and frequency domains some extra data is added to the serial data streams (these contain the encoded audio and data inputs) sent to the transmitters. This additional data stream is essentially a time reference signal inserted into the network. At each transmitter the OFDM modulator uses this time stamp to calculate the local delay so that a common on-air time is achieved.

With the SFN technique, large areas can be served with common multiplex at a common radio center frequency. The frequency efficiency of SFNs appears to be very high compared to MFNs. The SFN technique is also power efficient.

The advantage of the SFN approach are:

- High frequency efficiency;
- Low-power operation (internal network gain);
- High location probability;
- Easy gap-filling (frequency re-use).

The disadvantages are:

- Network splitting is not possible;
- Synchronization is necessary;
- Feed control is required [6].

B. Time Synchronization

The COFDM system operates correctly, when at the reception point reflected signals and the signals comes from the nearby transmitters are within the guard interval.

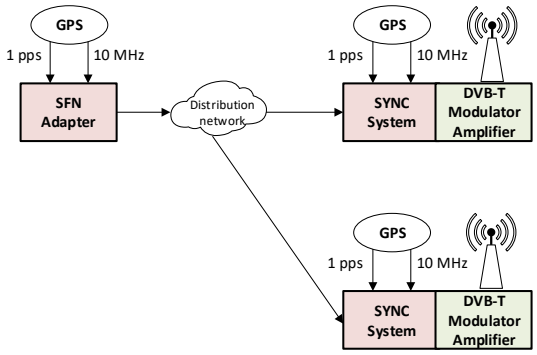

Figure 2. DVB-T network structure

If reflected signals exceeding this guard interval, resulting in intersymbol interference violating the orthogonality principle and increasing the BER (Bit Error Rate). This affects most of 64 QAM (Quadrature amplitude modulation). It is therefore necessary time synchronization in order to transmit the same information simultaneously from all transmitters in SFN, regardless of the different signal delay in the transmission network. Required accuracy of synchronization is not very high, because it is covered by the duration of the guard interval. In practice, the accuracy during the transmission of each OFDM symbols must be within the ± 1ms.

Synchronization signals of the individual transmitters cannot be transmitted via the transmission network as its delay will be different for the different transmitters. The only possibility is the use of an independent pattern for frequency and time, as the most suitable for this purpose is the GPS, which is taken the reference operating frequency 10MHz. The reference time from the GPS satellites is referred to herein as GPS absolute time. Synchronization is implemented by means of the remote control transmitter from the multiplexer with the broadcast of a special digital information in certain MPEG (Moving Picture Experts Group) packets. On Fig.2 we show DVB-T network structure with dynamic delay compensation.

Time synchronization of the all transmitted packets in the transport stream of the final data multiplex is ensured by the time 1 pps (pulse per second) signal to which a 10 MHz oscillator in professional GPS receivers is locked, which, in turn, acts as a reference signal for the DVB-T transmitters. This signal controls time synchronous insertion of the special packet MIP (Megaframe Initialization Packet) into the transport stream at the beginning of every mega-frame. Transport stream, generated for example in the playout center (TV studio), can be carried to the individual transmitters by the diverse distribution networks with different time delays. Therefore the time synchronization by the GPS signal is performed again in each of transmitters. A result of this operation is the state, where at every DVB-T transmitter broadcasts identical OFDM symbols at exactly the same time.[7]

In order to set up one SFN network, three conditions have to be fulfilled. DVB-T transmitters belonging to one SFN cell shall radiate:

- Over the same frequency;
- At the same time;

- The same OFDM symbols.

The first condition is basically easy to satisfy: all DVB-T transmitters will be configured once to the required broadcast frequency (at the modulator level). Conditions 2 and 3 imply to provide transmitters with extra information: synchronization and transmission parameters.

However, there is also a strict requirement with respect to the maximum distance between transmitters. Thus, distance is related to the length of the guard interval and the velocity of light, i.e. associated signal delay. Intersymbol interference can only be avoided if in the case of multipath reception, the delay on any path is no longer then the length of the guard interval.[7]

III. SPECIFIC FEATURES OF SFN

In general, the SFN mode has many advantages but one drawback is the frequency selective fading in DVB-T. Depending on phase relationship signals may cancel each other and this will appear as a notch (a slope across the band). The notch depth will depend on the relative amplitude of the receiving signals and delay. The worst case will happen if the received (RX) signals have the same amplitude and delay.

An increase of the SFN offset delay in one of two transmitters will decrease the notches and improve the quality of the receiving signal. There are many different configurations of SFN DVB-T/T2 networks but we will be considered three:

- Transmitter spacing is within the safety distance for SFN with high on-air redundancy (Fig.3).

The notch depth shown on Fig. 4 will depend on the relative amplitude of the receiving signals and delay. On Fig. 5 is presented the delay difference between two RX signals.

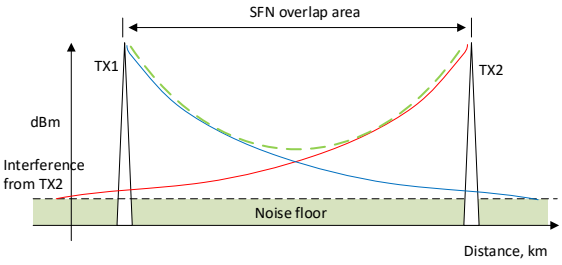

Figure 3. Distance between transmitters with high on-air redundancy

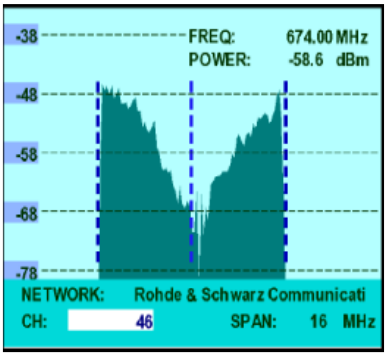

Figure 4. Notch in the spectrum

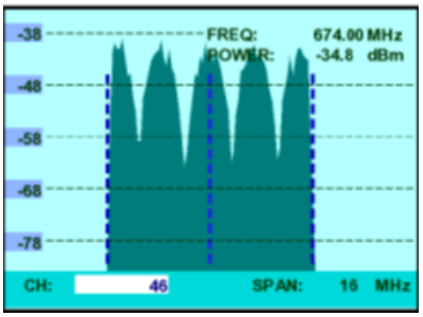

Figure 5. Delay difference between two RX signals is 0,5µs

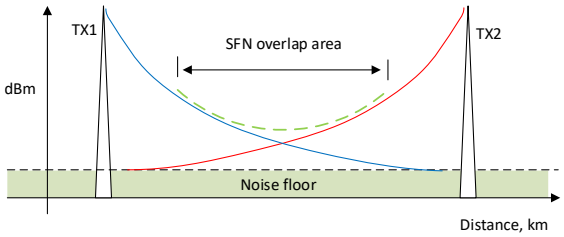

Figure 6. Distance between transmitters with low on-air redundancy

We supposed that all transmitters have the same ERP (Effective Radiated Power) and the SFN offset delay. In the middle of the SFN overlap area, with green dashed line can occur the notches in the spectrum

- Transmitter spacing is within the safety distance for SFN with low on-air redundancy (Fig.6).

To avoid the notches in the spectrum an SFN should be introduced an offset delay in one of two transmitters. This could move the problem to another location if the delay is relative small – approximately 3µs…5µs.

The delay should guarantee a reliable reception which will happen at the distance where the amplitude difference between two RX signals are relative large. If possible this distance should be set outside the overlap area.[8]

Based on the propagation curves defined in [9] we can determine the distance and using (1) to calculate appropriate SFN offset delay:

$$\tau = (L / C).10^6 , \qquad (1)$$

where τ is the delay in µs, L is the distance in km and C is the speed of light.

To avoid the notches in the middle of the SFN overlap area the SFN offset delay must be 35 µs, but we will move this problem to the distance 10 km far away where the amplitude difference between two RX signals is large enough to prevent a reoccur of the notches.

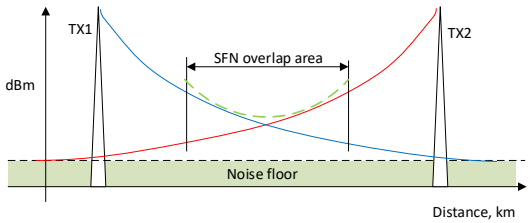

Figure 7. Distance between transmitters with out of the SFN limit

In Fig. 3, 6 and 7 the middle of the SFN overlap area, with green dashed line can occur the notches in the spectrum.

- Transmitter spacing is out of the SFN limit (Fig.7).

In general, the SFN offset delay will reduce the safety distance for SFN and could lead to the scenario shown on Fig. 6. This will not cause a problem if the level of the power between signals from TX_1 and TX_2 is greater than 35 dB in this non-SFN area.

For coverage estimation the FSPL (Free-Space Path Loss) formula can be used given by:

$$FSPL_{[dB]} = 20\log_{10}(L) + 20\log_{10}(f) + 32{,}45 \qquad (2)$$

where f is the frequency in MHz and L is the distance in km.

There are several ways to detect the lack of synchronization between the transmitters in an SFN area:

- Determine the position of the two transmitters in which the signals are received at a sufficiently high level;
- It is recommended this place to be open to both the transmitter, as well to avoid reflections;
- It is recommended to avoid potential sources of interference;
- The two TV transmitters are synchronized, if Impulse Response/Echo Pattern and the parameters are steady-state in time domain.

The RX spectrum of the signal on 674 MHz is shown on Fig. 8. To be a transmitter synchronized with another appropriate to their levels are significantly above the threshold “Echo Detection Treshold”, as shown on Fig. 9.

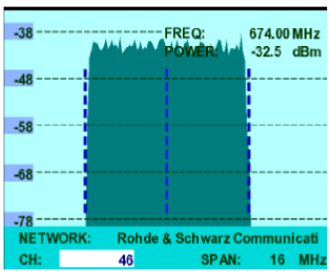

Figure 8. RX Spectrum

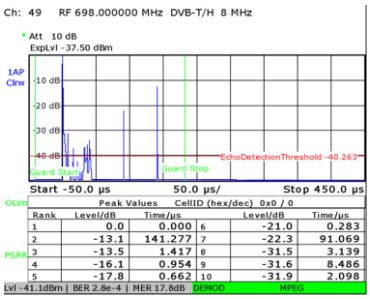

Figure 9. Measurement of synchronisation in SFN

IV. CONLUSION

In this paper are presented and discussed some of the methods for more effective use of the radio-frequency spectrum in DVB-T SFN in Bulgaria and their specific features. The improvement of the spectrum and bandwidth becomes possible with the use of single frequency networks, where all transmitters will broadcast synchronous on the basis of information provided by the DVB SFN adapter.

There are numerous reasons for the disintegration of the network, as some may be: Weather conditions and reflections; Exchange transport streams at the exciter inputs; Incorrect installation of the antenna (wrong azimuths); Delays from the radio relay link and satellite transmission; Incorrectly operating exciter; Improper grounding of the equipment (the ground shall be at the point of grounding of the transmitters) and Digital card error.

ACKNOWLEDGMENT

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[9] Rec. ITU-R P.370-7 VHF and UHF propagation curves for the frequency range from 30 MHz to 1 000 MHz

Test Cases and Challenges for Mobile Network Evolution from LTE to 5G

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***Abstract* - According to latest researches the number of mobile users will grow more than 21% in the next five years. With this enormous growth in mobile connectivity and yet the still rapidly increasing demand for data, there is a need to accommodate such a large data communication. In this paper are presented test cases and approaches for migrating from 4G to upcoming next mobile network in Bulgaria.**

Keywords – Mobile network; wireless communication; LTE;

I. INTRODUCTION

Current LTE/LTE-Advanced standards lack the performance needed to keep up with market demand for higher data throughput, greater cell capacity and more reliability. Thus, new 5G cellular standards are being developed to achieve the desired performance goals and to co-exist with 4G technologies. There is very limited spectrum available below 6 GHz so mmWave frequencies that can incorporate wide-bandwidth transmissions are being investigated for next generation cellular systems.

In order to define new channel models at mmWave frequencies, research and design engineers need to understand how the radio signal will propagate at the given frequencies. Key obstacles at these higher frequencies include path loss, Doppler Effect, environmental effects such as oxygen absorption and rain, and channel sounding techniques are used to analyze the impact of these obstacles on signal transmissions. These techniques use mathematical models to extract the characteristics of the wireless channel to determine the channel performance at a given frequency. [1]

II. DEVELOPMENT AND IMPLEMENTATION OF NEW GENERATION NETWORKS 5G

A. Characteristics of 5G

The European Commission and the European Parliament must play a key role in the development of standards for future networks and 5G PPP project and funding Horizon 2020 will help Europe to become an important part of global initiatives for the networks of the fifth generation. European society and the economic development of the EU will be highly dependent on the successful development of the 5G infrastructure in the period after 2020. "5G is more than just an evolution of mobile broadband technology, it will become the basis for a truly digital society with ubiquitous ultra-high-speed communications that will support all economic sectors as well as the ever-increasing demands of customers for new services". 5G is an opportunity for the European ICT sector, which is already well positioned in the global research race, contributes to about 5% of the GDP of Europe and now has a chance to expand its worldwide leadership achievements.

5G is a short form of the network of the fifth generation of mobile technology. This technology makes it possible to use a mobile phone with the ability to download more high traffic for an extremely short time. It uses the technology of CDMA, BMDA, and millimeter waves for wireless connectivity. To reach speeds of 1Gps are used new smart antenna techniques to reach high speeds and last but not least the area of coverage. The network of fifth generation 5 G used all existing wireless cellular technologies 2G, 3G and 4G. [2]

The advantages which will lead the network of fifth generation are as follows:

- Better revenue for service providers;
- Interoperability will become possible and easy;
- Low battery consumption of smartphones;
- A better coverage and high-speed data transfer;
- Multiple ways for data transfer simultaneously;
- More secure and reliable network;
- Flexible architecture based on Software Defined Radio;
- Greater spectral efficiency;
- Harmless for human health;
- Better quality of service (QoS);
- Ultimate downloading and uploading of information in broadband Internet;
- Most devices that use 5G will work with power as the USB devices as this will in due course is an ideal solution for developing economies in the world in which the interruption of electrical energy is often.

TABLE I. SPECIFICATIONS OF 5G NETWORKS

Specification /Feature	5G Support
Bandwidth	1Gbps or higher
Frequency range	3 to 300 GHz
Standard (access technologies)	CDMA/BDMA
Technologies	Unified IP, seamless integration of broadband, LAN/PAN/WAN/WLAN and 5G based technologies
Applications/Services	wearable devices, dynamic information access, HD streaming, smooth global roaming
Core network	flatter IP network, 5G network interfacing (5G-NI)
Handoff	vertical, horizontal
Peak Data Rate	Approx. 10 Gbps
Cell Edge Data Rate	100 Mbps
Latency	less than 1 ms

In Table I are presented operating specifications of the future network

As shown in Fig. 1 5G networks will use the flat IP concept for various RAN (Radio Access Network) to use the same Nano core technology for communication with each other.

RANs supported architectures in 5G are GSM, LTE, LTE-ADVANCED, WIMAX, CDMA2000, EV-DO, CDMA One, IS-95 networks. [3]

The flat IP architecture identifies the devices using symbolic names, as opposed to the hierarchical structure in which only real IP addresses are used. This architecture reduces the number of network elements in the data stream, therefore this leads to a significant reduction of costs. This type of architecture leads to a significant reduction of the waiting time.

5G aggregator summarizes and directs all traffic resulting from RAN, as it points to the appropriate Gateway.

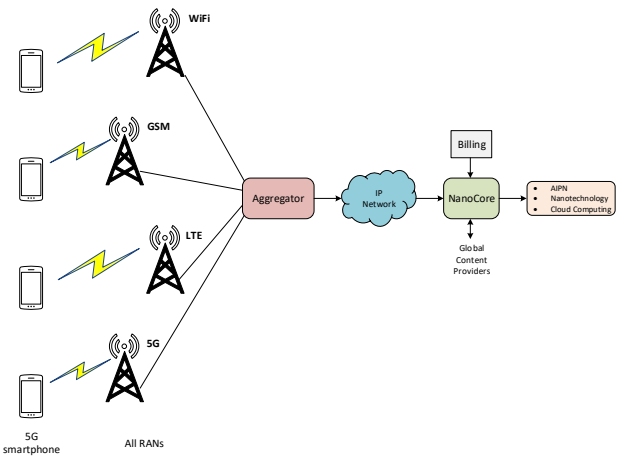

Figure 1. Physical architecture of the network of the Fifth generation

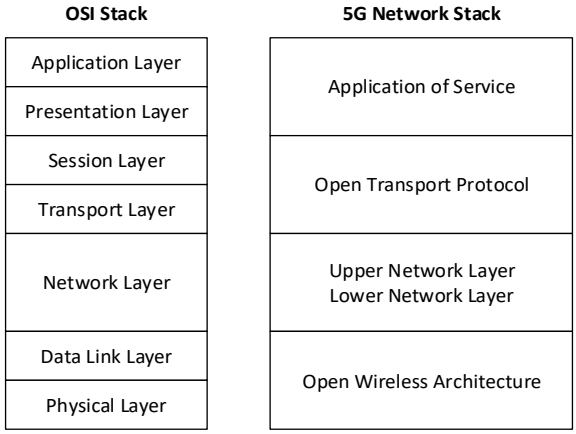

Figure 2. 5G protocol stack

5G aggregator is localized in the BSC/RNC area. Another component in the network of the fifth generation is 5G Nanocore technology. Nanocore consists of nanotechnology, computational machines in the clouds and all IP architecture.

Cloud computing uses the Internet, as well as the headquarters of the remote servers for maintenance of data and applications to the user. This technology allows users to use applications without any installation and access your files from any computer in the world with the help of the Internet. [4]

B. *Protocol Stack of the Fifth Generation Network*

Fig. 2 describes the 5G protocol stack, as well as the corresponding OSI layers.

OWA Layer is short form of Open Wireless Architecture. This architecture directs data to the physical layer of the OSI stack.

Network Layer is used for routing data from the IP source device to another system. Fixed IPv6 will be implemented in the user equipment by 5G phone manufactures. The 5G mobile phone must maintain virtual multi-wireless network techniques. For this purpose, there should be separation of network layer into two sub-layers in 5G equipment i.e.: Lower network layer (for each interface) and Upper network layer (for the mobile terminal). This is due to the general design of the Internet, where all the routing is based on IP addresses which should be different in each IP network worldwide. The middleware between the Upper and Lower network layers maintain address translation from Upper network address (IPv6) to different Lower network IP addresses (IPv4 or IPv6), and vice versa.

Open Transport Layer combines the functionality of all transport layers, including sessions layers. In 5G mobile terminals will have the ability for downloading and installing. Such user equipment must have the possibility to download (e.g., TCP, RTP, UDP etc.) version which is targeted to a specific wireless technology installed at the base stations. For that reason, it is called here Open Transport Protocol.

Application Layer marks the data in the appropriate format if necessary. Performs the encryption and

decryption of the data. This layer chooses the best wireless connection for a service. [5]

III. NETWORK TESTCASES AND CHALLENGES FOR 5G NETWORK

Development of 5G devices requires testing of equipment at different stages, starting from the design phase to the implementation phase. It includes tests of the various levels of the protocol stack of the 5G device. In the following table are listed the main tests that need to be made to the various phases of the life cycle of 5G.

Table II describes tests carried out on the 5G network with equipment of the Keysight company.

TABLE II. TEST CARRIED OUT ON 5G NETWORK

5G test	Test case
transmitter testing for compliance	Power spectrum mask, transmit power in terms of time, CCDF, I/Q vs. time
receiver testing for compliance	EVM, characteristic of the channel, spectral flatness
testing for compatibility	This ensures that the tests of 5G devices from one supplier will work with 5G devices from other vendors in the network without any problems.
tests for network stability	5G system works without any problems in the long run during transmission and other tests.
Inter-RAT tests	This test provides a 5G device to work well in all radio access technologies for which it was designed.
RF related tests	Other than the above tests, the RF device 5G as phase noise, 1 db compression, third intersection points, harmonics, fake noise figure, the rejection of the image are equally important to be fulfilled.

A. *Keysight 5G Test Equipment*

Fig. 3 depicts simulation of 5G network with equipment of Keysight. In addition to the above tools 5G, the bench requires Waveform Creation Software Application and VSA software applications. Waveform Creations allows users to configure the 5G basic parameters like PHY and MAC. VSA app allows users to analyze the different associated baseband parameters such as EVM, IQ response channel, power, range, and more. To reach high speeds up to 10Gbps, 5G technology targets in millimeter waves. [6]

In the range below the 6GHz network of fifth generation will be optimal for work in macro-optimized cells. In the range of 6-30GHz will be used small cell and in the range of 30-100GHz – Ultra Dense cells. [7]

The frequency bands which are located between 30GHz and 300GHz are known as the range of millimeter waves. There are many advantages and disadvantages in these waves. Along with increase in the number of subscribers of mobile data increases the volume of traffic.

Bandwidth is limited in the existing mobile spectrum. Due to this fact, mm wave band is studied as a mobile spectrum by mobile operators, due to the need to look for a solution for a larger data traffic.

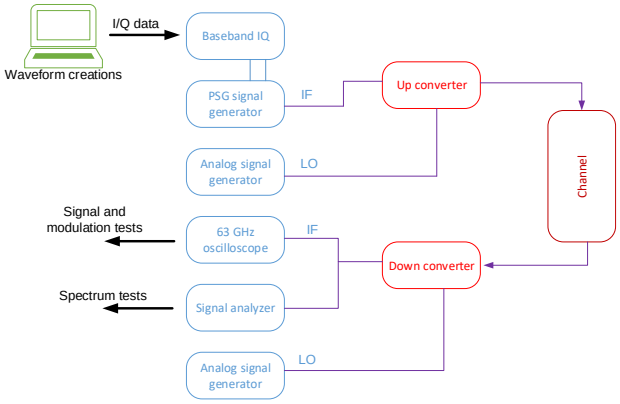

Figure 3. Simulation of 5G network

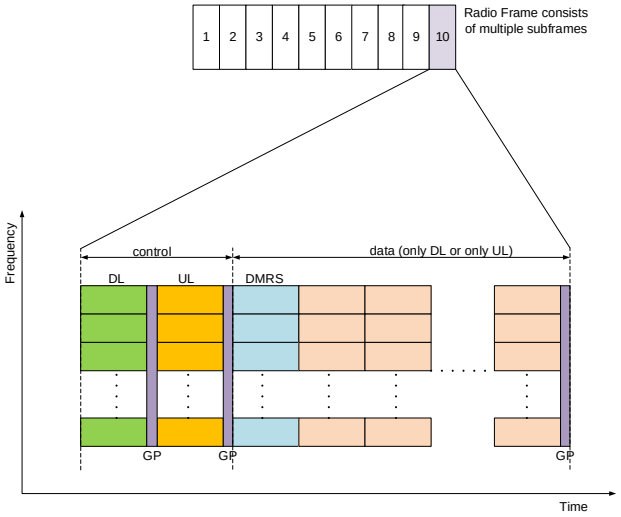

Figure 4. Proposed 5G milimeter wave frame and subframe

Millimeter waves have big losses of penetration through the building walls and other large complexes.

For frequencies above 40GHz Single Carrier Modulation is used to enable higher efficiency and effectively generate rays. This provides a constant envelope modulation in wavelength. [8]

The Fig.4 depicts a 5G millimeter wave with frame construction. As DL is displayed for downlink from the ENB to UEs and UL applies for uplink from UEs to ENB. In the shown figure, control and information data are completely separated, which helps to achieve a smaller timeout requirement. This is due to the fact that the processing of information units can operate in parallel. [9]

Advantages of 5G millimeter waves:

- Provide a lot of traffic, and hence a larger number of subscribers
- Thanks to the lesser traffic in mm range is more favorable the placement of small cells.
- Channel sound, the function is used to care for the various types of losses in mm wave frequencies, so 5G the network to work satisfactorily
- The size of the antennas is physically small which leads to massive use of MIMO in ENB/AP to increase capacity.

- Dynamically generating waves are used to reduced higher delay of time-distance in mm-wave frequencies.
- 5G millimeter range networks supports multi-gigabit transfer rates up to 400 meters and cellular access up to 300 meters.
- Because of these advantages 5G mm wave is suitable for mobile communications in 6GHz wireless technology.

Disadvantages of 5G millimeter waves:

- The influence of bad weather affects the signal
- Low penetration in massive walls of various buildings, leading to specific requirements for service boundaries between cells.
- Millimeter wave signal supports up to two meters indoors and up to 300 meters outdoors, depending on the channel conditions and AP/ENB height above ground.
- It is supported only the LOS (line of sight) for transmission, therefore, coverage is limited.
- Energy consumption is higher in millimeter waves due to the large number of RF modules and higher number of antennas.

B. 5G Channel Sounding Test Challenges

Evaluation of time-varying, multi-path frequency bands requires highly complex, multi-channel instrumentation that includes precise timing and synchronization and advanced software to capture and characterize a potential channel. [10] Key measurements include:

- Frequency response by amplitude and unwrapped phase and group delay;
- Absolute path loss and power delay profile (PDP);
- Angle of Arrival (AoA);
- Angle of Departure (AoD).

Key test challenges faced by design and research engineers include:

- Ability to generate and analyze wideband, MIMO signals at mmWave frequencies;
- Ability to do calibrations for wideband transmitter and receiver test that include vector pre-corrections, IQ frequency response and IQ imbalance, channel to channel skews;
- Significant time to collect and manage huge amounts of data;
- Tx/Rx timing and synchronization.

IV. CONLUSION

With its aggressive performance goals, the emerging 5G standard will almost certainly incorporate a combination of millimeter-wave (mmWave) frequencies, ultra-broad bandwidths and massive multiple-input/multiple-output (MIMO) methods. The successful deployment of mmWave-based systems requires a solid understanding of channel conditions. Currently, attention is being focused on radio-wave propagation at a variety of possible carrier frequencies above today's densely populated spectrum in the region below 6 GHz. Detailed characterization of channel propagation is vital for the development of a reliable 5G wireless system design. A technique called channel sounding is necessary step towards understanding the channel and, thereby, enable the data rates, spectrum flexibility and ultra-broad bandwidth envisioned for 5G.

ACKNOWLEDGMENT

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The Analysis of Geometry, Coverage and Capacity of Heterogeneous Networks

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***Abstract*—Mobile operators are confronted with the fact that a large portion of the calls and data transfer take place indoors. The aim of this paper is to present an analytical model for the planning and use of network resources in the heterogeneous networks (multitier, multistandard) whose topology will enable network enhancements of indoor and outdoor coverage, capacities and reliability of communication, reduction of investment costs and maintenance of the network, as well as reduction of electricity consumption. This model should set the theoretical framework in which it is possible to upgrade efficiently the existing network with the least costs of network deployment, while at the same time providing the capacity to meet user requirements in the necessary places and at the required time. Accordingly, a set of values of network resource parameters is presented as one of the main results achieved by this model. Hence, this set grasps parameters' values which enable increased energy and spectral efficiency, as well as required capacities, the satisfactory level of quality of service, and rational energy consumption within the real network in the time domain. In addition, the results include the establishment of a connection with the necessary limit values of the radio signal parameters at the cell boundaries, considering all cell tiers.**

Keywords: Heterogeneous cellular networks, Poisson point processes, spectral efficiency, deployment efficiency, HetNet, HNC, CapEx, OpEx.

I. Introduction

Fulfilling the users' needs for increased data traffic is achieved by optimizing the use of radio spectrum and by deploying low-range cells layered across existing macrocellular network architecture in tiers. In this paper we consider multiple access network design in a certain area on a downlink only. The basic metrics we will focus on are signal coverage and capacity.

- *Coverage* - The so-called service zone is an area in which user terminals can correctly receive both the control signaling and the data traffic at some minimum rate from the base station (BS). This means that the received signal from the BS is strong enough so the received signal power from the BS exceeds some threshold, and that the received signal to interference plus noise ratio (SINR) at the user exceeds some minimum value. SINR is the key indicator of coverage. However, for the sake of deployment efficiency analysis and though the modern cellular networks such as LTE and LTE-A enabled receivers with very low threshold on received signal power within a large distance from the transmitting BS, we are analyzing the signal power together with SINR.
- *Capacity* - It is known that there is a relation between the available data link rates and SINR on that link. This means that the link capacity is also dependent on SINR at user reception terminals [1].

A. Structure of the Problem

1) SINR calculation problem: Since coverage and capacity are both related to the SINR at the users receiver, we shall focus on the statistical properties of this SINR [2]. Three main deployment parameters for a network which will satisfy user demands in coverage and/or capacity are as follows:

- the number of tiers of the network,
- the densities of the BSs in the tiers, and
- the transmit powers of the BSs in the tiers.

2) Deployment Efficiency: Each service provider will try to optimize the costs of building and upgrading the network, i.e. Capital Expenditures (CapEx) and Operating Costs (OpEx) while meeting the requirements for coverage and/or capacity. In other words, in addition to the complex criteria of signal coverage and capacity requirements, there is a complicated utility function that is dependent on economic variables such as the cost pricing model, CapEx, OpEx and expected revenue. In this paper, these problems will be analyzed by performing the relationship between cost parameters and the distribution of SINR within the area of a heterogeneous network. Based on the selected SINR distribution, the service provider can select a set of base station allocation parameters based on its useful function, which considers economic reasons.

3) Candidate serving BSs and the serving BS: At an arbitrary temporal point t_0 network resources consist of one LTE resource block (one sub-carrier in one transmission interval) or one transmission interval for a frequency-selective cable in the HSPA standard. We observe one user located anywhere in the entire network area.

For each given user, one BS candidate serving was chosen from only one tier, according to certain criteria. Within the subsection B, which represents related work overview, we are studying some of the most commonly used criteria for selecting BS's candidate from all tiers and the criteria for selecting one serving BS from all the candidates serving BSs.

4) Serving tier, serving BS, and instantaneous SINR: As noted previously one candidate serving BSs is chosen by any of several criteria to be defined in B. out from all existing tiers as the serving BS. Thus, if there is only one accessible tier, the candidate serving BS from this tier is also the serving BS.

B. Related Work

The network topology, or spatial scheduling of the BSs, significantly affects the performance key parameters of the cellular networks such as the coverage and capacity. When we observe all through the main parameter, the SINR, which is a random variable in time from the receiver location perspective the layout of BSs represents the space of random events, i.e the distribution of the BS location belongs to the random process. Recently, it has become very popular to analyze the topological network in the form of Poisson Point Process (PPP), of which there are many interesting articles and very useful books [2]. Such modeling the BS cell site can describe irregular placements. Also, there are powerful tools of stochastic geometry [5] that can be utilized. The topology analysis in the PPP form commenced relatively long time ago [6] - [8]. However, the probability of the coverage of the signal and the average transmission rate based on Shannon's theory was derived recently [5]. Moreover, analysis of cellular networks with PPP distributed BSs has been extended to other network scenarios, including heterogeneous mobile networks [9] - [13], MIMO mobile networks [14], [15] and MIMO heterogeneous networks [14], [16], [17]. These papers do not consider systems with MIMO signal processing. The statistics of the propagation losses between a typical user and the BSs converge to the Poisson network model under i.i.d. shadowing with large variance [18]. However recent research demonstrate that these assumptions are quite restrictive and may not always hold in practice. Macro BSs are typically distributed more regularly than the realization of a PPP. However, this paper doesn't contain any research efforts devoted to investigating more accurate point process models for representing BS deployments. Such classes of point processes are the part of the future work [19].

C. Our Contributions

In previous work [3][4] authors made several analysis of trade-offs between deployment, spectral and energy efficiency based on multitier cellular networks in deterministic form (hexagonal).

In this work, we derive deployment vs. spectral efficiency (DE-SE) based on SINR metrics in cellular networks with PPP configured BSs for the first time. We used the relatively new approach to analysis of wireless networks trying to tackle the problem of SINR calculation at the receiver which is one and primary parameter for all interesting relations between power consumption spectral utilization and energy dispersal in wireless networks. This work belongs to unique research of trade-offs in wireless networks with a prime goal to derive one holistic utility function which will help operators to optimize the architecture and the topology of its networks. The main contributions of this paper are summarized in V.

II. System Model

We studied a network consisting of N_T, $k = \overline{1, N_T}$ tiers. Each tier is characterized as a homogeneous Poisson point process Φ_k with triplets $\{P_k, \lambda_k, \tau_k\}$, which denote the total transfer power in the k, the density of the access points AP and the SINR threshold below which the receiver cannot restore the content. Tiers are ranked in ascending order by the density of access points, i.e. $\lambda_1 \leq \lambda_2 \ldots \lambda_{k-1} \leq \lambda_k$. Given the density λ_k, the number of access points belonging to the layer k in the area A represents a random Poisson variable, with a mean density $A{\cdot}\lambda_k$, which is independent of other tiers. Furthermore, all access points in the k-tier have the same transmission power P_k.

Each downlink is affected constant path loss with exponent α and received signal from each AP is modeled by Rayleigh fading channel. With a sufficiently small thermal noise, this analysis can be reduced to considering interference from other RF signal sources only. Also, due to the simplicity of the analysis process, shadowing is neglected. For each tier, the factor of frequency reuse is one and the allocation of the RF band is according to the principle of orthogonality (which in principle means that one real channel is skipped between two tiers of the same standard). Therefore, at a typical user connected to tier k, the set of interfering APs include all the APs in tier k except the serving AP2. For the future work the results should be formed in such a way to enable spectrum sharing across tiers, lognormal shadowing, and any arbitrary fading distribution for the interfering signals.

We assumed following scenario [2]: the user is only allowed to access the BSs in tiers $1, \ldots, K_{open}$. For example, a macro-femto HCN with a mixture of open access (OA) and closed subscriber group (CSG) femtocells would be represented as an HCN with $N_T = 3$ and $N_{open} = 2$, with tier 1 representing the macrocells, tier 2 the OA femtocells, and tier 3 the CSG femtocells. Next, we assume that each BS in a tier transmits with the maximum power allowed for BSs in that tier. This immediately models the case of reference symbols (LTE) or pilot channels (HSPA), but also covers the case of data channels if we assume that the cells are all fully loaded.

We did not analyze the scenario which implies if the user moves quickly among service zones of two and more APs, which would cause that handoff occured [20].

III. Analytical Model

In order to demonstrate the relationship of deployment efficiency and spectral efficiency, it is necessary to firstly analyze the relationship between the network spectral efficiency and the total power in such a way that the base stations are distributed within the tiers in the form of PPP. The following analytical model consists of spectral efficiency for each tier, as well as of overall heterogeneous network's efficiency. Moreover, the model does not include thermal noise and considers path-loss exponent which is equal to 4.

Following the analytical models from [2], we observed two different cases: macro tier being the serving tier ($\mu_{c,i}i$) while pico tier being the candidate serving tier, and vice versa ($\mu_{c,j}$). The first case observes an arbitrarily located user served by micro tier, and the probability of its SINR to be greater than threshold can be expressed in the form presented by relation (1). In order to gain simplified model, η_{ABS} represents fraction of *almost blank subframes* (ABS), which are assumed to be subframes in which macro BSs do not transmit any power [2].

$$\begin{aligned}\mathcal{P}_i &= \mathcal{P}\left\{\Gamma_i > \gamma | R_i = r_i, R_j = r_j\right\} = \\ &= (1-\eta_{ABS}) \cdot \mathcal{P}\left\{\Gamma_i^{notABS} > \gamma | R_i = r_i, R_j = r_j\right\} = \\ &= 0.75 \cdot e^{-\pi \cdot \lambda_i \cdot r_i^2 \cdot \sqrt{\gamma} \cdot \left[\cot^{-1}\left(\frac{1}{\sqrt{\gamma}}\right) + \beta \cdot \cot^{-1}\left(\frac{\pi \cdot \lambda_j \cdot r_j^2}{\beta \cdot \sqrt{\gamma} \cdot \pi \cdot \lambda_i \cdot r_i^2}\right)\right]}\end{aligned} \tag{1}$$

On the other hand, the probability that a user is served by pico tier, having the satisfactory level of SINR is presented within relation (2).

$$\begin{aligned}\mathcal{P}_j &= \mathcal{P}\left\{\Gamma_j > \gamma | R_i = r_i, R_j = r_j\right\} = \\ &= (1-\eta_{ABS}) \cdot \mathcal{P}\left\{\Gamma_j^{notABS} > \gamma | R_i = r_i, R_j = r_j\right\} \\ &+ \eta_{ABS} \cdot \mathcal{P}\left\{\Gamma_j^{ABS} > \gamma | R_i = r_i, R_j = r_j\right\} = \\ &= 0.75 \cdot e^{-\pi \cdot \lambda_i \cdot r_i^2 \cdot \sqrt{\gamma} \cdot \left[\cot^{-1}\left(\frac{1}{\sqrt{\gamma}}\right) + \beta \cdot \cot^{-1}\left(\frac{\pi \cdot \lambda_j \cdot r_j^2}{\beta \cdot \sqrt{\gamma} \cdot \pi \cdot \lambda_i \cdot r_i^2}\right)\right]} \\ &+ 0.25 \cdot e^{-\pi \cdot \lambda_j \cdot r_j^2 \cdot \sqrt{\gamma} \cdot \cot^{-1}\left(\frac{1}{\sqrt{\gamma}}\right)}\end{aligned} \tag{2}$$

A range expansion bias(θ) is applied to the mean received pilot powers at the user in order to favor offloading users to pico tier. In that manner, τ (relation (3)) is selection bias for tiers k. Also, β is a function of intensity ratios and transmit power ratios (4).

$$\tau = \sqrt[4]{0.063 \cdot \theta \cdot \frac{P_2^{tx}}{P_{1,reg}^{tx}}} \tag{3}$$

$$\beta = \frac{\lambda_2}{\lambda_1} \cdot \sqrt{0.063 \cdot \frac{P_2^{tx}}{P_{1,reg}^{tx}}} \tag{4}$$

The probability density functions of user's distance from serving tier is expressed as relation (5), while the same function for distance from candidate serving tier is presented by relation (6).

$$f_{R_i}(r_i) = 2.5 \cdot \pi \cdot \lambda_i \cdot r_i \cdot e^{-1.25 \cdot \pi \cdot \lambda_i \cdot r_i^2} \tag{5}$$

$$f_{R_j}(r_j) = 2 \cdot \pi \cdot \lambda_j \cdot r_j \cdot e^{-\pi \cdot \lambda_j \cdot r_j^2} \tag{6}$$

Concise consideration of the previous statements converges to relations (7) and (8), which comprehend spectral deficiencies of macro and pico tier, respectively.

$$\mu_{c,i} = \frac{\lambda_i}{\ln 2} \int_0^\infty \int_0^\infty \int_{\tau \cdot r_i}^\infty \frac{f_{R_i}(r_i) \cdot f_{R_j}(r_j) \cdot \mathcal{P}_i}{1+\gamma} d\gamma dr_i dr_j \tag{7}$$

$$\mu_{c,j} = \frac{\lambda_j}{\ln 2} \int_0^\infty \int_0^\infty \int_{\frac{r_i}{\tau}}^\infty \frac{f_{R_j}(r_i) \cdot f_{R_i}(r_j) \cdot \mathcal{P}_j}{1+\gamma} d\gamma dr_j dr_i \tag{8}$$

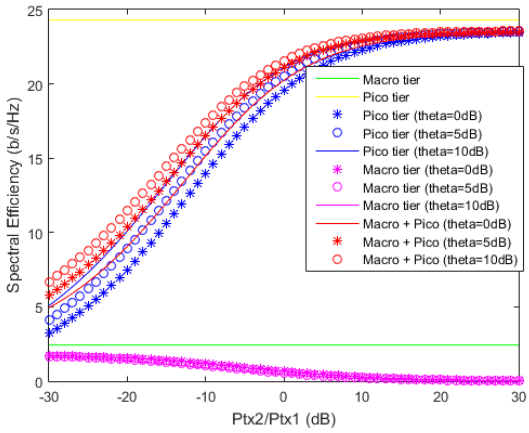

Fig. 1. Spectral efficiency vs. the relative transmit powers

Finally, the total spectral efficiency of heterogeneous network can be obtained by relation (9). Taking this analytical model into consideration, the Fig. 1 summarizes different scenarios which present spectral efficiency vs. relative transmit power.

$$\mu_{c,tot} = \mu_{c,i} + \mu_{c,j} \tag{9}$$

We can also draw similar conclusions to those obtained by authors from [2]. In this manner, from the spectral efficiency curves in Fig. 1, the benefits of spatial reuse of resources in a dense small-cell tier are significant. Comparing the scenarios of standalone pico and macro tiers emphasizes the strong potential of pico tier deployments, especially for the so-called green heterogeneous networks.

IV. Network Deployment Efficiency Analysis

Since analytical model was presented throughout the previous section, it is necessary to show the benefits and significant results that can be obtained using it.
Also, if we take the deployment efficiency into consideration, it has to be stated that this phenomena inevitably requires information about the total amount of cost of actual heterogeneous network deployment. Since our paper [4] provides relation between nominal power of considered BS and it's deployment cost, we present the model suitable for calculating the total deployment efficiency of heterogeneous network, in the form of relations (10) and (11).

Therefore, these relations are specified for the certain scenario of network deployment which envelopes two tiers ($N_T = 2$, pico and macro), each consisting of N_k BSs.
According to the relation (10), the total deployment cost for the engaged scenarios is presented in Fig. 2. The scenarios include the calculation of deployment cost for the certain value from a contemplated range of relative transmit power.

Accordingly, under the rule presented by relation (11) the total deployment efficiency is shown in Fig. 3, observing three different cases which differ in θ value. Finally, the

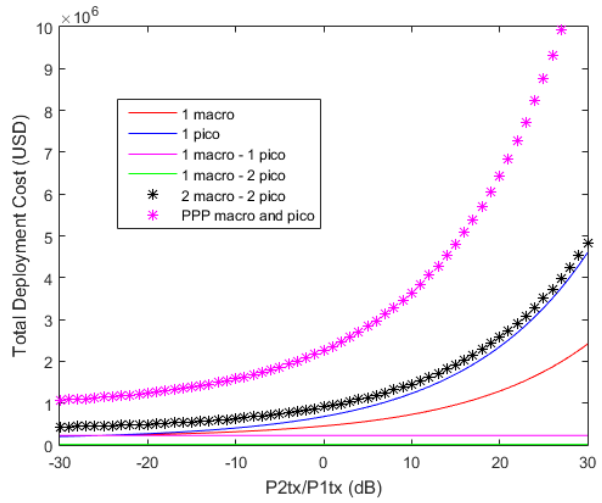

Fig. 2. Total deployment cost vs. the relative transmit powers

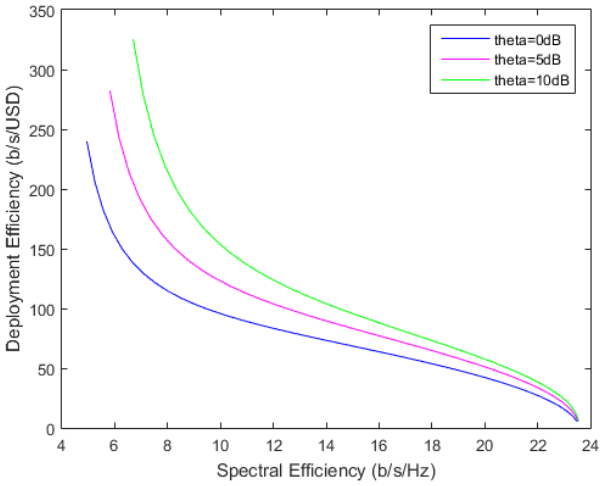

Fig. 4. Deployment efficiency vs. spectral efficiency

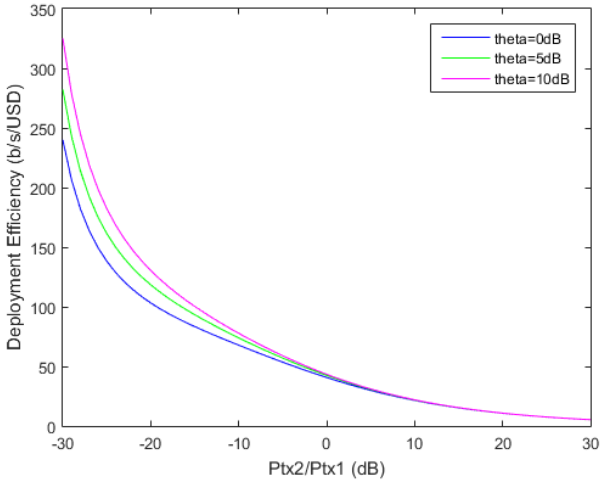

Fig. 3. Deployment efficiency vs. the relative transmit powers

trade-off between deployment and spectral efficiency is shown within Fig. 4.

$$C_{tot} = \sum_{k=1}^{N_T}\sum_{m=1}^{N_k} C_{BS_{k,m}} = \sum_{k=1}^{N_T}\sum_{m=1}^{N_k}\left(a \cdot P^{b}_{BS_{k,m}} + c\right)$$
$$N_T = 2, \quad N_k = \{N_1, N_2\}$$
$$N_1 = \lambda_i, \quad N_2 = \lambda_j \tag{10}$$
$$\{a, b, c\} = \left\{8.807 \cdot 10^4, 0.305, -4.53 \cdot 10^4\right\}$$

$$DE = \frac{B \cdot \mu_{c,tot}}{C_{tot}} \tag{11}$$

V. Simulation Results

Within this subsection, we will briefly present the background of the simulation set in ns3 simulator environment. The main idea was to inspect whether the simulation results can follow the presented analytical model or not. Therefore, three different scenarios were created in order to collect necessary data about SINR values at user terminals. Subsequently, being familiar with SINR results enabled the calculation of the spectral efficiency of heterogeneous network in a certain scenario.

Namely, the positions of BSs were determined by following the PPP, and their presentation is visible in Fig. 5. Also, the picturesque presentation of BSs' radiation, including one macro and ten pico BSs, is given within radio environment map (REM) shown in Fig. 6. Hence, all scenarios analyzed the distribution of SINR at user locations, as well as spectral efficiency, considering different transmit power levels for the pico tier, keeping the macro tier transmit power as a constant. It can be concluded that spectral efficiency has a growing trend in relation to relative transmit power. Also, the scenarios with greater number of pico cells within network deployment inevitably lead to higher spectral efficiency, which roughly follows the adopted analytical model.

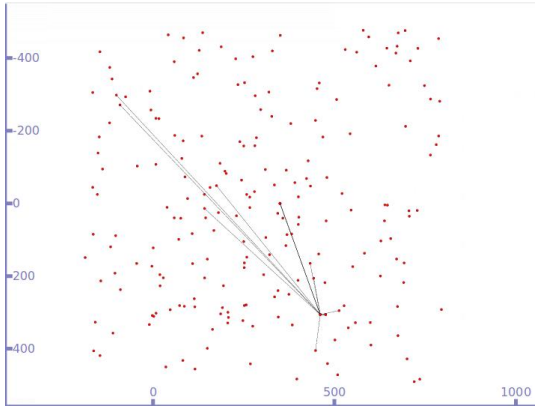

Fig. 5. Macro and pico tier BSs locations

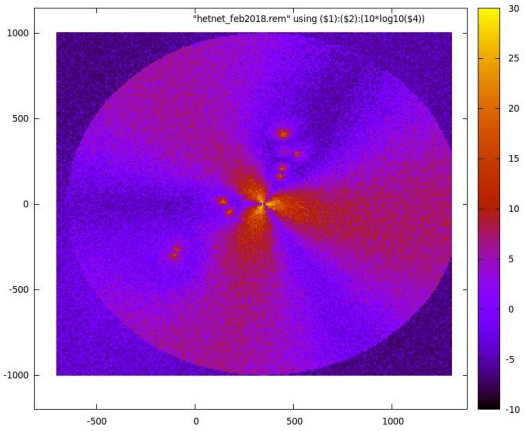

Fig. 6. Radio environment map (one macro and ten pico BSs)

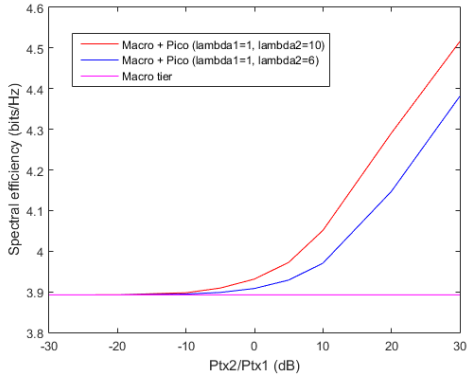

Fig. 7. Spectral efficiency vs. the relative transmit powers obtained from simulation

VI. Conclusions

The heterogeneous network concept in many respects meets customer requirements and maintains high energy efficiency. In this paper, we mainly investigate the impact of deployment efficiency of heterogeneous small cells BSs compared to the advantages of increasing the performance of wireless networks as a whole. Opposite to our previous work we used novel and very popular modeling the BS distribution over the heterogeneous multitier network as the Poisson Point Process. It is quite satisfying seeing that the results match both with the current state-of-art research articles and with our previous achievements. However it is early to say that by this work we achieved any major contribution since there is a lot of room for further investigations especially taking more complex scenarios under consideration and using enhanced models of PPP. The main achievement is that we made much easier analysis using such an approach and also simulation in NS3 is quite more tractable and comparable to an analysis. In summary, this analysis shows that the introduction of small cells in heterogeneous networks with any chosen distribution of base stations has a major impact on energy efficiency, and spectrum efficiency with acceptable cost reduction (it has the limitations as shown in the paper). The introduction of the small cells, i.e. pico cells, obviously increase the initial investments (Fig. 2), but analyzing the efficiency of network deployment in which the pico BSs are located, we obtained satisfactory results from which we conclude that deployment efficiency is in the upward trend until the total strength of the pixels is lower than the maximum power of one macro stations.

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SERVICES AND APPLICATIONS

Smartphone GNSS positioning performance improvements through utilisation of Google Location API

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***Abstract* - A wide-range utilisation of Global Navigation Satellite Systems (GNSS) across technology and socio-economic domains renders the satellite navigation one of the pillars of the modern civilisation. Tackling and overcoming the inherent shortcomings and emerging threats to provision of robust and resilient GNSS Positioning, Navigation and Timing (PNT) services have become a research subject of the utmost importance. An open access to the GNSS positioning estimation process is fundamental for development of advanced methods for robust and resilient GNSS position estimation. Recent introduction of Google Android 7.0 revision allows for direct access to raw GNSS pseudoranges observed by smartphones. Here we address the opportunities for GNSS positioning estimation improvements, given through exploitation of Google Android Location API, in creation of bespoke GNSS position estimation process in navigation application domain of a GNSS Software-Defined Radio (SDR) receivers in smartphones. We present and validate opportunities for improvement of GNSS position estimation process through utilisation of distributed computing architectures, trusted sources of GNSS augmentation data and utilisation of GNSS positioning methods suitable for targeted classes of GNSS applications Authors are members of European GNSS Agency's GNSS Raw Measurements Task Force, and co-authored the white-paper on GNSS-related Google Android Location API applications.**

Keywords – GNSS; positioning performance; position estimation; Software-Defined Radio (SDR); Google Location API

I. INTRODUCTION

The assurance of the satellite navigation system's quality of Positioning, Navigation and Timing (PNT) services is the central pre-requisite for development of the growing number of Global Navigation Satellite System (GNSS) applications in various segments [12], ranging from Location-Based Services (LBS) and emergency services to Intelligent Transport Systems (ITS) and autonomous vehicles and vessels. The essential problem in the resilient GNSS development lies in immediate identification and mitigation of sources of GNSS PNT quality of service deterioration, mostly caused by the effects of the GNSS positioning estimation error sources [5]. While majority of those effects belong to the User Equivalent Ranging Error sources (Fig 1 and [11]), the mitigation of their effects requires the proper identification of the nature of the problem and deployment of the mitigation (correction) method most suitable for the nature of its cause [5], [10].

The introduction of the software-defined radio (SDR) concept [5], [9] in satellite navigation developed a hidden revolution in the GNSS resilience development by allowing for deployment of the bespoke correction models suitable for the position estimation conditions [4]. Still, the opportunities have not been exploited so far, due to rather conservative approach in the GNSS SDR design that utilises strictly proprietary signal processing and navigation methods and algorithms developed by a GNSS receiver manufacturer, and prohibited for access and modifications by third-party developers.

In recent developments, the Google LLC company, a subsidiary of Alphabet Inc., has announced its Location API's support to manufacturer-independent direct access to the Android smartphones raw (un-corrected) GNSS pseudorange observations [8]. The Location Application Programming Interface (API) is available in all the Android 7+ operating systems running the smartphones and the other computing devices, regardless of its or GNSS manufacturers.

Here we address the importance of opening raw GNSS pseudoranges for third-party developments, and present the methodology for the utilisation of the Google Location API for development of resilient GNSS applications through utilisation of bespoke models in a software-defined GNSS radio receiver. This manuscript extends and details the authors' involvement in the European GNSS Agency's GNSS Raw Measurements Task Force, and their contribution to preparation of the white paper on utilisation of the Google Location API [8].

II. GOOGLE LOCATION API FOR GNSS POSITIONING PERFORMANCE IMPROVEMENT THROUGH GNSS SDR UTILISATION

The GNSS position estimation process encompasses three essential signal domains: Radio Frequency (RF) domain, Base-Band (BB) domain, and Navigation Application (NA) domain [1], [4], [5]. The raw GNSS pseudoranges emerge as the results of the signal processing in BB domain, and are processed further in the NA domain [4], [5]. The GNSS pseudorange measurement process is

affected by numerous causes of measurement errors [11], [12], as depicted in Fig 1.

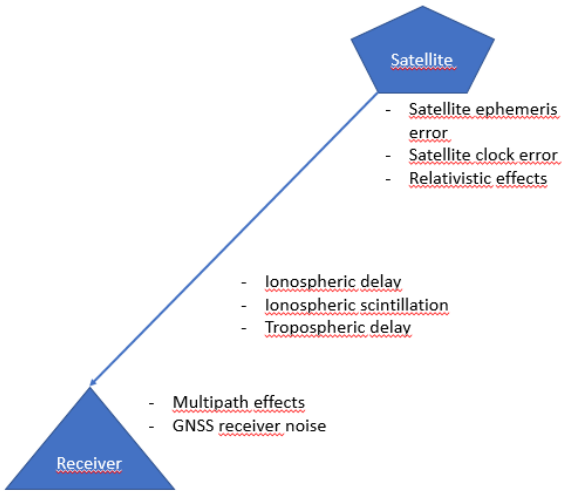

Fig 1Sources of GNSS pseudoramge measurement (ranging) errors

Raw GNSS pseudorange measurements thus comprise the actual (true) distance between the satellite's and the user's aerials, enlarged by the effects of pseudorange error sources [4], [11]. The pseudorange measurement errors can be split by their nature into systematic and stochastic errors [9], [4], yielding the pseudorange measurement model as depicted by equation (1):

$$\rho = d + \Delta d + \delta d \qquad (1)$$

where:

d … real (actual) distance between the satellite's and user's aerials (true pseudorange)

Δd … systematic pseudorange measurement error

δd … stochastic pseudorange measurement error

ρ … raw pseudorange

Systematic pseudorange measurement error sources are of known nature [9], [11], and their impact may be described with the appropriate correction models, provided by GNSS core and augmentation systems operators. For instance, GPS-based positioning is supported by provision of satellite clock offset correction model, Klobuchar model for GPS ionospheric time delay correction [3], [11], [5], and Saastamoinen tropospheric correction model [11]. Galileo system uses its own NeQuick model for the ionospheric time delay correction [11]. In general, the correction models embedded within the system are largely of general (global) nature, and often fail in taking account of the local disturbances [3], [11], [1]. This causes that the unknown portion of systematic pseudorange measurement errors remains at large [9].

Stochastic (random) pseudorange measurement errors cannot be described by correction models, and often remains uncorrected, causing the over-all position estimation errors [9]. In specific utilisation scenarios, random errors can be mitigated by exploring the nature (statistical description) of the process causing them.

A GNSS receiver processes raw GNSS pseudoranges in the NA domain by attempting to correct the pseudorange measurement first [4], [11], as depicted in Fig 2. The process shown takes the advantage in utilisation of the GPS-embedded correction model on raw GPS pseudorange measurement, before proceeding to GPS position estimation process [4], [5].

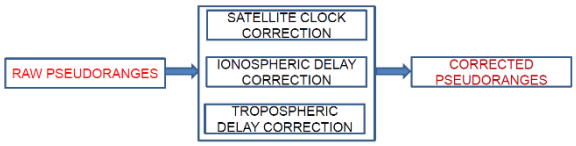

Fig 2 Position estimation in Navigation Applications (NA) domain

The utilisation of corrections removes the modelled systematic pseudorange measurement errors, thus reducing the over-all GPS position estimation errors, particularly when utilised in now prevailing Software-Defined Radio (SDR) GNSS design environment [10], [4]. Fig 3 depicts the optional utilisation of the GNSS ionospheric delay correction models in the RTKLIB, an open-source GNSS software-defined radio receiver.

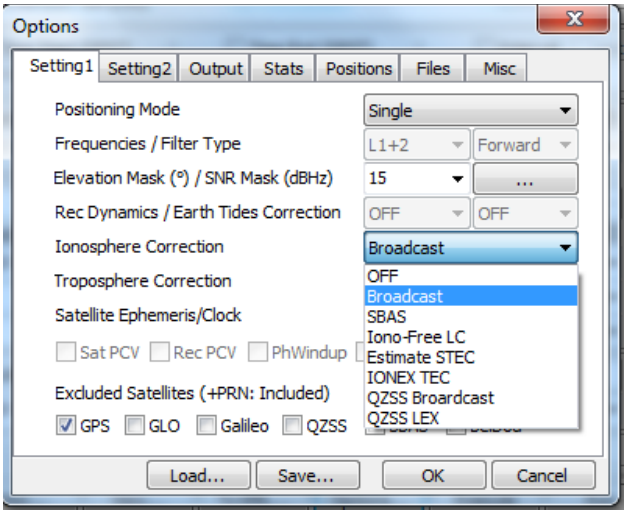

Fig 3 Configuration options for a software-defined GNSS radio receiver (RTKLIB library)

We propose the generalised methodology for exploitation of the Location API through utilisation of the position estimation model, as depicted in Fig 2. Implementation of the proposed generalisation impacts the GNSS receiver design trends, since it opens room for further transparency and distributed design approach.

The availability of raw pseudorange measurements through Android 7 API renders the NA domain process design more flexible and efficient in further error reduction through the opportunity to introduce bespoke correction models for un-corrected systematic errors, and even for random errors. In an analogy with the regional EGNOS Klobuchar-like ionospheric correction model tailored for Europe and Africa, the transparency in raw pseudorange measurement access allows for introduction of bespoke models that will suit targeted geographic region, or a scenario of GNSS positioning environment.

Our team has identified the anomalous daily pattern of the GNSS ionospheric delay in the Northern Adriatic Sea region in quiet space weather conditions in Summer period. Instead of a single maximum at around 1400 local time, the GNSS ionospheric delay demonstrates a multi-maxima pattern when observed in quiet space weather Summer conditions in the Northern Adriatic (Fig 4). The anomaly identification led to development of the Brcic-Kos model [2] for the Northern Adriatic, that allows for more accurate correction of GPS ionospheric delay in the observed region during quiet space weather conditions in Summer time [2]. Translated into appropriate format, the GNSS ionospheric delay estimates can be fed into GNSS SDR receiver directly, thus acting as a bespoke regional model with favourite quality over the standard global correction models (Klobuchar or NeQuick models) [5].

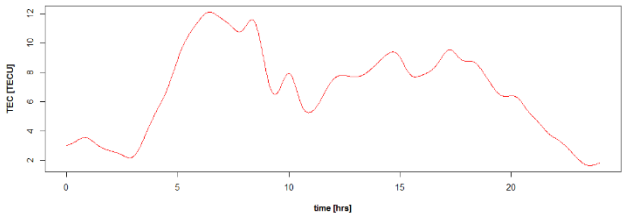

Fig 4 A case of non-specific GNSS ionospheric delay daily pattern, observed in the Northern Adriatic region in quiet space weather Summer conditions

In the other potential use-case, a bespoke model targeting a specific positioning environment (for example, oak forest) may reduce the multipath effect, that has already been identified as a GNSS random error source [11]. Such a model can be applied directly in the GNSS SDR receiver to raw GNSS pseudorange observations provided by Google Location API, thus improving the GNSS position estimation accuracy.

Bespoke models must be carefully developed, verified and validated, and trusted (certified), while being developed with patience and care. Well-designed bespoke model can reduce the GNSS pseudorange measurement error significantly, thus providing the more accurate and clean input to the GNSS position estimation process, and allowing for more robust and resilient GNSS applications development [12].

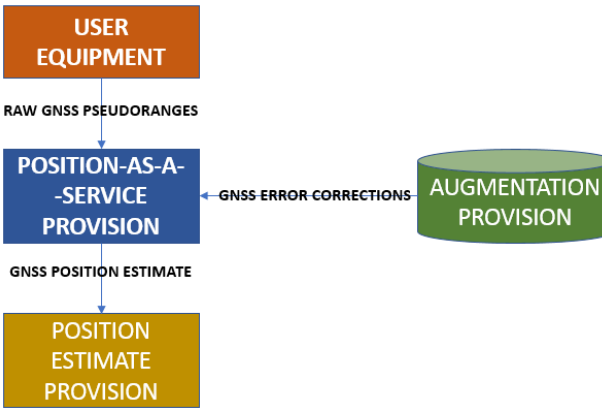

Fig 5 Positioning-as-a-Service using Location API

Availability of the Location API in question opens room for additional improvement through utilisation of the advanced computer engineering concepts and infrastructures. The already proposed concept of distributed GNSS SDR receiver [6] gains attraction through utilisation of Location API that can serve as a gateway for raw GNSS pseudoranges distribution to the computing facilities (independent servers [7], or a cloud computing system [6]) capable of conducting GNSS position estimation process efficiently and more accurately due to their enhanced computing performance and a potential access to trusted GNSS augmenting data for the improved error correction. The approaches establish a framework for Position-as-a-Service (PaaS), as depicted in Fig 5. PaaS may be considered a new development from various perspectives. Firstly, it allows for modification of existing and development of entirely new approaches in mathematics of positioning. Additionally, the realisation of PaaS will require the modification of existing and development of the new position estimation and data visualisation algorithms. Further to this, computational aspects of cloud-based PaaS should be addressed, with potentially new architectures and concepts emerging from the specific requirements for position estimation in real-time. Finally, PaaS will initiate research in establishment of the appropriate business environment, with dedicated stakeholders contribution to be fine-tuned to allow for achievement of the quality of position estimation suitable for a wide range of related information and communication services.

III. CONLUSION

Transparency of the GNSS position estimation process has improved significantly after the wide-spread introduction of the GNSS software-defined radio receiver design. This allows for conceptual introduction of bespoke software-based signal processing and position estimation methods and algorithms that facilitate robust and resilient GNSS positioning performance and operation. The introduction of Google Location API renders the access to raw GNSS pseudoranges the foundation for a completely novel design of the GNSS SDR Navigation Application domain. Being manufacturer- and GNSS system-independent, Location API allows for the GNSS SDR Navigation Application domain (i. e. development of position estimation methods and error correction models) to be designed and developed independently and adapted to the requirements of the immediate positioning environment (space weather, ionospheric, multipath etc.) conditions.

Here we presented the generalised methodology for the Google Location API deployment in GNSS SDR Navigation Application domain design, that allows for integration of bespoke, independent and third-party developed correction models into GNSS positioning process, rendering it resilient to various source of GNSS ranging errors. We proposed the concept of Position-as-a-Service, and addresses the impact of the proposal on research in related technology and business disciplines. Our research will further to exploitation of utilisation of the distributed computing concept for even more robust, resilient and efficient GNSS position estimation process based on the raw GNSS pseudorange observations.

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Adding Security to the JavaScript-based Agent Middleware SiebogJS

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Abstract **- JavaScript-based agent middleware frameworks are rare and the security handling of these is uncommon, since JavaScript does not have built-in security mechanisms and due to the lack of external security libraries. This paper gives possible solutions for including security in the SiebogJS, an agent middleware developed using NodeJS and thus implemented in JavaScript. It gives the end user the ability to upload agent files and execute them on the server. However, such actions can cause security problems. In order to prevent security issues, two security mechanisms were implemented and integrated into the SiebogJS: the ESLint library for the static code analysis and the Nodesentry library for securing external libraries that are required by an agent. The ESLint library is used to detect problematic code and the Nodesentry library is used for preventing an agent to execute malicious code during the runtime. In this way, malicious code execution can be prevented within an agent, both before and during the execution. This approach represents a good starting point for implementing security standards for the SiebogJS agent middleware, and therefore it is planned to use these security measures as standard security representation in SiebogJS.**

Keywords - agent framework; security; SiebogJS; ESLint; NodeSentry.

I. INTRODUCTION

Agents represent a new way of developing software by offering a new and often more appropriate approach in development of complex systems, especially in open and dynamic environments [1]. Agents are software entities capable of searching and processing a large quantity of information [2]. When building a middleware to support large and open agent-based systems, security, robustness, and scalability are major issues [3].

Communication between agent-based applications often relies on delegation of goals and tasks among the trusted parties [3]. Agents should not pose threats to their environment and other agents with which they exchange messages.

This paper addresses some of the potential security issues in the SiebogJS agent middleware [4], which has been developed at University of Novi Sad. SiebogJS agent middleware is the JavaScript branch of the Siebog [5] agent middleware, which has been written in Java and which provides high availability and cluster support. The idea was to port the Siebog middleware to JavaScript to investigate performance and to enable easier migration of agents from the server to browsers and vice versa. The SiebogJS agent middleware is implemented in NodeJS [6] and therefore it is prone to security problems since NodeJS does not have built-in security mechanisms. To prevent security problems happening during execution of the agents' code, it is necessary to implement at least two security mechanisms:

1. source code analysis in order to detect problematic code, and
2. establishment of runtime security based on policies, which would prevent an agent to execute malicious code.

The NodeJS framework [6] does not have a standard protection mechanism and therefore specific implementation and inclusion of security is needed. The NodeJS framework depends on multiple modules that are used when code is executed which can pose a security threat. For example, code tries to access sensitive information on a local machine, which can be a security threat. Another example of a security threat is the *eval* function in JavaScript that can be used to parse and evaluate strings and can iterate over properties of an object or access the object using string expressions instead of literals.

There are different threats to agent security, one of them being malicious code. Other threats include: message interception, message tampering, agent mobility tampering, etc. In this paper, we focus on preventing malicious code execution in software agents. That is why we need two types of security mechanisms: detection of malicious code and a mechanism to prevent malicious usage of NodeJS modules. It should be noted that the mentioned security mechanisms cannot guarantee full protection of the system as it is very hard to detect malicious code.

This paper presents one solution for detection of malicious code and prevention of malicious code execution in the SiebogJS agent middleware. The solution is based on two libraries [7], [8]:

- the ESLint library for static code analysis and

- the Nodesentry library for preventing an agent to execute malicious code during the runtime on the Server-Side.

The agent code is analysed prior to the execution, while various policies prevent the code from being misused during the code execution. By integrating the Nodesentry and ESLint into the SiebogJS agent middleware, we are able to detect and prevent the execution of malicious agents – i.e. prevent malicious code to be executed within an agent, both before and during the execution.

The rest of the paper is organized as follows. Related work is presented in section II. Section III discusses the architecture of the security solution, the ESLint analyser layout and its integration in SiebogJS as well as the integration of the Nodesentry library for the server-side security checks. The last section summarizes the contribution and gives future directions of our research work.

II. Related Work

Most JavaScript applications include protection mechanisms to prevent malicious code execution in the browser (client-side). JSand [9] is such a framework, which does not require additional browser modifications. It is implemented in JavaScript enforces a server-specified policy on included scripts without requiring server-side filtering or rewriting of scripts. A similar solution is Lightweight Self-Protecting JavaScript [10], which does not require modifications to the browser or any runtime parsing and transformation of code. In [10] authors introduce a method to control JavaScript execution. The idea is to modify the code such a way that can be self-protecting. The security policy is embedded into the code and intercepts security relevant API calls. The process is based on the mechanism known as reference monitoring [10].

Another approach to tackle JavaScript agent middleware security is presented in [11]. The work discusses four threat categories that depend on the flow of the communication: an agent attacking a platform, a platform attacking an agent, an agent attacking another agent and other entities attacking an agent. Each category contains a set of potential threats that can be found in each scenario. There are threats such as masquerading, denial of service, unauthorized access, repudiation, eavesdropping, alteration, copy, reply etc. There are two solutions for these threats as presented in [11]: hardware based solution and software based solution. The software-based solution is cheaper and can either protect the agent platform or protect the agents. Two techniques that use a similar idea as the Nodesentry library and ESLint are Software-Based Fault Isolation and Safe Code Interpretation [11]. Software-Based Fault Isolation is a software-based solution for detection of potential threats on an agent platform. It uses the isolation of application modules into distinct fault domains enforced by software [11]. In other words, access to untrusted code is restricted to a predefined domain. This technique is also known as sandboxing. Such an approach is similar as used by the Nodesentry library, which restricts the access of modules to other files and domains. This will be further discussed in the next section where the use of the Nodesentry library is explained in detail.

The Safe Code Interpretation is a software-based solution that is also used for detecting malicious code on agent platforms. This technique includes static type checking in the form of bytecode verification and dynamic checking that can be performed during runtime. ESLint also employs the idea of static code analysis. The benefits of this technique will be further explained in Section III. In [12], the Lightweight Coordination Calculus (LCC) is used to implement interaction models and formulate various attacks, which are categorized on open multi-agent systems (MAS). A three-layer taxonomy is suggested: the first level is a classification based on the violation against the four main security properties i.e. confidentiality, integrity, availability, and accountability; the second level are the attacks based on the novelty of the technique used to run an attack; the third level is the classification by the attacked target, e.g. sender agents, recipient agents, and transferring information. The security approach in the multi-agent security domain is divided into two parts [12]: prevention, in which encryption based techniques and authentication methods are used; detection, which tries to detect attacks on MASs and adequately respond to them. This type of prevention can be compared to the use of the ESLint that is used for static code analysis before the agent is even started in the SiebogJS agent middleware. The detection of threats and recovery from malicious code is the idea of defining policies with the Nodesentry library.

On the server side, the security problems are magnified: applications run without sandboxing and serve many clients; server processes must handle the load without interruptions for extended periods of time [8]. In [3] the authors explain the application of a security standard in JADE. JADE is a framework used for implementing distributed multi-agent systems in compliance with the FIPA specifications. No form of security is built into the JADE agent platform. The proposed platform is a single-user system, where all agents belonged to a single owner and have equal rights and permissions. The adoption of concepts from SPKI (Single Public Key Infrastructure) and trust management principles led to a model where policies are based on keys instead of names [3]. Authorization does not need certificate directories for binding names to public keys; therefore, the unavailability of such services does not have a negative impact overall system [3]. This implies that the scalability and robustness are enhanced for large and dynamic systems. In the Java environment, there is an example of a security standard for J2EE based intelligent agent frameworks [2]. The approach describes several levels of security issues in agent framework and solutions to address them: agent authorization, message, and code encryption, verification and integrity, which provides secure agent execution on hosts and offers protection from malicious agents [2].

III. Security Mechanisms in SiebogJS

This section provides a detailed description of the security enforcement mechanisms in SiebogJS. The overview of the security implementation in the SiebogJS

middleware is given in Figure 1 and it includes two essential components/agents: the Process Upload Agent and the Process Running Agent.

The Process Upload Agent

The upload manager handles and stores uploaded agent code into a predefined local folder [4]. When the upload is finished, ESLint (static code analyser) is started automatically and performs the static code analysis. Depending on the analysis result, the agent code will be kept or removed from the system. When the analysis result has warnings or errors, the agent code is removed.

The Process Running Agent

The Agent Manager [4] handles the agent's lifecycle. Every agent is an object that extends the Agent class [4] and runs in a new Node.js process. The Agent process is extended with the Nodesentry library [8] devoted to the least-privilege library integration. The specific benefits of ESLint and Nodesentry will be explained further on.

A. ESLint

ESLint [7] is a static code analyser that started as the JSHint [12] project. Since then it has been split into two individual projects: JSLint [15] and ESLint. ESLint gives the developer the ability to define own rules for static code analysis, which are implemented as standalone plugins. This is the reason why ESLint was chosen as a building block for solving specific security problems in SiebogJS. When invoked, ESLint matches the given code against existing rules. This is done before the code is being executed and the rules are specified in a configuration file. The ability to write custom rules as independent files and execute them while listing a certain code makes ESLint a good choice for the SiebogJS middleware. It also supports built-in rules, which need to be enabled just like custom made rules and can be used to perform additional checks of the code. Built-in rules check for unreachable code, confusing multiline expressions, calling on the *Object.prototype* methods on objects, which, if executed, can contribute to having a safer code.

To describe how the implementation of a rule functions, it is necessary to understand the semantics of JavaScript. Objects are constructed by calling a function that creates objects and returns them as the result of the function call. Function and objects have properties that are accessed via the “dot” notation. To search for a type of action (function) or variable, the loop through the whole tree like structure that has been obtained as result of parsing process must be created. Rules are implemented as functions that are called if certain expressions are found in the analysed code. When a matching node is discovered, rules are invoked to check whether a warning or an error code should be activated for the caught node. The default parser *Espree*, which is a part of ESLint, is used to parse Abstract syntax trees (AST) code from JavaScript code. AST [16] are data structures mostly used by the compiler and represents the structure of software program code. AST shows the result of the syntax analysis when the ESLint plugin is executed in certain code. In our middleware, it is used for syntax analysis of a JavaScript code inside NodeJS. To perform code analysis in our SiebogJS middleware it is necessary to define new customs rules: a rule for forever loops detection and a rule to determine the correct usage of the *require* keyword.

The first rule is used to detect infinite loops such as: `for ( ; ; ) {}`. In the current version of SiebogJS, the rules check for `for loops` with no control statements. Figure 1 shows an example of a rule for the detection of infinite loops.

```
create: function(context) {
  return {
    Program: function(node) {
      if (node.body !== null) {
        node.body.forEach(function (body) {
          if (body.type === 'ForStatement' &&
              body.init == null &&
              body.test == null &&
                  body.update == null) {
             context.report(node, 'Infinite
loops are not allowed');
}});}}};}
```

Figure 1. Rule for detecting infinite loops.

The second rule analyses possible occurrences of the *require* keyword in the code:

- require is a variable declaration - e.g. `var fs = require('file-system');`
- require is an expression statement - e.g. `require('file-system');`
- require is an expression statement that is in an assign expression - e.g. `require('file-system').writeFile = function() {}.`

The *require* keyword represents a built-in function and an easier way to include modules that exist in separate files. It reads a file, executes the file, and then proceeds to return the exported object. As the packages are installed with the command `npm install name_of_package`, this poses a security issue. There is no way of knowing the nature of the code that will be executed when some package is included. Each published version of the package potentially poses a threat to the system on which the code is run. The rule for the detection of the incorrect us of the *require* keyword is shown in the Figure 2.

```
create: function(context) {
return {
  Program: function(node) {
    node.body.forEach(function (body) {
      if(body.type) {
        if(body.type == 'VariableDeclaration') {
          if(body.declarations) {
           body.declarations.
             forEach(function (declartions) {
               if(declarations.init) {
                 if(declarations.init.callee) {
```

```
if(declarations.init.callee.name
                     == 'require'){
                    context.report(node,'require
not allowed'+
                    ' on line '+
declarations.loc.start.line
                    +' please use
safe_require');
          }}}});
        }} else if(body.type ==
'ExpressionStatement') {
            ...
        } else {...}});}};}
```

Figure 2. Detecting the incorrect use of the *require* keyword as a variable declaration.

The code above detects one of three cases in which the *require* keyword is found in code. In this case the *require* keyword is defined as a variable declaration, e.g. `var fs = require('file-system');`. The other two examples of the *require* keyword are:

- expression statement, e.g. `require('util');`
- assignment expression statement, e.g. `require('file-system').writeFile = function() {}`

It has to be noted that the presented approach using ESLint cannot provide complete protection from malicious code, since an attacker could obfuscate malicious code to such extent that it would not be detected by ESLint. However, our approach using ESLint can detect just basic threats and that was the main reason to introduce the Nodesentry library approach.

B. Nodesentry

Nodesentry is server-side library for handling potential malicious code [8]. It is designed to intercept potentially harmful code execution. The difference between Nodesentry and other solutions lies in the fact that Nodesentry handles malicious code in such a way that if there is a possibility of malicious code, the program does not stop working [8]. The user, or developer, has the option of defining the outcome in such cases by creating the appropriate policies.

The rest of this section will describe how the Nodesentry library has been integrated into the SiebogJS project.

Setting up Nodesentry

The Nodesentry library must be downloaded and installed locally as there are issues with the online version Nodesentry. It is recommended to download it from the GitHub repository and install it via the `npm install nodesentry` command. When installing issues might arise and usually can be solved by setting the version of the node to 0.10.0.

In the `nodesentry/res/generic_membrane.js` file, the `makeGenericMembrane` function is called when a library is required and needs 3 parameters. The third parameter represents the name of the required library and all the methods from that library. The name is the whole file path to the library that can be found in the `node_modules` directory. The membrane that must be generated needs to be the same as the call function in our project. For example, the function that is going to be handled is the `writeFile` function from the file-system module. The generic membrane needs to create a `fs.writeFile` method. That is why the `membraneName` needs to be modified. In addition, another problem can arise, as the name of the variable that represents the module in the code needs to match with the one that `membraneName` gets from the safe required one. If the library is not a one-word name, it must be modified in the `makeGenericMembrane` function. Otherwise, it is highly recommended to name the variables so that they match the safe required library name.

File access policy

An example of a file access policy is the file system access restriction. This policy does not permit writing to a local file system. If we want to implement Nodesentry policies into a project, the Nodesentry Policy object must be required and defined as a variable (in our case it is the `var Policy`). Figure 3 shows the definition of a write access policy in our agent middleware. The method `notAllowed` will be called instead of the `fs.writeFile` method. When the `file-system` library is required inside the code, the `fs.writeFile` method is invoked.

```
require("nodesentry");
var Policy = require("nodesentry").Policy;
var p = new Policy()
   .before("fs.writeFile")
   .return(notAllowed)
   .build();
function notAllowed(writeFile) {
  writeFile = function() {
      console.log("Access to local file system
is not permitted!");
  }}
```

Figure 3. An example of the write restriction policy.

The `fs.writeFile` method is the standard function for writing a file in a directory. It has three parameters: `path`, `content` and `callback`. The first parameter represents the directory and the file name in which the file will be saved. The second parameter represents the content of the file and the third one is the function that handles errors. In Figure 3, the policy has been created, and the system is ready to detect the access of the local file system during runtime. Further extensions of this rule would be restricting the `fs.writeFile` to a specific directory to which agents will have access.

By integrating the Nodesentry library into the SiebogJS middleware, it is now possible to prevent malicious agent code from executing. In this way the tampering of the host systems can be prevented (e.g. tampering with the sensitive or forbidden areas).

IV. Conclusion

We have presented the inclusion of security mechanisms into the SiebogJS agent middleware developed at the University of Novi Sad. The possibility of executing arbitrary agent code written in JavaScript, inside the potentially unsafe NodeJS system, was the main motivation for the development of the security sub-system. The employed security mechanisms include the interception of the error prone code before it is executed (using static code analysis), and handling of the potential malicious code execution during runtime without terminating the program. This approach prevents malicious code to be executed within the agent, both before and during the execution. The Nodesentry library was used to prevent an agent to execute malicious code during runtime and the ESLint library was used to support custom rule implementations for the static code analysis. These two approaches address a part of potential security threats, since they both focus on detection and prevention of malicious agent code execution. Other threats need to be addressed in future work. However, those two promising approaches present a good starting point to extend current research in the direction of defining standard security mechanisms in SiebogJS.

Our future work will be oriented towards extensions of the definition of ESLint rules and Nodesentry policies. Additionally, protection mechanisms for the communication between agents will be developed. Ultimately, the research can go into the direction of analysis of possible attack scenarios and definition of the appropriate security mechanisms.

Acknowledgment

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Enterprise architecture for public administration

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Summary - Informatization of public administration is a complex and long-term process that needs systematic approach. The aim is to reduce the costs and increase the quality of services to citizens and the economy. The current status of public administration information systems is intertwined architecture with many isolated parts that are not interconnected. Strategic guidelines at the state level are the basis for achieving the goals for all public administration bodies to work on a common IT platform, along with the linked business processes and services. The concept of enterprise architecture for public administration bodies can serve as a vision of the desired state and as an impulse for launching activities aimed at consolidating and modernizing the system. Since enterprise architecture serves as a link between business and technology, it can be the basis for linking separate business units of public administration bodies into a single system, while accelerating information sharing and raising the level of availability of the required data.

Keywords: informatization of the public administration, common platform, linked business processes, enterprise architecture, consolidation, information exchange.

I. INTRODUCTION

In the Republic of Croatia, the current status of public administration informatization has many deficiencies: inefficient cost and investment management, IT projects are implemented within individual public administration bodies without systematic coordination and use of common resources, public administration bodies are developing their own applications whose data are not shared with other public administration bodies, while at the same time the same data is contained across different applications, there are no unified business processes and the integration system of existing applications and databases.

All these problems are recognized, and the Republic of Croatia is working on building a modern public administration system which will represent a system with common business, organizational, information and communication infrastructure.

The objective of this article is to introduce an enterprise architecture for the public administration information system, that will correspond to the desired vision and can serve to launch activities aimed at consolidating and modernizing the information system of the public administration bodies. The TOGAF methodology was used as a methodological framework for the development of the enterprise architecture.

The business inputs used to create the enterprise architecture for the public administration bodies are gathered from different sources: Public Administration Development Strategy for the period 2015-2020, e-Croatia 2020 Strategy, EU eGovernment Action Plan 2016-2020.

II. PUBLIC INFORMATION INFRASTRUCTURE - LEGISLATIVE FRAMEWORK

The term public administration represents all bodies of the state administration, local and regional bodies and legal entities with public authority.

By joining the European Union and adoption of EU legislation, the Republic of Croatia has an obligation to organize work of public administration on the principles of modern public administration that will contribute to the economic and sustainable development of the Croatian society by providing public services in a reliable, predictable and socially responsible manner[1].

Emphasis is on increasing the efficiency of the public sector, through the use of Information and Communication Technologies (ICT). In order to achieve this, it is necessary to improve and better manage business processes, as well as to build public information infrastructure.

We can conclude that public information infrastructure does not exist, instead we have a sporadically informatised public administration where individual bodies are developing and publishing some of their services over the Internet. The aim is to work on a common IT platform with linked business processes and services, rather than duplication of work where each institution looks at its scope of work and consequently loses time and money to collect data and create information.

These shortcomings are recognized and further on in this document will be elaborated what has been done to establish a public information infrastructure.

At its session held on February 2, 2012, the Government of the Republic of Croatia founded a Committee for the Coordination of Public Sector Informatization with the task of directing the development and coordination of all projects in the public sector which include information and communication technology. The Committee consists of five working groups: a Working Group for Basic Registers

[1] Public Administration Development Strategy for the period 2015-2020, Official Gazette 70/2015.

and Electronic Data Exchange, Working Group for Electronic Identity and Authentication, Working Group for Standardizing Customer Access Solutions, Working Group for Defining Areas for Joint Public Procurement, and an Infrastructure Working Group.

In 2014, the Law on State Information Infrastructure was adopted, which specifies the rights, obligations and responsibilities of the public sector bodies regarding the establishment, development and management of the state information infrastructure system, the establishment and management of the system of public registers, as well as the use of a common basis for secure data exchange, a common identification and authentication system and a unique point of interaction with citizens and other users.[2]

This law defined several important things:

- Jurisdiction for the management and coordination of electronic public administration, whereby the Ministry of Public Administration takes on a key role;
- The ProDII Register is introduced, in which the data about all IT projects in public sector bodies are entered, for the purpose of coordinating and rationalizing investment in the state information infrastructure;
- A virtually unique site is established – namely the e-Citizens – and and it is defined that each e-service must be included in that virtual site;
- A Public Register is established, namely Metaregister, in order to ensure the availability of data and the existing ways of submitting/ receiving data from different public registers.

In September 2015, the Government of the Republic of Croatia adopted the Regulation on Organizational and Technical Standards for Connecting to the State Information Infrastructure (Official Gazette 103/15). The Regulation lays down organizational and technical standards for linking the state information infrastructure, conditions and activities necessary for the launching, implementation, development and supervision of projects related to the state information infrastructure, management, development and other elements necessary for the operation of the state information infrastructure.

By analyzing the activities toward establishing a state information infrastructure that have been initated in the last 5 years, it can be concluded that things have been moving forward, but in a relatively slow pace. In the following chapters some of the major projects that contributed to establishing a networked knowledge-based economy and an open information society will be explained in detail, as well as critical review to the shortcomings and unfinished activities that arise from these projects.

A. Metaregister

The Metaregister is a public register listing the registers and official records kept by the public administration bodies, as well as the ways and conditions of for the usage of the data. The purpose of the register is to provide a tool for reviewing all public registers and their data with associated connectivity methods.

There are currently 63 public registers registered in the Metaregister with different delivery methods: web (on the website of the service provider institution), data.gov.hr (the data is published in machine readable form and can be downloaded from the open data portal), a web service (the name of the service and the technology base is specified), FTP and CD. Along with some unfinished subregisters on the portal, there is no information on whether all public registers run by public administration bodies or only a part of them are covered.

Regulation on Organizational and Technical Standards for Connecting to the State Information Infrastructure prescribes the content of data in the Metaregister, along with the subregisters it must contain. In reality only a few subregisters are available, while other subregisters are unrealized idea.

The Metaregister as a semantic asset catalog provides insights into existing registers along with the data they contain and the ways of connecting, whereby the data is collected once, and it is done in electronic form. What has not been acompished with Metaregister, is the interoperability of public registers, ie the connection of each public registry with the original register. This is important for semantic mapping while ensuring that the data in a public registry contains the same semantic data as well as data from the original registry. In addition to semantic mapping, the structure of the data in the public and source registers is also important.

It can be concluded that the Metaregister represents a good platform for the establishment of electronic public services, but without the interoperability of registers and the semantic mapping of data from individual registers, the ultimate goal of increasing efficiency, cost reduction and transparency of public administration operations has not been achieved.

B. e-Citizens

The e-Citizens system consists of three parts: Central Government portal which is the public part of the system, e-Citizen Inbox and the National Identification and Authentication System (NIAS). NIAS is a unique place for verifying electronic identity for accessing electronic services. The e-Citizen Inbox allows direct access to electronic public services and the receipt of personal electronic mail from the public administration.

Some of the available electronic services are:

- electronic certificate from birth register, marriage register and citizenship register

[2] Law on State Information Infrastructure, Official Gazette 92/14

- electronic certificate of residence and ownership of vehicles
- information about the child's grades at school
- information about prescriptions raised in pharmacies over the past 6 months
- information about the chosen physician
- information on the expected amount of pension
- calculation of income tax
- electronic certificate wich confirms that a citizen is not under criminal proceedings for criminal offenses
- checking the data in the voter register and changing the voting place
- land registry certificate

Looking at the statistical indicators, we can conclude that a small number of citizens use digital services through the e-Citizens system. In relation to the overall population, only 12,6% of all citizens of the Republic of Croatia use the e-Citizens system after five years of existence.[3] This is not satisfactory if we consider that according to the data of the Croatian Central Bureau of Statistics, 76% of households in the Republic of Croatia have access to the Internet.[4] One of the reasons is surely that Croatia is one of the last EU countries on "Usability, Ease of Use and Speed of Use" eGovernment services benchmark.[5]
In conclusion, a plan for the implementation of the e-Citizens Program should be made, which will define the timeframe in which more number of citizens will be using e-Citizens system, along with defined checkpoints in order to follow the implementation of the plan.

C. Shared Service Center

The Regulation on Organizational and Technical Standards for Connecting to the Public Information Infrastructure defines the establishment of the Shared Service Center (SCC), which has the role of consolidating the public information infrastructure. Based on the regulation, APIS IT d.o.o. is a provider of services for the the public-sector bodies. According to the 2015 regulation, these services can also be provided by the Financial Agency and the Croatian Academic and Research Network CARNet.

Committee for the Coordination of Public Sector Informatization was established as a working body of the Government of the Republic of Croatia, which adopts the annual work plan and plan for development of shared services. On the Ministry's website it is evident that the last meetings of this committee date back to 2015.

Each project is entered into the Public Register for Public Information Infrastructure Projects Coordination and approved by the Commission based on the recommendation of the Ministry of Public Administration.

The Regulation states that basic operating systems, databases and specific services will be defined in the Catalog of Services, which will be published on the SCC website and the Ministry of Public Administration. It is defined that the catalog must be made within three months since adoption of the Regulation (1 January 2016). Two years have elapsed, and the official publication of the service catalog is still not available to public.

According to the Regulation, hosting services are mandatory for public sector bodies that do not have a space that meets the requirements of the TIER 3 International Datacenter Standard (dual component power supplies, dual cooling systems, multiple network connections that ensure availability of resources, guaranteed availability of 99.982%, unavailability not more than 94 minutes per year). It is not known how it is analyzed and determined which public-sector bodies meet these conditions and can therefore use their own data centers instead of data centers of SCC.

SCC should provide technical services such as infrastructure, platforms, interoperability system, e-learning platform, test platform, helpdesk platform, business intelligence system.

It should also offer business services, software solutions and platforms covering the common business functions of public sector bodies such as e-business, office operations, central public procurement, human resource management, e-archives, financial management and control, strategic planning, performance management and so on.

The new Regulation on Organization and Technical Standards for Connecting to the Public Information Infrastructure (Official Gazette 60/2017) was issued on June 23, 2017 and brings some changes to the previous Regulation. Service Provider based on the principles of the Shared Services Center for the public-sector bodies becomes the Agency for Commercial Activity d.o.o. SCC Services are established with technical infrastructure financed by public funds provided by the Ministry of Public Administration. The SCC should consolidate the public information infrastructure on the principles of shared services and establish technical infrastructure for following services: Software as a Service (SaaS), Infrastructure as a Service (IaaS), Platform as a Service (PaaS), Facility as a Service (FaaS), Consultancy as a Service (CaaS), for the needs of the public-sector bodies.

In conclusion, we can say that the concept of the SCC is good and broadly defined, only there are no measurable criteria for monitoring the dynamics of realization.

D. Public Register for Public Information Infrastructure Projects Coordination

According to the Regulation on the Organization and Technical Standards for Connecting to the Public Information Infrastructure, projects related to the Public Information Infrastructure are initiated, developed and implemented by registering in the Public Register for Public Information Infrastructure Projects Coordination.

[3] Available on https://data.gov.hr/dataset/e-gradjani-statistika
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[5] Available on https://ec.europa.eu/digital-single-market/en/news/eu-egovernment-report-2016-shows-online-public-services-improved-unevenly

The goal of establishing this Register is to rationalize, direct the development and coordinate all projects of public information infrastructure, while at the same time increasing the quality of public services and preventing the implementation of similar projects in the public sector.

From all available information on the Register, the conclusion is that the register is just a place where only some information about projects is collected, without visible strategic coordination and project management.

III. ENTERPRISE ARCHITECTURE FOR THE PUBLIC ADMINISTRATION INFORMATION SYSTEM

Enterprise Architecture (EA) is a term that appears in the 1980s and can in essence be described as a comprehensive link between business and technology.

The definition of enterprise architecture says that EA represents a comprehensive plan and strength of collaboration between aspects of business planning such as goals, vision, strategy and management principles; business aspects such as organizational structures, processes and data; aspects of automation such as information systems and databases; as well as technology infrastructure such as computers, operating systems and networks.[6]

From this definition, we can conclude that enterprise architecture is a technology-organizational concept that combines business strategy, key processes in organization and technology, linking them into one entity for the purpose of aligning IT with the business life cycle.

By analyzing the overall public sector informatization, there are some good solutions, but there is no systematic approach to investments that can reduce the costs and increase the quality of services to citizens and the economy. Public administration information systems act as isolated parts of a complex architecture. In addition, public administration bodies require many human resources for providing support to their application and infrastructure portfolios developed through operational business needs of individual bodies, rather than through strategic guidelines at the state level. Consequently, it has become difficult to control the costs due to the complexity of the system where each body develops its own IT solutions.

The Enterprise architecture of public administration bodies should strive to achieve the following goals: alignment with the business strategy defined in the Public Administration Development Strategy for the period 2015-2020, the development of a architecture that meets business requirements, the rationalization of the application portfolio by sharing functionalities among applications, standardization of technology components, designing data warehouse and business intelligence architecture, and the adoption of a plan for operational management and prioritization.

The public administration system operates in an environment that has its own limitations which need to be considered when defining the desired state. One of the most important deficiencies is that there are no defined performance indicators that would allow for high-quality monitoring of IT projects implementation. Also, there are not enough educated public administration employees who at the same time have technological competencies and understand business processes. There is no central management of the IT architecture and political decisions too often negatively affect long-term sustainable development.

A. Architecture Vision

According to TOGAF methodology, the goal of an architectural vision is to create a high-level vision that has a business value.

The business goals that architecture of public administration bodies should support are described in the Public Administration Development Strategy for the period from 2015 to 2020, highlighting the realization of the vision of modern public administration.

The architectural vision shown in Figure 1. identifies the business goals that architecture needs to support, defines business and functional requirements, and defines the key principles and technical requirements of architecture.

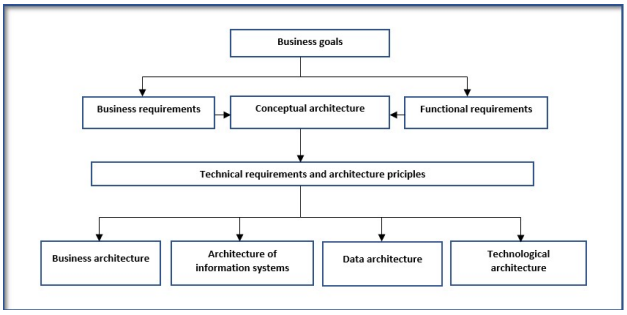

Figure 1. Architecture vision

Business requirements for the architecture include the definition of a functional and modular architectural solution that can support different business systems of public administration bodies. Using already-developed functionalities, business reporting and reducing the amount of paper documents are just some of the business requirements that aim to build a long-term, cost-effective architecture that allows the control of total cost of ownership.

Functional requirements for business process have not been thoroughly analyzed, but some common elements have been identified for all public administration bodies. Functional requirements include process automation, document management, establishment of a data warehouse system that would have the role of a repository for unique source data across different public administration bodies, enabling e-government functionality to enable citizens access to electronic services.

[6] Schekkerman J. (2009): Enterprise Architecture Good Practices Guide, How to Manage the Enterprise Architecture Practice, Trafford Publishing

B. Conceptual architecture

The vision of the conceptual architecture for public administration bodies is shown in Figure 2. conceptual architecture represents a targeted architecture for public administration bodies, which includes:

- Business architecture in the form of business models supported by business systems of public administration bodies and common business functions of public administration bodies
- The architecture of information systems that includes data distribution, security layer and business systems
- A data architecture that combines data warehouse and business intelligence
- A technological architecture that includes a technology platform such as servers, storage systems, network

The following chapters describes in detail each of the above-mentioned areas of architecture and suggest further steps that should be taken in order to build an enterprise architecture for public administration bodies.

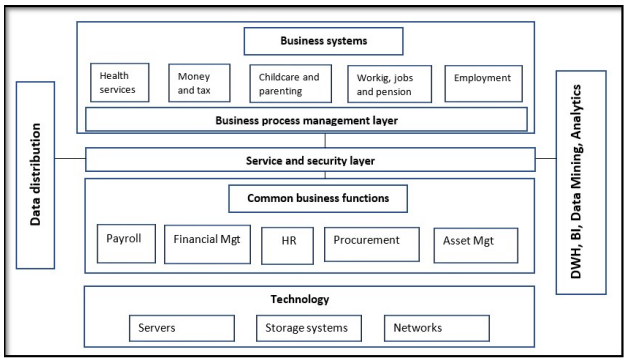

Figure 2. Conceptual architecture

C. Business Architecture

The public administration operates in a very complex environment in which there are independent and autonomous bodies. Business architecture should cover all key business processes of public administration bodies, as well as provide functionalities in order to meet business needs and support business processes.

Business process defined by architecture needs to be supported by a flexible business process management layer that allows for changes to existing processes and the introduction of new processes. There is currently no detailed diagram of all processes of public administration bodies and is out of scope of this document. However, the analysis of the processes that take place in each body and designing a detailed process diagram is an activity that should be carried out in parallel with the designing of an architecture.

Further steps to follow, in order to establish the business architecture of public administration bodies include the following:

- Analysis of the processes that take place in each body and designing a detailed process diagram
- Defining process models for key business processes of public administration bodies
- Redesigning and optimizing business processes
- Defining the prerequisites for e-Government
- Defining common business processes of public administration bodies

D. The architecture of information systems

The architecture of information systems describes the design of applications. Multilayer architecture is a suitable pattern of architectural design for public administration bodies, with separate presentation, business and data logic layer.

Service Oriented Architecture (SOA) should also be a way of designing architecture to create flexible and sustainable information systems.

From the perspective of overall architecture, public administration bodies should use a service and security layer for service exposure, event synchronization, as a business logic storage, for business process management, interoperability between services, authorization and authentication and meta data management. The service and security layer should also support reference data management to provide a unique reference point for critical data.

The architecture should incorporate Identity and Access Management (IAM) components, to ensure that actions are performed by authorized users or services.

Data warehouse and business reporting system should support the information system architecture, which includes the implementation of a data warehouse containing unchangeable historical data that is collected and processed to support business decision-making. The use of Extract, Transform, Load (ETL) tools for extraction, transformation and loading of data to enable extracting data from source systems, converting them to an application-neutral model and loading into a data warehouse. This also includes using data-marts and OLAP (Online Analytical Processing) cubes for operational reporting and using specialized tools for predictive analysis and mining.

Recommendations for establishing the architecture of information systems of public administration bodies include the following:

- Using a multi-layered SOA design to allow multiple use of individual components
- Using interoperability between applications
- The use of a common service and security layer that will be used by all information systems of public administration bodies
- Implementation of Master Data Management (MDM) functionality
- Implementation of a data warehouse and business intelligence tools
- Implementing defined standards and ensuring that application systems are aligned to these standards.

E. Data architecture

Architecture is a set of rules, standards and models that define and manage the types of data collected and how they are used, stored, organized, and integrated within the organization and the database[7].

In the scope of data architecture, the data warehouse architecture is designed, ways to establish ETL processes that are carried out when transferring data from databases or other sources to data warehouses, use of OLAP (Online Analytical Processing) tools and data mining tools, use of data marts or local data storages.

Recommendations for setting up a data architecture for public administration bodies are:

- Implement a data architecture that will support the model of central data warehouse and business reporting
- Define data management processes
- Define Master Data Management processes
- Identify data owners who are responsible for the quality of the data
- Establish policies and procedures for data access and data security.

F. Infrastructure architecture

Infrastructure architecture defines non-functional requirements for web applications, compatibility with standards, high availability, modularity of design, system security, openness of solutions, response rate, all with the aim of uninterrupted use, expandability and easier maintenance of the system.

The network environment of public administration bodies consists of a Hitronet network that serves to connect different public bodies through a common communications infrastructure. Since October 2012, all bodies receive access to an Internet connection. In addition to the above-mentioned Internet connection, the exchange of Internet traffic through CIX (Croatian Internet eXchange) was also established. According to the e-Croatia 2020 Strategy, the development of the Hitronet network should include the renewal of the technological infrastructure and the expansion of the network capacity. In addition to technological renewal, it is necessary to increase the security level by preventing hacker attacks by implementing appropriate technologies against such attacks.

A few years ago, a project for the consolidation of fiber optic infrastructure in Croatian owned companies was started, several models were considered, but to this day the project did not give any noticable results.

Recommendations for the infrastructure architecture for the public administration bodies include:

- Defining the standards to be met, as well as using the existing standards defined by the leading standardization bodies
- Web applications should be compatible with standard web browsers
- To increase modularity and openness
- To increase high availability of the system
- To increase system security
- To increase response rate
- Independence in the choice of used technology
- Consolidation of fiber optic infrastructure in Croatian owned companies in order to use the Hitronet network for public administration bodies in a cost-effective manner
- Define a plan for the integration of information systems of the public-sector bodies, so that the Shared Service Center can be fully utilized.

IV. CONCLUSION

Analyzing the legal framework of public information infrastructure in the Republic of Croatia, we can say that there is a shift in the use of electronic public services.

The e-Citizen Project has established a central government portal, a national identification and authentication system and a e-Citizen Inbox, which set the foundation for e-service development.

The shared service center, as a state cloud, is a great initiative that has not come to life in practice. The conceptual business model of Shared Service Centers that is based on the standardization and consolidation of the infrastructure, business processes and applications that support them, is aligned with the vision of enterprise architecture of the public administration based on the TOGAF methodology.

The public administration bodies are reviewed through the TOGAF framework in the above mentioned architectural areas, and further steps and recommendations are identified in each area as guidelines for the action to be taken.

All these recommendations can serve as guidelines for a strategic management and coordination of the development of public administration information systems.

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Overview of Indoor Positioning System Technologies

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Abstract - **Constant changes in the field of indoor positioning systems (IPS) dictate that we keep up with new and developing trends and technologies. With improving accuracy, IPS found widespread application in commercial environments, such as asset or personnel tracking. However, it is yet to be established in the everyday personal usage applications. In this paper, we present a technological overview and classification of the most relevant IPS technologies. We compare technologies based on their cost, accuracy, performance and complexity. Hybrid approaches are also investigated as a way to overcome limitations of specific IPS technologies. The paper is mostly focused on IPS technologies that can be used in personal applications, using pocket-sized devices (e.g. smartphone).**

Keywords – Indoor positioning systems; Location based services; Navigation

I. INTRODUCTION

Outdoor location based services, such as global navigation satellite systems (GNSS), are widely used in everyday life. In recent years, location awareness in indoor environments became a popular topic. Whether the application is asset tracking, location detection of personnel or simply finding a way around an unfamiliar building, there is a great need for indoor positioning systems (IPS).

Unlike outdoor positioning systems where 1-3 m accuracies can be achieved using satellites, IPS cannot effectively use GNSS for location detection. The main reason is signal degradation that occurs when radio signals used by GNSS hit obstacles (such as walls and roofs). This results in signal attenuation and scatter, so existing infrastructure like Global Positioning System (GPS) cannot provide sufficient accuracy [1].

In the last two decades, a great effort has been put into improvement of indoor location sensing. This resulted in commercial availability of several IPSs as well as a number of systems currently being tested and improved.

In this overview, we will focus on most relevant IPS technologies and their corresponding measuring principles, methods and algorithms, that can be implemented on pocket-size devices (e.g. smartphone). We will compare the technologies based on their cost, accuracy, performance (latency, advantages and disadvantages) and complexity (installation and usage). Since IPS technologies often have drawbacks, mostly in accuracy, we will also investigate combinations of different technologies (hybrid technologies), which help to overcome disadvantages of a single IPS.

II. MEASURING PRINCIPLES AND METHODS

Location detection can be achieved using different techniques and algorithms, which provide data in the form of signal strength or range. From the acquired data, a position estimation of an object can be calculated. In this section, we will explain measuring principles, methods and algorithms that are used in the technologies described in Section III. Note that there are other techniques which are out of scope of this overview, and are, therefore, not explained.

A. Triangulation

One of the most common techniques for location detection is triangulation. Triangulation uses geometric properties of triangles to determine distance or orientation. It can be done in two ways: lateration or angulation. Time of arrival (TOA), time difference of arrival (TDOA) and angle of arrival (AOA) are most common techniques of triangulation, but received signal strength (RSS) and return time of flight (RTOF) can sometimes also be used. With all triangulation techniques, line of sight (LOS) between transmitters and receivers is important. If LOS is not established, signal attenuation, scatter and multipath can have a great impact on accuracy.

1) Lateration

TOA uses the time t, that a signal takes to travel from a transmitter to a receiver, in order to calculate the distance between the two [2]. After obtaining the time, the distance is calculated using a simple linear motion equation:

$$d = c * t, \tag{1}$$

where c is the speed of light.

In 2-D spaces this leads to the following circle equation:

$$d = \sqrt{(x_{ref} - x)^2 + (y_{ref} - y)^2}, \tag{2}$$

where (x_{ref} , y_{ref}) are coordinates of a known reference point and (x, y) are coordinates of a target.

Having measurements from several devices, it is possible to calculate the position of a target. Say we have a target T and three reference points R_i, as shown in Fig. 1. If 2-D coordinates of each reference point R_i are known, and the distance between the target T and each of the reference points R_i is obtained, the 2-D position of the target T can be calculated. At least three reference points are needed to

determine 2-D location unambiguously. When using TOA, it is a requirement that the internal clock of each device is synchronized with other devices and that timestamps of transmissions are embedded in the signal being transmitted.

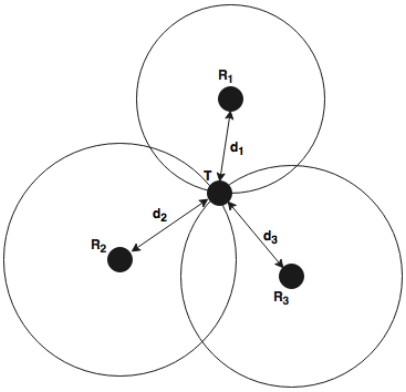

Figure 1. TOA measurements

TDOA is similar to TOA, since they both use the time a signal takes to travel a distance between a transmitter and a receiver. TDOA is a technique used to determine the difference in time at which the same signal arrives at multiple receivers [3]. This is in contrast to measuring the absolute time that a signal takes to travel between a single transmitter and a single receiver in TOA. Once the signal has been received at multiple reference points, a difference in distances between two reference points Δd can be calculated by multiplying the speed of light c and a difference in the time of arrival - Δt:

$$\Delta d = c * \Delta t. \quad (3)$$

In 2-D spaces, this leads to the following hyperbolic equation:

$$\Delta d = \sqrt{(x_i - x)^2 - (y_i - y)^2} - \sqrt{(x_j - x)^2 - (y_j - y)^2}, \quad (4)$$

where (x_i, y_i) and (x_j, y_j) are known coordinates of two reference points I and J, and (x, y) are coordinates of the target T. Once at least two hyperbolas are obtained, the target's location can be estimated, and when at least three hyperbolas are obtained, the target can be pin-pointed. Since absolute time of arrival is not used in this calculation, there is also no need for the time of transmission to be known, hence, transmitter's clock does not need to be synchronized with the receiver's clock (receiver's clock still needs to be synchronized to other receivers).

2) Angulation

AOA technique, sometimes called direction of arrival (DOA), determines the target's location by estimating the intersection of directions (angles) at which signals arrive at receiving sensors. Once the intersection is estimated, a distance between the target and the reference points can be calculated. Only two angles are needed to determine a 2-D location. Technologies implementing AOA usually use directional antennae.

B. Fingerprinting

One of the most widespread and successful techniques in indoor positioning is radio fingerprinting. It is based on a scene analysis – mapped area is analyzed and signal properties in different locations are collected and stored to a database. When a target demands position estimation, signal properties of the target's position are compared to the database and the closest match is returned as a position estimate. A received signal strength (RSS) is commonly collected during scene analysis. There are different algorithms that can be used for fingerprinting, such as neural networks, k-nearest-neighbors, support vector machine or probabilistic methods, as discussed in [4]. For this paper, the k-nearest-neighbors (kNN) is particularly interesting. The kNN uses RSS from multiple reference points, collected at the target's position, and determines the k closest reference points by comparing collected values to the database values. While it is advantageous that fingerprinting based technologies can often use existing infrastructure (such as WLAN access points), often there is a need for upgrading that infrastructure to achieve satisfactory accuracy. A disadvantage of RSS, and fingerprinting in general, is susceptibility to errors caused by radio signal scatter, multipath and attenuation.

C. Signal propagation modeling

Signal propagation modeling, also called radio propagation modeling, is a technique that provides an alternative to the empirical method of fingerprinting. With this technique, mathematical signal propagation models are made, and theoretically-computed signal strength data set is created. User's location can then be estimated by matching the signal strength measured in real-time with the theoretically-computed signal strengths.

Most common models are Ricean and Rayleig fading models. Ricean fading model is used in cases where dominant multipath component can be determined, and Rayleig fading model is used in cases where dominant multipath component cannot be determined.

D. Dead reckoning

Dead reckoning is one of the oldest positioning techniques. It relies upon estimation of the current position based on a previously known position and estimated movement distance and direction (heading). Distance and direction are usually estimated using inertial sensor (gyroscope, accelerometer, and compass) measurements. Dead reckoning techniques are rarely used as the only technique in an IPS, since small errors in direction estimation can result in larger error in position estimation.

To improve accuracy and reduce errors, particle filtering (PF) was introduced [5]. PF uses impassable obstacles (e.g. walls and furniture) to eliminate positions in which a target could not have possibly been located. PF is a numerical approximation to a Bayesian filter [6]. Bayesian filter uses probability distribution for the location estimate, and PF represents the probability ($Bel(x_t)$) using a set of weighted samples ($\{x_t^i, w_t^i\}$):

$$Bel(x_t) = \{x_t^i, w_t^i\}, i = 1 \dots n, \quad (5)$$

where (x_t^i) is a discrete hypothesis of object's location, and (w_t^i) is a weight representing importance factor which sums up to one. In each iteration, PF updates each weighted sample using motion model, weighs all samples by sensor's likelihood model (for the current measurement), and resamples (using importance factor).

E. Proximity

Proximity location technique provides information on the location of a target with respect to a known position in an area. It doesn't necessarily provide absolute location of an object, but a relative approximate of the location. When the target is detected at a reference point, it is considered to be in proximity of that reference point. The Approximation accuracy of the target's location depends on number and sensitivity of detectors.

F. Cooperative positioning

Cooperative positioning is an approach which allows users of a positioning system to be connected in a peer-to-peer (P2P) network where they can share their position information and receive position information from their peers. Using information acquired from peers in their vicinity, users can estimate, or improve accuracy and reliability of their position.

Social-Loc is a middleware that can be installed to improve accuracy of a system by using cooperative positioning. It has been implemented and tested with Wi-Fi fingerprinting and dead reckoning systems (separately) [9], both on Android smartphone. Authors report improved accuracy by at least 22% (for Wi-Fi) and 37% (for dead reckoning). System works in such a way that users, upon encountering each other, scan their respective positions (via RFID), compare them and do the corrections if necessary.

III. INDOOR POSITIONING TECHNOLOGIES

A. Wireless local area network

Wireless local area network (WLAN) technology is used for wireless exchange of data in computer networks, in a limited distance of 20-100 m from access points. WLANs are based on IEEE 802.11 standards (Wi-Fi brand name). They operate in 2.4 or 5 GHz frequency bands and can achieve throughput in excess of 1Gbit/s. Indoor positioning systems relying on WLAN technology use multiple WLAN access points to determine the target's position in an area. In order to improve accuracy, additional access points must often be added to the existing network. Most common techniques for IPS implemented with WLANs are fingerprinting and signal propagation modeling.

One of the first WLAN indoor positioning systems was RADAR [8], which used two techniques to determine location: fingerprinting, i.e. measurement of signal strength for each access point, and signal propagation modeling. To improve the system's accuracy, wall attenuation and floor attenuation factors are used (in contrast to Rayleigh fading model and Rician distribution model which are used in outdoor positioning systems). RADAR managed to achieve accuracy of around 2-3 m and could be used by multiple tracked devices at the same time.

Ekahau positioning system [9] is one of the most popular commercial systems that uses existing WLAN infrastructure (APs). The system consists of APs, tags and mapping and calibration software (site survey). Tags are worn by users or attached to objects and they transmit Wi-Fi signals periodically, when the tracked object moves, or when the specific button is pressed. When the signal is detected on different APs, received signal strength indicator (RSSI) values are used to triangulate target's 2-D location. The reported accuracy is 1-3 m. During mapping and calibration, the site survey software detects network coverage area, overlapping of WLAN APs, signal strength and SNR. Ekahau system is a low-cost system and it is simple to use with multiple tags.

B. Radio-frequency identification

Radio-frequency identification (RFID) is a technology that uses radio waves to store and retrieve data between a reader and a tag. RFID readers are able to read data emitted from RFID tags. RFID is a cheap and flexible wireless technology that already found widespread usage in identification of objects (inventory, personnel, animals etc.), but it can also be used to determine position of an object in a mapped area. There are two types of RFID technologies. One is the passive RFID where the tracked tag is a receiver. The working range of passive RFID systems is short (1-2 m). They work in several frequency bands (usually LF: 125-134 kHz, HF and NFC: 13.56 MHz, UHF: 865-960 MHz) and their price is low. The tag modulates and reflects a signal back to the transmitter and does not require a power source for its operation. The other RFID type is active RFID, where tracked device is a transmitter. Active RFID systems can cover longer distances (10-100 m) and usually operate in the 433 MHz or 915 MHz frequency bands. Their price is higher than the price of passive RFIDs. The device acts as a 'beacon' and periodically transmits signals containing ID, or some other data, to readers. RFID usually uses proximity techniques to detect weather a target is in range of a reference point.

LANDMARC (Indoor Location Sensing Using Active RFID) [10] was a pioneering system that used RFID to determine location indoors. The system used active RFID tags, attached to the tracked objects, and multiple readers placed in fixed locations. Except the tags for tracked objects, the system also introduced reference tags in order to improve calibration accuracy. Signal strength from each tag was measured at readers and kNN method was used to calculate the location of target's RFID. In a 40 m^2 room, with 4 receivers and 16 reference tags, accuracy of the system was 1 m for 50th percentile and maximum error distances were less than 2 m. Battery life of a tag was 3-5 years. Downside of the system was that it took a long time to estimate target's location (7.5 s in a system of 500 tags) because additional processing of signal was needed to calculate signal strength - RFID receivers only reported if a tag is "detectable" or "not detectable" and did not give any information on signal strength.

C. Ultrasonic

Ultrasonic positioning systems use sound frequencies above the upper audible limit of human hearing (usually around 40 kHz). Such systems determine target's position by measuring the time needed for a signal to travel from a

Figure 2. Active Bat Tag

transmitter to receivers. Audible sound IPSs work on similar principles but ultrasonic systems are more convenient since they are not intrusive to people who are using (or are surrounded by) the system. A disadvantage of the technology is that new infrastructure, in form of sensors and transmitters, is needed in every room where the system is used.

Active Bat positioning system [11] gives 3D position of the tracked tag, Fig. 2. Tag broadcasts ultrasonic signals which are received by receivers (microphones) mounted on a room ceiling. A position is calculated using triangulation technique by measuring signal's TOA. To calculate the 3D position, at least 3 receivers need to receive target's signal. In an area of 1000 m^2 with 750 receivers, accuracy is 3 cm for 95th percentile and each tag can be located 50 times per second. Tags have battery life of about 15 months.

Lok8 [12] is an indoor positioning system for smartphones that uses off-the-shelf smartphone speaker to produce ultrasound signals (around 22 kHz). The system uses TDOA, hence no need for synchronization of clocks on system devices is needed, making it even more simple to use. It was tested in 49 m^2 room with 4 receivers (one in each corner of the room) and accuracy is 10 cm on average.

D. Bluetooth

Bluetooth technology is used to transfer data over short distances (10-100m, with Bluetooth 2.0). It is defined in IEEE 802.15.1 as a form of a Wireless personal area network (WPAN) and works in 2.4 GHz frequency band with data transfer rates of 1-3 Mbit/s. The main purpose of the Bluetooth technology is to create a simple wireless communication that doesn't require LOS. Because of Bluetooth's low price and complexity, today, this technology is present in most smartphones and wireless computer peripherals.

Topaz local positioning system [13] utilizes Bluetooth technology to locate targets indoors. The initial system could only provide 2-D location, with accuracy around 2 m for 95th percentile, but later it was enhanced with usage of IR technology to improve accuracy. Locating delay is 15-30 s. System consists of a positioning server, wireless access points placed every 2-15 m, and tags worn by targets.

iBeacon by Apple [14] is a technology standard that uses Bluetooth Low Energy (BLE) for proximity measuring. One of iBeacon's purposes is to enable users to locate products in stores by telling them proximity to the wanted item or a shelf. The system can also be used for indoor positioning by distributing beacons on predetermined fixed points in an area and then triangulating position with usage of multiple proximity measurements. Beacons transmit signals, while an application installed on portable devices determine proximity of each beacon: immediate (less than 50cm), near (between 50 cm and 3 m) and far (3-30 m). iBeacon applications are available on both Android and iOS.

E. Inertial

Inertial sensors, such as accelerometers and gyroscopes, in combination with other sensors (e.g. compass) can be used to determine a target's speed and direction. When speed and direction are obtained, having knowledge of initial position, we can estimate the future position – dead reckoning technique. An advantage of this technology is that most modern smartphones have all the sensors necessary for dead reckoning. A disadvantage is the accumulation of errors in cases where small deviations in calculation of direction can cause large errors in estimation of position as long distances are traveled. To reduce the error accumulation, a lot of dead reckoning based IPSs also use particle filtering (PF) algorithms. Inertial technology IPSs are usually used in combination with some other technologies (i.e. WLAN, Bluetooth, RF).

Beauregard et al. [15] proposed a pedestrian dead reckoning (PDR) system with inertial technology and backtracking particle filter (BPF). BPF introduces improvement in comparison to regular PF in sense that it enables deletion of previous impossible particles and trajectories when target meets an impassable barrier, which can be seen in Fig. 3. Beauregard et al. report accuracy of 2.5 m when only an external map of walls is available and 0.74 m when a detailed map of walls is available. In their experiments, a motion sensor was attached to one shoe of a subject who walked in a 60m by 60m multi-story building. Advantage of this system is that it can be used to record movements and trajectories of a target even if the map is not available at the moment of recording. This feature is very useful for first responders (e.g. firefighters) as their movement can be recorded during intervention at an unmapped location, and the map can be added afterwards.

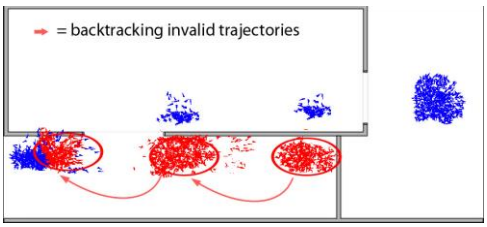

Figure 3. BPF example [15]

Figure 4. Ubisense Tags (www.inition.co.uk/)

F. *Ultra-wideband*

Ultra-wideband (UWB) is a technology where electromagnetic waves are emitted in short pulses (less than 1 ns) and in a wide frequency band (>500 MHz), which makes it possible to filter reflected signals from the original signal, hence minimizing the multipath problem and improving the accuracy of TOA. Unlike other RF based technologies, UWB transmits signals in multiple frequency bands (from 3.1 to 10.6 GHz) simultaneously. Besides high accuracy, low power requirements made this technology commercially successful in environments with pervasive usage of IPSs (e.g. warehouses). A disadvantage is a costly equipment and installation.

Ubisense company made UWB indoor positioning system [16], which consists of sensors distributed across a mapped area and tags (Fig 4.) attached to the objects being tracked. The tags have both UWB transmitter (for location) and radio transceiver for communication with network. The system uses TDOA and AOA of the UWB signal to calculate target's location. Tag's signal needs to be received by two sensors in order to calculate a 3D location of a tag. The accuracy is about 15 cm. Disadvantages of the system are that it is costly and, when used to locate people, users location is known to the system at any time.

G. *Hybrid technologies*

Recently, most promising results in indoor positioning were achieved with hybrid IPSs, which use multiple technologies to overcome the disadvantages of any individual technology. With many combinations possible, in this article we are going to cover only some promising combinations that can be implemented in pocket-sized and affordable devices.

Leppäkoski et al. [17] proposed a hybrid system with inertial sensors, particle filtering and WLAN RSS. Inertial sensors composed of a gyro sensor and a three-axis accelerometer attached to users back, along with WLAN signal strengths, were scanned every 2.3 s with a handset WLAN device, during a 17-minute walk in a 1000 m^2 area. They reported accuracy of 3 m in distance (and 12° in heading), in contrast to inertial only PDR system where accuracy was 5 m (and 24° in heading). The advantage of the system is that it is cheap and it can be implemented with a smartphone.

Cricket [18] is an ultrasound and RF indoor positioning system which works similar to the Active Bat system, but in this case, emitters are mounted to the fixed points, and a receiver is carried by the target. Cricket also uses TOA and triangulation technique to locate a target. Emitters transmit RF messages that are used to synchronize TOA measurements and give out approximate location (of the emitter) in cases when there is not enough emitters for triangulation. Reported accuracy is around 10 cm. Advantages of the Cricket system is that the receiver being carried by the target provides more privacy to the user (target) and the system is low cost ($10 per receiver). On the other hand, since Cricket uses both ultrasound and RF, it is power consuming.

Table I. Han Zou et al. experiment accuracies [19]

Approach	**Mean Error**
Dead Reckoning (DR)	2.732 m
WiFi fingerprinting	1.968 m
DR + WiFi	1.480 m
DR + WiFi + iBeacon	0.594 m

Han Zou et al. [19] built a smartphone system that utilized inertial sensors, WiFi signal strength and iBeacon (Bluetooth technology). They made tests and compared accuracies of different technologies and their combinations. Results are shown in Table I. The tests were performed in a 600 m^2 multifunctional office using Google Nexus 6 smartphone. During the tests with iBeacons, six beacons were installed in the same office room. The advantage of the system is that it works on a smartphone.

IV. TECHNOLOGIES COMPARISON

Comparison of technologies we described can be seen in Table II. In the *Cost* column, we describe the cost of installation (which includes equipment and labor, if required) and the cost of each user unit. The performance is described in columns *Advantages* and *Disadvantages*. The Complexity describes total complexity of installation and usage of the system.

V. CONCLUSION

In this paper, we provide an overview and compare the most relevant indoor positioning technologies that had been developed over the recent years and can be incorporated in pocket-size devices. We describe the underlying technologies and techniques, and give leading examples in each one of them. Each IPS architecture and working principle is discussed, investigating their advantages and disadvantages, complexity, accuracy, and cost. For deployments, most interesting parameters are accuracy and complexity. Sub-meter accuracies had been achieved in multiple systems using ultrasound, ultra-wideband, Bluetooth and hybrid technologies, but not all of them are fit for everyday usage by an average person since most of them are too expensive and too complex to be implemented in most indoor areas.

We show that each system has its limitations and strengths. Some of the described systems could be

Table II Comparison of IPS technologies

IPS	Technology	Accuracy	Cost (installation/ unit)	Advantages	Disadvantages	Complexity
RADAR	WiFi	2-3 m	L/L	Low price, existing infrastructure	Low accuracy, complex system	Medium
Ekahau	WiFi	1-3 m	H/L	Existing infrastructure, good mapping software	Expensive mapping software	Low
LANDMARC	RFID	2 m	H/L	Very cheap user units	Locating delay 7.5 s	Medium
Active Bat	Ultrasound	3 cm	H/L	Cheap user units, very precise	Requires a lot of beacons, medium battery life	High
Lok8	Ultrasound	10 cm	L/L	Smartphone user units, precise	Requires new infrastructure in every room	Medium
Topaz	Bluetooth	2 m	L/L	Low price	Locating delay 15-30 s	Medium
iBeacon	Bluetooth	0.5-3 m	H/L	Smartphone user units, ease of access	Requires a lot of beacons for better precision	Low
Beauregard et al.	Inertial	0.74-2.5 m	L/L	Cheap, map can be added post-hoc	Requires a detailed map for better precision	Medium
Ubisense	Ultra-wideband	15 cm	H/H	Very precise, very robust	Expensive installation and units	High
Leppäkoski et al.	Inertial +WiFi	3 m	L/L	Cheap, could work on smartphone	Low accuracy, time consuming installation	Medium
Cricket	Ultrasound + RF	10 cm	H/L	Cheap user units, provides privacy, precise	complex installation, low battery life	High
Han Zou et al.	Inertial +WiFi +Bluetooth	0.59 m	L/L	Cheap, precise	Requires detailed mapping	Medium

combined into hybrid systems, to improve accuracy and overcome their limitations. Smartphones are also a promising land for hybrid systems, since modern smartphones already include most of the necessary sensors that can be used for location sensing.

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Simulating the Error-Detecting Capability of the Error-Detecting Code

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***Abstract* - Using simulations, we analyze an error-detecting code from the aspect of the number of errors that the code surely detects. In order to conclude whether and how the order of the quasigroup used for coding affects the number of errors that the code surely detects, we use quasigroups of different orders for coding. Also, we code input blocks of different lengths in order to conclude whether the number of errors that the code surely detects depends on the length of the input block, i.e., the length of the code word.**

Keywords - error-detecting code; linear quasigroup; noise channel; binary symmetric channel; code word

I. INTRODUCTION

In this paper we consider an error-detecting code based on linear quasigroups ([1]). The probability of undetected errors for the analyzed code, i.e., the probability that there will be errors in the input block that the code will not detect is obtained in [1] and [2]. But, for every error-detecting code an important parameter is the maximum number of incorrectly transmitted bits to which the code detects the error for sure. In this paper, using simulations, we obtain this parameter. Namely, using simulations we obtain the number of code words that have j incorrectly transmitted bits and the number of code words that have j incorrectly transmitted bits, but the errors are not detected, where j runs from 1 to the length of the code words. Using these two values we calculate the percentage of detected incorrectly transmitted code words in which j bits are incorrectly transmitted, for every j from 1 to the length of the code word. We obtain these results for different values of the length of the code words and different values of the probability of bit-error in the binary symmetric channel. We consider the case when linear quasigroup of order 4 is used for coding, but also the case when linear quasigroup of order 8 is used for coding.

II. THE ERROR-DETECTING CODE

Since the code is defined using linear quasigroups in what follows we give the definition of this algebraic structure.

Definition 1: Quasigroup is algebraic structure $(Q,*)$ such that

$$(\forall\, u, v\in Q)(\exists!\, x, y\in Q)(x*u=v\wedge u*y=v) \qquad (1)$$

Definition 2: The quasigroup $(Q,*)$ of order 2^q is linear if there are non-singular binary matrices A and B of order $q\times q$ and a binary matrix C of order $1\times q$, such that

$$(\forall x, y\in Q)\; x*y=z \Leftrightarrow \boldsymbol{z}=\boldsymbol{x}A+\boldsymbol{y}B+C \qquad (2)$$

where $\boldsymbol{x}$, $\boldsymbol{y}$ and $\boldsymbol{z}$ are binary representations of x, y and z as vectors of order $1\times q$ and + is a binary addition.

When we say that $(Q,*)$ is a quasigroups of order 2^q, then we take $Q=\{0, 1, 2,\ldots, 2^q-1\}$.

Due to the Definition 2, linear quasigroups instead to be presented with the quasigroup operation * can be presented with a binary matrices A, B and C. We will do so in the future in this paper. Also, elements from the linear quasigroup Q of order 2^q will be presented as a binary vectors of length q.

Let the linear quasigroup Q of order 2^q is used for coding and let the input block be $a_1a_2\ldots a_n$, where $a_i\in Q$, $i=1, 2, \ldots, n$. Let A, B and C be the matrices that satisfy (2) and let $\boldsymbol{a_i}$ be the binary representation of the character a_i as a vector of length q, for $i=1, 2, \ldots, n$. The redundant characters are calculated using the following equation:

$$\boldsymbol{d_i}=\boldsymbol{a_i}A+\boldsymbol{a_{i+1}}B+C,\; i=1, 2, \ldots, n \qquad (3)$$

where all operations in indexes are modulo n and + is a binary addition.

Now, the extended block $\boldsymbol{a_1a_2\ldots a_nd_1d_2\ldots d_n}$ is the code word that is transmitted through the binary symmetric channel. Since there are noises in the channel some of the characters may not be correctly transmitted. In order to check if there are errors in transmission, the receiver checks if the output block satisfies (3) for all $i\in\{1, 2, \ldots, n\}$. If for some i, (3) is not satisfied, the receiver concludes that there are errors in transmission and it asks the sender to send the block once again. Since the redundant characters are also transmitted through the channel, noises affect them also. Therefore, it is possible (3) to be satisfied for all $i\in\{1, 2, \ldots, n\}$ although some of the characters are incorrectly transmitted. This means that it is possible to have undetected errors in transmission. In this paper we will be focused on the maximum number of incorrectly transmitted bits in a code word to which the error will be detected for sure.

III. THE ERROR-DETECTING CAPABILITY

We will consider the case when linear quasigroup of order 4 is used for coding and the case when linear quasigroup of order 8 is used for coding. Also, we will consider several values for the length of the code words and several values for the probability of bit-error p in the binary symmetric channel. From the obtained results we will conclude whether and how the order of the

quasigroup and the length of the code words affect the number of errors that the code surely. First, we will explain the simulation process.

A. The simulation process

In this subsection we will give short description on the process of simulation. For given n and j, the percentage of detected incorrectly transmitted code words of length n bits with j incorrectly transmitted bits, transmitted through a binary symmetric channel with a probability of bit-error p is obtained in the following way:

We use quasigroup Q of order 2^q for coding. First, we generate a long input message, for example around 2000000 characters from the alphabet Q. Then, this message is separated into blocks with length $n/(2q)$ and each block is coded separately. The length of the generated input message is chosen so that it is divisible by $n/(2q)$. After that, this coded message, which contains all the coded blocks, is turned into binary form. Since the rate of the code is ½, each coded block, i.e., each code word will have $2n/(2q)=n/q$ characters from the quasigroup Q. The binary representation of each character from the quasigroup Q contains q bits, from where follows that the code words have length $q \cdot n/q=n$ bits. We generate the noise in the binary symmetric channel, which is a binary string with length equal to the length of the coded input message turned into binary form. The noise string is generated such that the probability of occurrence of 1 in this string is p. The positions in the noise string to which there is 1 are the positions on the coded input message in a binary form that are incorrectly transmitted. The output message is calculated with simply adding per modulo 2 the coded input message in a binary form and the noise string. Now, from the noise string, for every $j \in \{1, 2, \ldots, n\}$, we count the number of incorrectly transmitted code words with j incorrectly transmitted bits and using the output message we obtain the number of incorrectly transmitted code words with j incorrectly transmitted bits in which the error is not detected. The percentage of undetected incorrectly transmitted code words with j incorrectly transmitted bits is calculated by simply dividing this two numbers and multiplying the result by 100%. To obtain the percentage of detected incorrectly transmitted code words with j incorrectly transmitted, we subtract this percentage from 100%.

The accuracy of the simulation procedure depends on the length of the generated input message. A larger length of the message implies greater accuracy. Since the goal is to obtain the number of errors that the code surely detects, in order to have higher accuracy, we need to have large number of incorrectly transmitted code words with small number of incorrectly transmitted bits. For that reason, first we chose the probability of bit-error p in the channel to have small value (i.e., 0.05, 0.07 and 0.09) and we generated messages with length of approximately 2000000 characters from the quasigroup since in this case the obtained results from the simulation showed that the number of incorrectly transmitted blocks whit j incorrectly transmitted bits mostly is of order 10^4, for small values of j. On the other hand, the number of such code words in which the error is not detected mostly is of order 10^0 and sometimes 10^1. This means that the precision in the quotient of the number of undetected incorrectly transmitted code words with j incorrectly transmitted bits and the number of incorrectly transmitted code words with j incorrectly transmitted bits mostly is of order 10^{-4}, i.e., up to the fourth decimal and sometimes is 10^{-3}, i.e., up to the third decimal. Therefore, when the number of incorrectly transmitted bits j is small number, the precision of the percentage of detected incorrectly transmitted code words with j incorrectly transmitted bits mostly is up to the second decimal and in some rare cases up to the first decimal. When the quasigroup of order 4 is used for coding, we are interested to see what happens when there are more incorrectly transmitted bits in a code word. For that reason, to obtain the same accuracy as previously, we need to obtain larger number of incorrectly transmitted code words with more incorrectly transmitted bits. Therefore, we chose larger values of the probability of bit-error p in the channel (i.e., 0.15 and 0.2), which ensures sufficient accuracy of the results.

The focus of the paper is in the number of errors that the code surely detects, which means that for every j we are interested whether the code detects all incorrectly transmitted code words with j incorrectly transmitted bits or some of them pass undetected. This means that we are interested only whether the percentage of detected incorrectly transmitted code words with a given number of incorrectly transmitted bits is 100% or it is not 100%. For all above, the obtained accuracy is more than sufficient.

B. Linear quasigroup of order 4 is used for coding

In what follows, we will represent the linear quasigroups used for coding by their binary matrices that satisfy (2). The matrices will be presented as a list of lists, i.e., the matrix is a list in which the first list is the first row, the second list is the second row of the matrix etc.

We use the following linear quasigroup of order 4 for coding:

$$A=\{\{0, 1\}, \{1, 1\}\}, B=\{\{1, 1\}, \{1, 0\}\}, C=\{\{0, 0\}\} \quad (4)$$

First, in the next example we will illustrate the coding, transmitting and simulation procedure when for coding is used the linear quasigroup given in (4)

Example 1: Let for coding be used the linear quasigroup given in (4). In practice the generated input message is long a few million characters, but for this example we will take small input message with length 15 characters from the quasigroup Q and the code words will have length $n=20$ bits. Let the input message be 230122100132131. First, we divide the input message into blocks of length $n/(2q)=20/(2 \cdot 2)=5$ characters and we code each block separately. The first block is $a_1a_2a_3a_4a_5$=23012, which turned into binary form is $\boldsymbol{a_1a_2a_3a_4a_5}$=1011000110. Now, using (3) we code this block:

$$\boldsymbol{d_1}=\boldsymbol{a_1}A+\boldsymbol{a_2}B+C=[1\ 0]A+[1\ 1]B+C=[0\ 0]$$
$$\boldsymbol{d_2}=\boldsymbol{a_2}A+\boldsymbol{a_3}B+C=[1\ 1]A+[0\ 0]B+C=[1\ 0]$$
$$\boldsymbol{d_3}=\boldsymbol{a_3}A+\boldsymbol{a_4}B+C=[0\ 0]A+[0\ 1]B+C=[1\ 0]$$
$$\boldsymbol{d_4}=\boldsymbol{a_4}A+\boldsymbol{a_5}B+C=[0\ 1]A+[1\ 0]B+C=[0\ 0]$$
$$\boldsymbol{d_5}=\boldsymbol{a_5}A+\boldsymbol{a_1}B+C=[1\ 0]A+[1\ 0]B+C=[1\ 0]$$

The coded block, i.e., the code word is $cw_1=\boldsymbol{a_1a_2a_3a_4a_5d_1d_2d_3d_4d_5}$=10110001100010100010. In a same manner we code the other two blocks 21001 and

32131 whit what we obtain the code words cw_2=1001000 0011111001000 and cw_3=11100111010111100010 respectively. The coded input message is obtained by concatenation of the three codewords: $cw_1cw_2cw_3$=10110 0011000101000101001000001111100100011100111010 111100010. Now, the noise, which is a binary string with length equal to the length of coded input message $cw_1cw_2cw_3$, is generated. To generate this string, we need the probability of bit-error in the binary symmetric channel. Let say that it is p=0.1. The noise string is a string in which on each position the probability of occurrence of 1 is p, while the probability of occurrence of 0 is 1-p. In order to generate such string, for each position a random number in the interval (0, 1) is generated. If this number is smaller than p, the element on that position is 1, otherwise it is 0. Let the generated noise string be: ns=00101100000010000000000001000000 10000000000000000000000000000000. The output message is calculated as a sum modulo 2 of the coded input message and the noise string, i.e., the output message is $ou=cw_1cw_2cw_3+ns$=10110001100010100010100 0100000111110010001110011101011110001 0+0010110 0000010000000000100000010000000000000000000000 0000000=10011101100000100010100000000101110010 0011100111010111100010. This is the message that the receiver receives. The message contains three blocks: 10011101100000100010, 10000000010111001000 and 11100111010111100010. From the noise string, we can see which code words are incorrectly transmitted and how many bits are incorrectly transmitted. Namely, first 20 bits represent the errors in the first code word, etc. If there is 1 on some position the corresponding bit from the code word is incorrectly transmitted, otherwise it is correctly transmitted. Therefore, if there is at least one 1 in the noise string, the code word is incorrectly transmitted. In this way we conclude that the first and the second code words are incorrectly transmitted, while the third code word is correctly transmitted. Since in the noise string for the first code word there are four 1's, we conclude that there are four incorrectly transmitted bits in the first code word. In a same manner we conclude that there are two incorrectly bits in the second code word. For each incorrectly transmitted code word, in order to check whether the code will detect the errors in transmission, we check whether the output block satisfies (3). The output block that corresponds to the first code word is 10011101100000100010. If the code word is correctly transmitted, the first 10 bits are the information bits, while the last 10 bits are the redundant bits. Now, we check whether the last 10 bits 0000100010 are the redundant bits for the first 10 bits 1001110110:

$$\boldsymbol{a_1}'A+\boldsymbol{a_2}'B+C=[1\ 0]A+[0\ 1]B+C=[1\ 1]\neq[0\ 0]=\boldsymbol{d_1}'$$

We see that (3) is not satisfied for i=1, which means that the code will detect the error in transmission of the first code word. In the same way we conclude that the code will detect errors in transmission of the second code word.

But, if the noise string is 00101100001100100000000 00000000000000000000000000000000000000, then there is one code word with six incorrectly transmitted bits (the first code word), while the other two code words are correctly transmitted (the output is 100111011011100000 10100100000111110010001110011101011110010). Now, we can check that the code will not detect the error in transmission. Namely, the output block for the first code word is $\boldsymbol{a_1}'\boldsymbol{a_2}'\boldsymbol{a_3}'\boldsymbol{a_4}'\boldsymbol{a_5}'\boldsymbol{d_1}'\boldsymbol{d_2}'\boldsymbol{d_3}'\boldsymbol{d_4}'\boldsymbol{d_5}'$=10011101101 110000010. We check whether (3) is satisfied:

$$\boldsymbol{a_1}'A+\boldsymbol{a_2}'B+C=[1\ 0]A+[0\ 1]B+C=[1\ 1]=\boldsymbol{d_1}'$$
$$\boldsymbol{a_2}'A+\boldsymbol{a_3}'B+C=[0\ 1]A+[1\ 1]B+C=[1\ 0]=\boldsymbol{d_2}'$$
$$\boldsymbol{a_3}'A+\boldsymbol{a_4}'B+C=[1\ 1]A+[0\ 1]B+C=[0\ 0]=\boldsymbol{d_3}'$$
$$\boldsymbol{a_4}'A+\boldsymbol{a_5}'B+C=[0\ 1]A+[1\ 0]B+C=[0\ 0]=\boldsymbol{d_4}'$$
$$\boldsymbol{a_5}'A+\boldsymbol{a_1}'B+C=[1\ 0]A+[1\ 0]B+C=[1\ 0]=\boldsymbol{d_5}'$$

We see that (3) is satisfied for all $i\in\{1, 2, 3, 4, 5\}$, which means that the code will not detect the error in transmission in the first code word.

Since we want to obtain the maximum number of incorrectly transmitted bits to which the code detects the error for sure, first we want to have large number of incorrectly transmitted code words with small number of incorrectly transmitted bits. For that reason, we choose small values for the probability of bit-error. We made simulations for three different values of the probability of bit-error in the binary symmetric channel, i.e., p=0.05, p=0.07 and p=0.09. When the information block has length m characters from the quasigroup, then the coded block has length 2m. Since every character from the quasigroup of order 4 is represented with 2 bits, follows that the code words have length 4m, $m\geq2$. We coded input blocks of length 4m characters, where $2\leq m\leq16$, which means that the code words have length n from 8 bits to 64 bits with step 4 bits, i.e., $n\in\{4m|\ 2\leq m\leq16\}$. The obtained results when the values of the probability of bit-error p is 0.05, 0.07 and 0.09 are given in Table I, Table II and Table III, respectively. In the tables are given the percentages of detected incorrectly transmitted code words of length n bits when j bits are incorrectly transmitted, $j\in\{1, 2, \ldots, n\}$. As we can see, the code surely detects up to 3 incorrectly transmitted bits, regardless of the length of the code word. Also, we can notice that for j=4, the percentage of detected errors increases when the length of the code words increases. For these small values of the probability of bit-error p, the number of code words with larger number of incorrectly transmitted bits is small and the code detects all such incorrectly transmitted code words. Therefore, the percentages of detected incorrectly transmitted code words with larger number of incorrectly transmitted bits in Table I, Table II and Table III are 100%. The empty fields in the tables indicates that there are no incorrectly transmitted code words with the corresponding length and number of incorrectly transmitted bits.

To see what happens when the number of code words with larger number of incorrectly transmitted bits is greater, we increase the probability of bit-error in the binary symmetric channel. In Table IV and Table V are given the percentages of detected errors when the probability of bit-error p is 0.15 and 0.2. Since in these cases the probability of bit-error is higher, there are more incorrectly transmitted bits. From the tables we can see that the code detects errors in transmission whenever odd

number of bits are incorrectly transmitted. For given j, increasing the length of the code words n generally results with increased percentage of detected incorrectly transmitted code words with j incorrectly transmitted bits.

TABLE I. PERCENTAGES OF DETECTED INCORRECTLY TRANSMITTED CODE WORDS OF LENGTH N BITS WITH J INCORRECTLY TRANSMITTED BITS WHEN LINEAR QUASIGROUP OF ORDER 4 IS USED FOR CODING AND THE PROBABILITY OF BIT-ERROR IS P=0.05

	j									
n	1	2	3	4	5	6	7	8	9	10
8	100%	100%	100%	75,3463%	100%					
12	100%	100%	100%	97,4871%	100%	100%				
16	100%	100%	100%	99,1865%	100%	100%	100%			
20	100%	100%	100%	99,5680%	100%	100%	100%	100%		
24	100%	100%	100%	99,8111%	100%	100%	100%	100%		
28	100%	100%	100%	99,8957%	100%	100%	100%	100%		
32	100%	100%	100%	99,8478%	100%	100%	100%	100%	100%	100%
36	100%	100%	100%	99,9360%	100%	100%	100%	100%	100%	100%
40	100%	100%	100%	99,9544%	100%	100%	100%	100%	100%	100%
44	100%	100%	100%	99,9689%	100%	100%	100%	100%	100%	100%
48	100%	100%	100%	99,9762%	100%	100%	100%	100%	100%	100%
52	100%	100%	100%	99,9909%	100%	100%	100%	100%	100%	100%
56	100%	100%	100%	99,9689%	100%	100%	100%	100%	100%	100%
60	100%	100%	100%	99,9912%	100%	100%	100%	100%	100%	100%
64	100%	100%	100%	99,9781%	100%	100%	100%	100%	100%	100%

TABLE II. PERCENTAGES OF DETECTED INCORRECTLY TRANSMITTED CODE WORDS OF LENGTH N BITS WITH J INCORRECTLY TRANSMITTED BITS WHEN LINEAR QUASIGROUP OF ORDER 4 IS USED FOR CODING AND THE PROBABILITY OF BIT-ERROR IS P=0.07

	j									
n	1	2	3	4	5	6	7	8	9	10
8	100%	100%	100%	80,2281%	100%	100%				
12	100%	100%	100%	96,5970%	100%	98,2143%	100%			
16	100%	100%	100%	99,1708%	100%	100%	100%	100%		
20	100%	100%	100%	99,5536%	100%	99,6785%	100%	100%	100%	
24	100%	100%	100%	99,8296%	100%	99,8612%	100%	100%	100%	100%
28	100%	100%	100%	99,9014%	100%	100%	100%	100%	100%	100%
32	100%	100%	100%	99,9138%	100%	100%	100%	100%	100%	100%
36	100%	100%	100%	99,9080%	100%	100%	100%	100%	100%	100%
40	100%	100%	100%	99,9813%	100%	100%	100%	100%	100%	100%
44	100%	100%	100%	99,9723%	100%	99,9893%	100%	100%	100%	100%
48	100%	100%	100%	99,9844%	100%	100%	100%	100%	100%	100%
52	100%	100%	100%	99,9806%	100%	100%	100%	100%	100%	100%
56	100%	100%	100%	99,9932%	100%	100%	100%	100%	100%	100%
60	100%	100%	100%	99,9926%	100%	100%	100%	100%	100%	100%
64	100%	100%	100%	99,9899%	100%	100%	100%	100%	100%	100%

TABLE III. PERCENTAGES OF DETECTED INCORRECTLY TRANSMITTED CODE WORDS OF LENGTH N BITS WITH J INCORRECTLY TRANSMITTED BITS WHEN LINEAR QUASIGROUP OF ORDER 4 IS USED FOR CODING AND THE PROBABILITY OF BIT-ERROR IS P=0.09

	j									
n	1	2	3	4	5	6	7	8	9	10
8	100%	100%	100%	78,5852%	100%	100%				
12	100%	100%	100%	96,7768%	100%	97,9275%	100%	100%		
16	100%	100%	100%	99,1552%	100%	99,4166%	100%	100%	100%	
20	100%	100%	100%	99,6004%	100%	100%	100%	100%	100%	100%
24	100%	100%	100%	99,7429%	100%	99,9766%	100%	100%	100%	100%
28	100%	100%	100%	99,8510%	100%	99,986%	100%	100%	100%	100%
32	100%	100%	100%	99,8777%	100%	99,9903%	100%	100%	100%	100%
36	100%	100%	100%	99,9429%	100%	100%	100%	100%	100%	100%
40	100%	100%	100%	99,9629%	100%	100%	100%	100%	100%	100%
44	100%	100%	100%	99,9681%	100%	100%	100%	100%	100%	100%
48	100%	100%	100%	99,9764%	100%	100%	100%	100%	100%	100%
52	100%	100%	100%	99,9799%	100%	99,9953%	100%	100%	100%	100%
56	100%	100%	100%	99,9885%	100%	100%	100%	99,9888%	100%	100%
60	100%	100%	100%	99,9865%	100%	100%	100%	99,9907%	100%	100%
64	100%	100%	100%	99,9946%	100%	100%	100%	100%	100%	100%

TABLE IV. PERCENTAGES OF DETECTED INCORRECTLY TRANSMITTED CODE WORDS OF LENGTH *N* BITS WITH *J* INCORRECTLY TRANSMITTED BITS WHEN LINEAR QUASIGROUP OF ORDER 4 IS USED FOR CODING AND THE PROBABILITY OF BIT-ERROR IS *P*=0.15

	j									
n	1	2	3	4	5	6	7	8	9	10
8	100%	100%	100%	79,6357%	100%	100%	100%			
12	100%	100%	100%	97,0214%	100%	96,4126%	100%	95,3488%	100%	
16	100%	100%	100%	99,5851%	100%	99,3124%	100%	99,3464%	100%	100%
20	100%	100%	100%	99,6125%	100%	99,8402%	100%	99,8948%	100%	98,9583%
24	100%	100%	100%	99,7836%	100%	99,9415%	100%	99,9788%	100%	100%
28	100%	100%	100%	99,8367%	100%	99,9854%	100%	100%	100%	99,9208%
32	100%	100%	100%	99,9084%	100%	99,9920%	100%	99,9850%	100%	100%
36	100%	100%	100%	99,9491%	100%	99,9973%	100%	100%	100%	100%
40	100%	100%	100%	99,9593%	100%	100%	100%	99,9953%	100%	100%
44	100%	100%	100%	99,9842%	100%	100%	100%	100%	100%	100%
48	100%	100%	100%	99,9846%	100%	100%	100%	100%	100%	100%

TABLE V. PERCENTAGES OF DETECTED INCORRECTLY TRANSMITTED CODE WORDS OF LENGTH *N* BITS WITH *J* INCORRECTLY TRANSMITTED BITS WHEN LINEAR QUASIGROUP OF ORDER 4 IS USED FOR CODING AND THE PROBABILITY OF BIT-ERROR IS *P*=0.2

	j											
n	1	2	3	4	5	6	7	8	9	10	11	12
8	100%	100%	100%	80,1485%	100%	100%	100%					
12	100%	100%	100%	96,9511%	100%	96,3782%	100%	98,0226%	100%	100%		
16	100%	100%	100%	99,1185%	100%	99,3189%	100%	98,7104%	100%	96,4912%	100%	100%
20	100%	100%	100%	99,6090%	100%	99,8510%	100%	99,8310%	100%	100%	100%	100%
24	100%	100%	100%	99,7872%	100%	99,9282%	100%	99,9268%	100%	100%	100%	100%
28	100%	100%	100%	99,8308%	100%	99,9921%	100%	99,9884%	100%	99,9857%	100%	99,9047%
32	100%	100%	100%	99,9044%	100%	99,9887%	100%	99,9937%	100%	100%	100%	100%
36	100%	100%	100%	99,9331%	100%	100%	100%	100%	100%	100%	100%	100%
40	100%	100%	100%	99,9790%	100%	100%	100%	99,9968%	100%	100%	100%	100%
44	100%	100%	100%	99,9840%	100%	99,9942%	100%	100%	100%	100%	100%	100%
48	100%	100%	100%	99,9980%	100%	99,9911%	100%	100%	100%	100%	100%	100%

C. *Linear quasigroup of order 8 is used for coding*

We use the following linear quasigroup of order 8:

$$A=\{\{1, 0, 1\}, \{0, 1, 1\}, \{1, 1, 1\}\},$$
$$B=\{\{0, 1, 1\}, \{1, 1, 1\}, \{1, 0, 1\}\}, \quad (5)$$
$$C=\{\{0, 0, 0\}\}$$

Again, we make simulations for values of the probability of bit-error p=0.05, 0.07 and 0.09. When we use quasigroups of order 8, the code words have length that is multiple of 6. We obtained the percentage of detected incorrectly transmitted code words for code words of length *n* from 12 bits to 66 bits with step 6 bits, i.e. $n \in \{6m \mid 2 \le m \le 11\}$. The obtained results are given in Table VI, Table VII and Table VIII. From the tables can be seen that for code words of length 12 and 18 bits, the code surely detects up to 2 incorrectly bits, while for code words od length greater than 18 bits, the code surely detects up to 3 incorrectly bits. As in the case when quasigroup of order 4 is used for coding, when the length of the code word increases, the percentage of detected incorrectly transmitted code words with *j* incorrectly transmitted bits generally increases, too. Due to the small number of incorrectly transmitted code words with more than 4 incorrectly transmitted bits, this property is not so obvious when *p*=0.05, but when *p*=0.09 it becomes obvious.

TABLE VI. PERCENTAGES OF DETECTED INCORRECTLY TRANSMITTED CODE WORDS OF LENGTH *N* BITS WITH *J* INCORRECTLY TRANSMITTED BITS WHEN LINEAR QUASIGROUP OF ORDER 8 IS USED FOR CODING AND THE PROBABILITY OF BIT-ERROR IS *P*=0.05

	j									
n	1	2	3	4	5	6	7	8	9	10
12	100%	100%	98,1302%	98,5625%	99,4792%	100%	100%			
18	100%	100%	99,5710%	99,9352%	99,8875%	100%	100%			
24	100%	100%	100%	99,9751%	100%	100%	100%	100%		
30	100%	100%	100%	99,9775%	100%	100%	100%	100%	100%	100%
36	100%	100%	100%	99,9828%	100%	100%	100%	100%	100%	100%
42	100%	100%	100%	99,9929%	100%	100%	100%	100%	100%	100%
48	100%	100%	100%	99,9968%	99,9931%	100%	100%	100%	100%	100%
54	100%	100%	100%	99,997%	99,9942%	100%	100%	100%	100%	100%
60	100%	100%	100%	99,9942%	100%	100%	100%	100%	100%	100%
66	100%	100%	100%	99,9971%	100%	100%	100%	100%	100%	100%

TABLE VII. PERCENTAGES OF DETECTED INCORRECTLY TRANSMITTED CODE WORDS OF LENGTH *N* BITS WITH *J* INCORRECTLY TRANSMITTED BITS WHEN LINEAR QUASIGROUP OF ORDER 8 IS USED FOR CODING AND THE PROBABILITY OF BIT-ERROR IS *P*=0.07

	j									
n	1	2	3	4	5	6	7	8	9	10
12	100%	100%	98,2049%	98,8929%	98,5149%	98,7342%	100%			
18	100%	100%	99,6278%	99,8986%	99,8930%	99,8358%	100%	100%	100%	
24	100%	100%	100%	99,9564%	99,8890%	100%	99,7506%	100%	100%	100%
30	100%	100%	100%	99,9723%	99,9743%	100%	100%	100%	100%	100%
36	100%	100%	100%	99,9846%	99,9908%	100%	100%	100%	100%	100%
42	100%	100%	100%	99,9979%	100%	100%	100%	100%	100%	100%
48	100%	100%	100%	99,9958%	100%	100%	100%	100%	100%	100%
54	100%	100%	100%	99,9933%	100%	100%	100%	100%	100%	100%
60	100%	100%	100%	99,9976%	100%	100%	100%	100%	100%	100%
66	100%	100%	100%	99,9972%	100%	100%	100%	100%	100%	100%

TABLE VIII. PERCENTAGES OF DETECTED INCORRECTLY TRANSMITTED CODE WORDS OF LENGTH *N* BITS WITH *J* INCORRECTLY TRANSMITTED BITS WHEN LINEAR QUASIGROUP OF ORDER 8 IS USED FOR CODING AND THE PROBABILITY OF BIT-ERROR IS *P*=0.09

	j									
n	1	2	3	4	5	6	7	8	9	10
12	100%	100%	98,1008%	98,8065%	99,1677%	97,9381%	100%			
18	100%	100%	99,6734%	99,9135%	99,8203%	99,8158%	100%	100%	100%	100%
24	100%	100%	100%	99,9605%	99,9614%	100%	100%	100%	100%	100%
30	100%	100%	100%	99,9706%	99,9679%	100%	99,9782%	100%	100%	100%
36	100%	100%	100%	99,9904%	99,9950%	100%	100%	100%	100%	100%
42	100%	100%	100%	99,9932%	99,9977%	100%	100%	100%	100%	100%
48	100%	100%	100%	99,9980%	99,9977%	100%	100%	100%	100%	100%
54	100%	100%	100%	99,9952%	100%	100%	100%	100%	100%	100%
60	100%	100%	100%	99,9970%	100%	100%	100%	100%	100%	100%
66	100%	100%	100%	99,9967%	100%	100%	100%	100%	100%	100%

D. Comparison of the error-detecting capability for quasigroups of order 4 and order 8

In both cases, when the length of the code words is greater than 18 bits, the code surely detects up to 3 incorrectly transmitted bits. But, for shorter code words, i.e., a code words with length smaller than or equal to 18 bits, the code based on a linear quasigroup of order 4 detects for sure up to 3 incorrectly, while the code based on a linear quasigroup of order 8 detects for sure up to 2 incorrectly transmitted bits.

We can notice that in both cases, for a given number of incorrectly transmitted bits *j*, the percentage of detected incorrectly transmitted code words increases when the length of the code word increases. Also, for a same probability of bit-error in the binary symmetric channel and equal lengths of the code words, the quasigroup of order 8 gives greater percentage of detected incorrectly transmitted code words with *j* incorrectly transmitted bits, for all possible even values of *j*. For all odd values of *j*, the code based on linear quasigroup of order 4 detects all incorrectly transmitted code words with *j* incorrectly transmitted bits, while this is not a case when linear quasigroup of order 8 is used for coding.

IV. CONCLUSION

When the linear quasigroup of order 4 is used for coding, the analyzed code surely detects up to 3 incorrectly transmitted bits, regardless of the length of the code words. When the linear quasigroup of order 8 is used for coding, the code surely detects up to 2 incorrectly transmitted bits when code word has length 12 or 18 bits and up to 3 incorrectly transmitted bits when code word has length greater than 18 bits. Also, when linear quasigroup of order 4 is used for coding, the code detects the errors in transmission whenever odd number of bits are incorrectly transmitted.

ACKNOWLEDGMENT

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Analysis, Design and Implementation of a Helpdesk Management System - Case Study "Albanian Radio Television"

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***Abstract* - As companies grow, so do the complex demands placed on the IT Department. Without a good Help Desk Software, IT Departments can begin losing the ability to effectively provide employees with the technical support they need to do their jobs. Many enterprises rely on IT Ticketing Systems to deliver fast, reliable internal customer service, resulting in improved IT department operations and satisfied employees.**

This paper describes the process of creating an IT Ticketing System from scratch for the IT Sector of a well-known organization in Albania - Albanian Radio Television, the public broadcaster of the country. The new way of collecting information about IT problems in the institution and also a new way of distributing work to the IT Staff members will bring benefits not only to the IT Sector but also to the employees which this sector supports.

The system is developed using JavaFX a software platform for creating and delivering desktop applications, as well as rich internet applications from Oracle.

Keywords – helpdesk management system, It ticketing, system analysis

I. INTRODUCTION

In today's world every organization is heavily dependent on information technology. Information Technology has changed the way they work and function. Almost every employee in the today's organization has to rely on an IT device like a computer, smart phone, tablet etc. to accomplish their everyday job. These devices make their job easier but also present to them a wide range of technology related problems, hardware or software related. The need for a help desk system where they can rely on to solve these problems is more than evident and many organizations use On Call Help Desk or Help Desk Software's to support their employees [5, 15].

In the market today there are dozens of Help Desk Software [4, 3]. Developing companies are integrating every day more features in the attempt to get more market share. These features add value to the software but they have their down sides. The software's are becoming bigger, are demanding more resources and expensive hardware. Their complexity has increased and the employees who will use them need to be trained first. So they have a learning curve associated. Last but not least important, the major part do need an initial investment, a monthly payment/copy or monthly payment for each user/month.

Even developing an IT Ticketing System from scratch, will not be better than today's software on the market, which are developed from dozens of developers working on them for many years but it will have its main features:

- Lightweight with no expensive hardware needed.
- No installation needed on clients.
- Almost no learning curve
- Very simple and intuitive Graphical User Interface.
- Free. No initial investment and no monthly costs.
- Open for further development and improvements in the incoming Development Department of the Albanian Radio Television.

II. PROBLEM STATEMENT

Albania Radio Television (ALRT) is a well know organization in Albania. Until March 2017 there was no Help Desk Software in use in any of the Departments of the Albanian Radio Television. From this fact the idea of creating a Help Desk Software for the IT Sector developed [1].

The department offered help to every employee which requests it by calling on the department office number, sending an email to the department e-mail address, asking for help coming at the office or calling the head of the department in the mobile phone. The head of the department then sends one of the IT staff to help the employee or deal with a specific problem. After solving the problem, the staff reports back to the head of the department about the problem and the measures taken to solve it.

The overall process is very time consuming. Phone calls back and forth. Employees move from their desk to seek help at the office. Many of them call the IT staff directly after calling the head of the department.

The software purpose is to organize the work of the IT Sector increase efficiency, reduce the response time to the end user and measure the performance of the IT Sector staff. The system will offer help to employees based on tickets opened by them in the system with no need to make a phone call or to leave their desk.

A ticket is an entry in the list of issues or help requests which may include various information like a description of the problem or help request, a unique reference number, an issue number, a computer IP address (Internet Protocol address), MAC address (Media Access Control address) and location, the name of the user who created the ticket, the time and date when created, a priority index, a status etc.

The software should be installed in every computer of the organization and every employee will have a username and password to login in the system. The system has a very easy to use Graphical User Interface which will be different for different roles. There are four roles in the system:

- Administrator
- IT Manager
- IT Staff
- User

The role is automatically determined at the login and the system opens the correct GUI for each employee.

The system will try to solve problems like:

1. Give to the supervisor of the department a centralized system where can distribute and assign work to the team.
2. Help employees with technical problems, hardware or software related in a work environment.
3. Hold IT Sector staff accountable for their actions.
4. Not knowing where or to whom to address a problem of the hardware or software in a work environment.
5. Having no way to contact the IT Sector staff.
6. Minimize misunderstandings between IT Sector staff and other employees.
7. Measure the IT Sector staff performance, problem solving skills and their response time to problems.
8. Difficulties in describing IT problems from non-technical employees to the IT Sector staff.
9. Sending 2 people to solve the same work.
10. Track the frequency of help from a user or computer which may tell that the user is not qualified and need training or the hardware must be replaced.

The software is developed in Java [6, 7]. The Graphical User Interface (GUI) is created in JavaFx [8]. In the backend it has a MySQL (My Standard Query Language) database [11], a simple synchronization server developed in Java and running as a service in the database server machine. The software uses the local mail server to send emails to IT staff and employees and an online gateway to send SMS (Short Message Service) text messages in their mobile phones. The developing IDE (Integrated Development Environment) chosen was NetBeans IDE which is the official IDE for Java [2, 10].

III. SYSTEM ARCHITECTURE

When choosing the application network architecture, the two predominant architectural paradigms used in modern network applications, to be taken in consideration are: the client-server architecture [13] or the P2P (peer-to-peer) architecture [14].

The developed IT Ticketing System uses both of this architectures, the two-tier and the three-tier architecture. The two-tier is used in:

- Database
- GUI Synchronization
- E-mail Notification

The database and the GUI synchronization work over the Local Area Network (LAN) of the Albanian Radio Television, while the e-mail notification works over the internet because the e-mail server configuration doesn't allow accessing it from the LAN. The IT Ticketing System clients belong to the fat-client model where the presentation logic and most of the application processing are done on the client making use of the client personal computer processing power. As we can see from the figure below, in each case the clients communicate directly with the server through LAN or Internet.

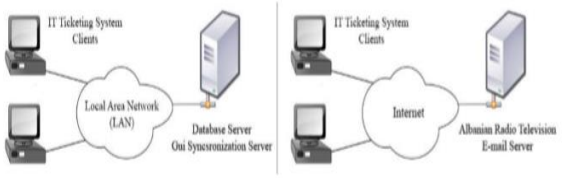

Figure 1. Two tier client server architecture of the IT Ticketing System

The three-tier architecture is used in:

- SMS Notification

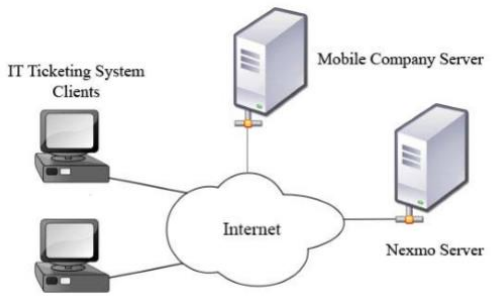

Figure 2. Three tier client server architecture for the SMS notification

Differently from the two-tier architecture the clients here don't communicate directly with the mobile company server who sends the SMS to the Users or to the IT Staff. They send a request to the Nexmo Server through the Nexmo API, while the Nexmo server communicates with the mobile company server to send the requested SMS [9,17].

IV. SYSTEM DESIGN

The IT Ticketing System will improve the IT Staff everyday job and the support for the employees who request help every day. In the design process the focus is on the software quality characteristics like: Correctness, Usability, Efficiency, Reliability, Portability etc. [16].

The users of the IT Ticketing System will have an everyday interaction with the system so is very important to understand what users want from the system and what the system can accomplish for them. The process of capturing requirements for a system developed is represented in a Use Case Diagram [12].

In the use case diagram are represented the users of the system as actors and what the users can do with the system as use cases. The actor is not necessarily a user. It can be another system interacting with this system.

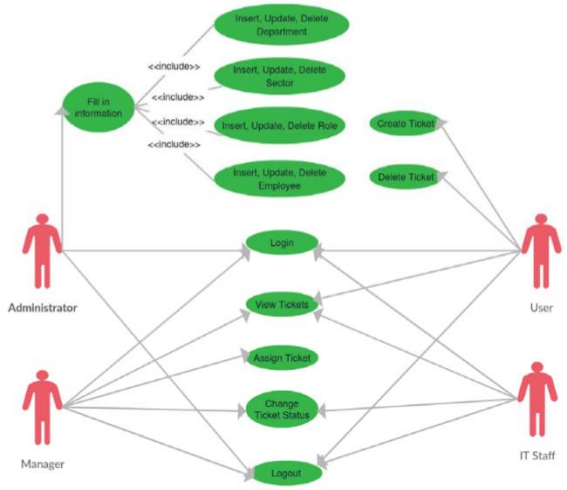

Figure 3. Use Case Diagram of the IT Ticketing System

A. Authentication

As we saw in the use case before there will be four actors in the IT Ticketing System. Each one will have different functions and options so the GUI will be different for each of them. An approach to the situation may be to build four different distributions of the login interface and install each of them in the employee's computers based on the actor they represent to the system. But in this situation the Administrator and the Manager will have only one computer to login while the IT Staff and the Users can login at their office computer.

A better approach will be that the same login interface is used for all actors. Those, the software can be easily distributed to all computers with different technologies of distribution over the network.

To accomplish this, we need to know the department, sector and the role of the employee that is logging in. Having this information, the login interface will automatically identify which actor the employee represents:

1. If the user is the Director of the Human Resources, then the role will be Administrator.
2. If the user is the Chief of the IT Sector, then the role will be Manager.
3. If the user is a member of the IT Sector but is not the chief, then the role will be IT Staff.
4. If the user in none of three cases, then he can login as a User.

Figure 4. The login interface of the IT Ticketing System

B. Administrator

In the authentication section it was mentioned that the Administrator role in the It Ticketing System will be assigned to the Director of the Human Resources of the Albanian Radio Television. This was the obvious choice because the Human Resources have all the detailed information for each employee which is already hired in the institution.

After logging in, the Administrator is presented with the following interface:

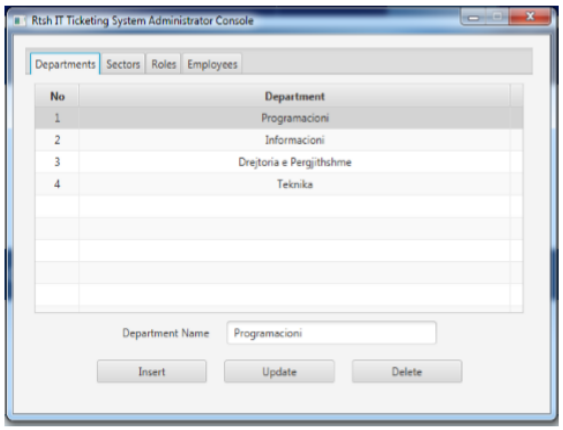

Figure 5. The Administrator GUI of the IT Ticketing Syste

The GUI has four sections divided in tabs. In the first tab the Administrator manages the information about the Departments of the institution. The second section is the Sector Tab. Sectors are smaller organizational units and are parts of departments for example a department can have many sectors. The main difference here is that when inserting a new sector, the Administrator must choose which department it belongs to. The third section is the Roles Tab for managing role information. Roles are unique and are an attribute of the employee. Many employers can have the same role for example the role Director can be used for the Director of the Marketing Department, Director of Human Resources etc. The fourth section is the Employees Tab. There are differences in the amount of information requested to insert a new employee or the information which is allowed to update to an existing employee like his department, sector, role of the new employee, select his/her birthday from the calendar and enter other details like e-mail, phone number, username and password. The details are used by the system to login the employee and notify him/her by email and SMS for solved tickets.

Finally, as we can read through this role explanation the Administrator have nothing to do with help requests from users nor manages any work distribution in the system. He/she just fills in essential information which the system needs to function correctly.

C. *IT Manager*

The second actor in the use case diagram is the IT Manager. This role is naturally assigned to the chief of the IT Sector of the Albanian Radio Television. After logging in the following GUI is presented to the IT Manager.

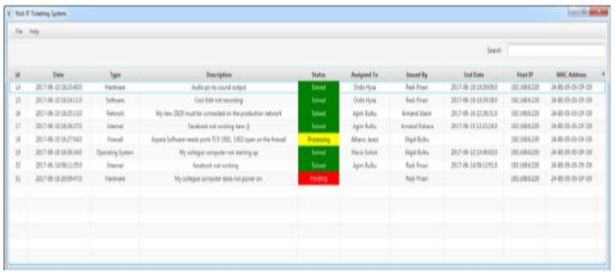

Figure 6. IT manager GUI of the It Ticketing System

The IT Manager can view and take action on all the tickets that are submitted to the system. Every submitted ticket has its status “Pending” and its marked with the red color. The IT Manager after reading the ticket details, assigns the ticket to one of its IT Staff. After the ticket is assigned to one of the employers of the IT Staff its status turns to “Processing” and its marked with the yellow color. The “Solved” status marked with green is for the solved tickets and its status is changed by the IT Staff at his/her GUI. After solving a ticket, the IT Staff marks the ticket as solved and must report back to the IT Manager what measures has taken to solve it.

D. *IT Staff*

The third actor in the use case diagram is the IT Staff. This role is for all the members of the IT Sector except the chief. After logging in, the following GUI is presented to the IT Staff.

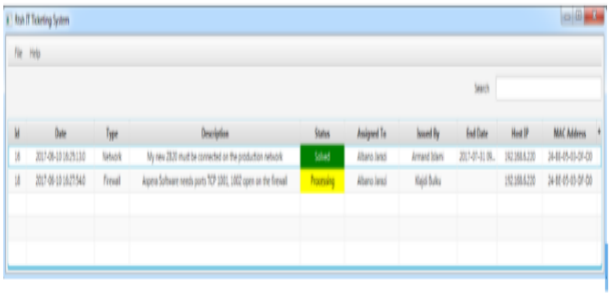

Figure 7. IT Staff GUI of the It Ticketing System

In the GUI, the IT employer who is logged in, has a list of tickets that are assigned to him by the IT Manager. After getting the required information like type of problem, description, name of person who issued the ticket, IP and Mac address of the computer, the IT employer takes all the measures to solve the problem. After solving the problem, he/she changes the ticket status to “Solved”. Then he/she has to report to the IT Manager the measures taken to solve the issue.

E. *User*

The fourth actor in the use case diagram is the User. This role is for all employers of the institution except for the Director of Human Resources and all the IT Sector. After logging in the following GUI is presented to the User.

Figure 8. User GUI of the IT Ticketing System

A list of all the ticket submitted by him/her are displayed. Every ticket has its status updated instantly and the user may get information about each of them. There is an option in the Edit menu to Delete a Ticket. The delete ticket option is made possible to the user because there may be cases in which after submitting a ticket the user solved the problem himself.

F. *System Operations*

There are some operations in the IT Ticketing System that are accomplished by the system itself and not by the user’s interaction but which are very important for the smooth operation.

Date and Time are used in every ticket submitted and solved to measure the time taken for the ticket to be solved. Taking in consideration that the system is used in

many computers, each computer date and time may be different and using the local date and time can bring confusion. The system solves this by entering in the database for each ticket submitted and solved the date and time of the server on which the database is operating.

IP address and MAC address are two other information useful for the IT Staff in identifying the computer from which the ticket was submitted. Also knowing the IP and MAC may help in problem solving. For example, if a user gets a new computer and the old computer IP address is assigned to the new but the computer still does not have internet access, the firewall MAC address filter may be preventing it accessing the internet because the old MAC address must be replaced with the new one. These information is extracted automatically and entered in the database at the ticket submission.

The ticket status is also identified and colored by the system automatically for two statuses, the Pending status and the Processing status. The system identifies and marks every ticket with Pending status and red color every ticket which is submitted but have not been assigned to one employer of the IT Staff to be solved and marks with Processing and yellow color every ticket submitted which have been assigned to be solved.

1) Notifications

The notification is an essential part of the IT Ticketing System because it saves time and effort to the Users, IT Staff and IT Manager. The users don't have to make a phone call or go to the IT office to ask for help. The IT Manager doesn't have to make a phone call or call its IT Staff to the office to give them the work to be done. The IT Staff doesn't have to go to the IT Manager office to get the work or to go to every User office to tell them that their problem is solved. The IT Ticketing System can notify in three different ways:

- Instant notification through the IT Manager, IT Staff and User GUI
- By E-mail
- By SMS

With this three notification ways, the system reduced to the minimum the time taken to assign a work to the IT Staff.

2) GUI Synchronization

The three main actors of the IT Ticketing System which use the system on an everyday basis are the IT Manager, the IT Staff and the User. These three actors along with the interaction with the system through their GUI must "communicate" with each other. Basically:

- The User asks for help the IT Manger.
- The IT Manager notifies the IT Staff that there's a problem to deal with and the User that the IT Staff is working on the problem.
- The IT Staff notifies the IT Manager and the User that the problem is solved.

This is achieved through the GUI synchronization. The software synchronizes all the running instances of the GUI for all actors. The client part of the client/server architecture is already embedded in the IT Ticketing System. Every instance of the program registers as a client in the server.

3) E-mail

The second notification method is by e-mail. E-mail has been widely used in Help Desk software for notification or even to submit a ticket in the system. In this case it serves as a notification service only.

4) SMS

The third notification method is by SMS. In the today's world every person has a mobile phone, and almost we can't live without it.

Each IT Staff member and User receives along with the e-mail a SMS text message which notifies about an assigned ticket to be solved or a solved one.

V. CONLUSION AND FUTURE WORK

In this paper, the process of designing and implementing a ticketing system for the IT Sector of the Albanian Radio Television is presented. This system not only will offer a centralized way of collecting information about IT problems in the institution but will also offer a better way to deal with them. It will organize the work of the IT Sector members but also will help other employers to report problems to the IT Sector easily and also get information if their problem is being processed or is solved. It also provides an easy way for work distribution, staff members performance measurement and their problem solving skills etc.

The contribution of this paper is that it can serve as guideline for other institutions and researchers facing the same problems.

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Aplikacija za podizanje razine svijesti o potpomognutoj komunikaciji

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***Sažetak* - Telekomunikacijski proizvodi i usluge sve se više koriste u svrhu pozitivnog utjecaja na društvo. U ovom znanstvenom radu predstavljena je aplikacija za podizanje razine svijesti o potpomognutoj komunikaciji *Pričajmo slikama* koja informiranjem javnosti o problemu potpomognute komunikacije pokušava pozitivno utjecati na društvo kako bi se kroz edukaciju društva poboljšao položaj osoba s teškoćama koje komuniciraju isključivo pomoću potpomognute komunikacije. Aplikacija je osmišljena i razvijena u sklopu kolegija Diplomski projekt na Fakultetu elektrotehnike i računarstva. Rezultat projekta je 2D igra razvijena pomoću programa *Unity*, a elementi igre dizajnirani su i nacrtani pomoću programa *Adobe Illustrator* i *Inkscape*. Igra se sastoji od tri razine koje prikazuju različite scenarije i predstavljaju različite izazove za korisnike kako bi se on što duže animirao te tako zapamtio što više informacija, koje mu se osim kroz samu igru prikazuju na zanimljiv način i između razina. Cilj aplikacije je tako kroz interaktivni i zanimljiv sadržaj igre korisnika zabaviti te ga u kratkom vremenu educirati o osnovama potpomognute komunikacije kako bi se kroz minimalni napor članova društva ono osvijestilo o ovom problemu te tako uvelike pomoglo poboljšati položaj osoba s teškoćama u društvu i tako povećao i njihov osjećaj pripadnosti.**

Ključne riječi- potpomognuta komunikacija; aplikacija; igra; Unity; podizanje svijesti

I. UVOD

Komunikacija je proces razmjene poruka prilikom kojeg se koristi dogovoreni sustav znakova. Uz to što je pravo na komunikaciju jedno od temeljnih ljudskih prava, ona kao takva predstavlja jedan od preduvjeta za ostvarivanje različitih oblika društvenih aktivnosti. Postoje osobe koje iz različitih razloga nisu u mogućnosti komunicirati putem osnovnog sredstva komunikacije među ljudima – govorom (npr. osobe s poremećajima iz autističnog spektra, intelektualnim teškoćama, razvojnom govornom apraksijom) pa su takvim osobama potrebne metode komunikacije koje potpomažu i/ili nadomještaju njihov govor [1]. Potpomognuta komunikacija[1] (PK) je svaki oblik komunikacije koji ne uključuje govor, a pomaže osobama sa složenim komunikacijskim potrebama. Svakodnevno se koristi u obliku korištenja simbola, gesti, mimike, pisanih formata, korištenjem emotikona i sl. Osobama s teškoćama u razumijevanju govora ili samom govoru potpomognuta komunikacija je od velike važnosti i često je jedini način na koji te osobe mogu komunicirati sa svojom okolinom.

U sklopu istraživačke grupe koja intenzivno provodi istraživanja u domeni potpomognute komunikacije posljednjih devet godina, posebice u okviru projekta ICT-AAC [2], razvijeno je više od trideset aplikacija koje se koriste u radu s djecom mlađe predškolske dobi sa složenim komunikacijskim potrebama, u radu s odraslim osobama nakon traumatskih ozljeda mozga i cerebrovaskularnog inzulta, ali i za rad s djecom starije predškolske i mlađe školske dobi kod usvajanja vještina koje prethode čitanju pisanju i računanju. Kako bi se unaprijedile društvena uključenost te mogućnosti za učenje i zapošljavanje osoba sa složenim komunikacijskim potrebama, osim za razvojem boljih ICT usluga i rješenja, ukazala se potreba za podizanjem svijesti o potpomognutoj komunikaciji budući da i dalje samo manji broj ljudi u potpunosti razumije pojam i ulogu koju potpomognuta komunikacija ima u životima onih koji mogu isključivo na taj način komunicirati s drugima.

S obzirom na sve navedeno, cilj diplomskog projekta bio je razviti odgovarajuće rješenje čija će svrha biti osvješćivanje okoline o potpomognutoj komunikaciji. Korištenjem programa *Unity* razvijena je interaktivna igra koja osim što objašnjava pojam potpomognute komunikacije, kroz zanimljiv način informira korisnika o različitim oblicima iste. Primarna svrha igre je utjecati na društvo kroz podizanje svijesti o potpomognutoj komunikaciji, a to je vidljivo i kroz zahtjeve igre. Cilj je bio zainteresirati korisnika te održati njegovu pažnju na visokoj razini pa je stoga kreiran zabavan interaktivni sadržaj.

Rad je u nastavku organiziran na sljedeći način: Poglavlje II. opisuje cilj aplikacije, u Poglavlju III. dan je pregled aplikacije, Poglavlje IV. daje informacije o tehničkim značajkama aplikacije te je na posljetku zaključak dan u Poglavlju V.

II. CILJ APLIKACIJE

Pokušaj utjecaja telekomunikacijskih proizvoda i usluga na društvo u ovom je radu obrađen na primjeru igre *Pričajmo slikama*[3]razvijene u sklopu projekta Razvoj aplikacije za podizanje razine svijesti o potpomognutoj komunikaciji.

[1] Izraz potpomognuta komunikacija je hrvatska prevedenica za augmentativnu i alternativnu komunikaciju (eng *Augmentative and Alternative Communication* AAC)

Cilj projekta je širenje svijesti o ulozi koju potpomognuta komunikacija ima u životima onih kojima je ona potrebna na dnevnoj razini. Uspješnost ovog projekta očituje se u razvijenoj igri koja osim svog izgleda, funkcionalnosti te zadovoljstva kojeg pruža korisnicima, djeluje pozitivno na krajnje korisnike kroz podizanje razine njihova znanja u području PK.

Problem koji se pokušava riješiti kroz projekt je neupućenost društva u definiciju i značenje potpomognute komunikacije u svakodnevici te sukladno tome loše snalaženje u konkretnim situacijama u kojima su pojedinci suočeni s nekim oblikom potpomognute komunikacije u svakodnevnom životu. Odgovor na taj problem ponuđen ovim projektom je igra koja se sastoji od tri razine od kojih svaka ima prepreke koje zahtijevaju interakciju korisnika kroz odabir točnog odgovora na ponuđeno pitanje ili dani scenarij. Nastavno između razina ponuđen je dodatni edukativni sadržaj o temi oblikovan na način zanimljiv i poticajan korisniku.

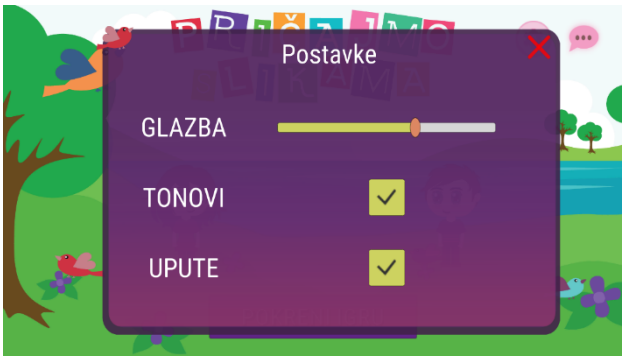
U projektu je sudjelovalo deset studenata pod vodstvom mentorice i dvije asistentice u sklopu kolegija Diplomski projekt na diplomskom studiju Fakultetu elektrotehnike i računarstva te u stalnoj suradnji s logopedicom s Edukacijsko rehabilitacijskog fakulteta. Suradnja sa stručnjacima iz različitih područja te primjena znanja i vještina vezanih za upravljanje projektima ključni su elementi uspješnosti, osobito kada se radi o multidisciplinarnoj suradnji. S obzirom na navedeno, članovi razvojnog tima su prije početka oblikovanja prijedloga rješenja sudjelovali u sažetoj edukaciji provedenoj od strane logopedice. Implementacija projekta trajala je četiri mjeseca.

III. PREGLED APLIKACIJE

Aplikacija je napravljena u obliku 2D igre i sastoji se od tri razine. Svaka razina je drugačije zamišljena i stavlja pred igrača različite zadatke, a osim razina unutar igre se nalaze i uvodni ekran te prijelazi između razina.

U uvodnom ekranu se nalaze tipke: *Informacije*, *Postavke* i *Pokreni igru*(*Slika 1*). Klikom na *Pokreni igru* igraču se nudi odabir lika – djevojčica ili dječak, i zatim se pokreće igra. Unutar *Postavki* igrač može namjestiti glasnoću glazbe, uključiti/isključiti ostale tonove i upute (*Slika 2*). Klikom na tipku *Informacije* otvara se prozor s informacijama o razvijenoj aplikaciji (*Slika 3*).

Slika 1 *Uvodni zaslon*



Slika 2 *Postavke*

Slika 3 *Informacije*

Prva razina je zamišljena kao scena kuće u kojoj odabrani lik mora ići od jednog objekta do drugog i odabrati sliku radnje vezanu uz objekt i napisani tekst. Objekti iz ove razine susreću se svakodnevno; televizor, kauč, krevet, stol, štednjak, ormar i kada. Na ovaj način igrač se upoznaje s potpomognutom komunikacijom odabirući slike preuzete s portala ARASAAC[2] kojima se koriste osobe s teškoćama u komunikaciji. Objekt do kojeg igrač mora doći je obilježen zelenom animirajućom elipsom(*Slika 4*) i dolaskom do njega igraču se otvara prozor. Unutar prozora se nalazi tekst koji opisuje radnju te dvije slike od kojih je jedna točan odgovor. Ako se odabere krivi odgovor preko slike će se prikazati simbol za netočan odgovor - crveni X, a za točan će se prikazati zelena kvačica (*Slika 5*). Nakon točnog odabira prozor se zatvara i aktivira se zeleni krug kod sljedećeg objekta do kojeg igrač mora doći. Kada se svi zadaci uspješno riješe, otvaraju se vrata kuće i igrač može napustiti trenutnu razinu te prijeći na sljedeću.

U svakom trenutku je omogućen izlazak iz igre ili vraćanje na uvodni ekran klikom na odgovarajuću tipku u donjem lijevom kutu ekrana.

[2]ARASAAC –nekomercijalna galerija simbola (http://www.arasaac.org/)

Slika 4 *Prva razina – obilježen objekt*

Slika 5 *Prva razina - odgovori*

Druga razina je organizirana poput trgovine u kojoj se nalaze tri kupca (*Slika 6*). Cilj je pomoći kupcima u snalaženju pri kupovini, a komunicirati s njima se može jedino uz pomoć potpomognute komunikacije. Kupci su osoba treće životne dobi, djevojčica s invaliditetom i žena muslimanske vjeroispovijesti koja priča strani jezik. Svatko od njih ima različite zadatke za igrača i svi se zadaci moraju uspješno riješiti kako bi se razina mogla završiti. Za razliku od prve razine, u drugoj nije točno određen redoslijed obilaska objekata, odnosno kupaca u trgovini. Igrač prilazi kupcu i otvara se prozor s kratkim uputama, a zatim igrač započinje s odgovaranjem na pitanja. Točnim odgovorom otvara se novo pitanje i nakon što se odgovori na sva pitanja jednog kupca, prozor se zatvara. U gornjem desnom kutu prozora se nalazi gumb za izlazak što omogućuje korisniku da u tom trenutku napusti pitanje i odgovori na njega kasnije.

Osobi starije životne dobi se može pomoći odgovaranjem na četiri njegova pitanja vezanih uz odjele u trgovini i gdje se što može naći (*Slika 7*). Djevojčici se olakšava snalaženje u trgovini odgovaranjem na tri pitanja s višestrukim točnim odgovorima (*Slika 8*). Treću prepreku koju igrač mora savladati predstavlja žena koja priča stranim jezikom (*Slika 9*). Cilj te prepreke je razumjeti što kupac želi u trgovini slušajući njegov nerazumljiv govor, čime se skreće pozornost na osobe s teškoćama u govoru.

U komunikaciji s kupcima su korištene slike preuzete s portala ARASAAC. Kao i u cijeloj aplikaciji; krivo odabrani odgovori su označeni s crvenim X-om, a točni sa zelenom kvačicom. Na početku iznad svakog kupca stoji upitnik što je znak da igrač nije riješio njegova pitanja, a nakon što se uspješno pomogne jednom kupcu iznad njega se pojavi zelena kvačica. Ako su sva pitanja uspješno riješena, pojavi se animirajuća strelica kod blagajne do koje igrač mora doći kako bi prešao u zadnju razinu.

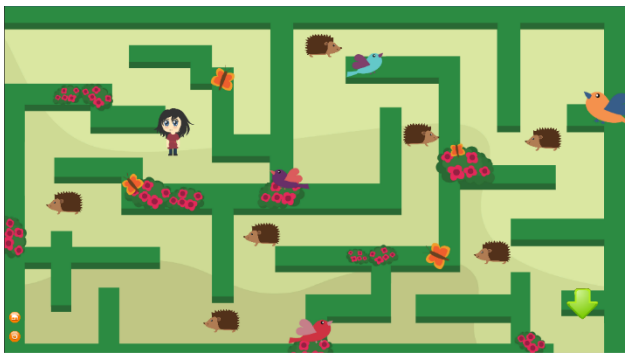
Slika 6 *Druga razina*

Slika 7 *Druga razina – prva prepreka*

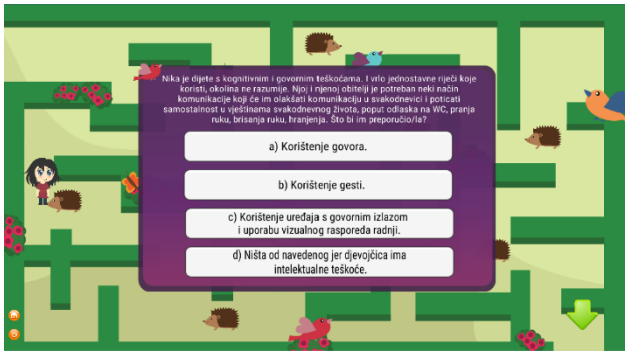
Slika 8 *Druga razina – druga prepreka*

Slika 9 *Druga razina – treća prepreka*

Treća razina je labirint iz kojeg se može izaći tek kada se uspješno savladaju prepreke – pitanja o potpomognutoj komunikaciji (*Slika 10*). Postoji ukupno osam pitanja i svako pitanje ima četiri ponuđena odgovora od kojih je samo jedan točan. Igrač prilazi ježu, kojeg ne može zaobići niti preskočiti, i otvara mu se prozor s pitanjem i ponuđenim odgovorima (*Slika 11*). Kada igrač odabere točan odgovor prozor se zatvara i jež se miče s puta što omogućuje igraču da nastavi dalje do sljedeće prepreke; ježa. Animirajuća zelena strelica pokazuje izlaz iz labirinta i dolaskom do nje se izlazi iz treće razine i odlazi na završni ekran.



Slika 10 *Treća razina*



Slika 11 *Treća razina - pitanje*

Nakon uspješnog rješavanja razine i prije prelaska u sljedeću, igraču se prikažu informacije o potpomognutoj komunikaciji (*Slika 12*). Završavanjem zadnje, treće, razine otvara se završni ekran s linkovima vezanim uz ICT-AAC (*Slika 13*).

Slika 12 *Prijelaz između razina*

Slika 13 *Završni zaslon*

IV. TEHNIČKE ZNAČAJKE

U razvoju aplikacije *Pričajmo slikama* korišteni su programi *Unity*[4], *Adobe Illustrator*[5] i *Inkscape*[6].*Adobe Illustrator* i *Inkscape* su programi za dizajniranje i uz njihovo korištenje, nije bilo potrebe za korištenjem gotovih, preuzetih pozadina i likova s različitih web sjedišta te je time u igri postignuta veća raznolikost i kreativnost.*Unity* je jedan od najpopularnijih *game enginea*[3] u svijetu i specijaliziran je za razvoj 2D ili 3D igrica.Nudi mogućnost odabira platforme za koju se razvija igra poput; iOS, Desktop, Android, Web i ostalih platformi. Igra *Pričajmo slikama* je razvijena za Desktop i Web platforme.

Adobe Illustrator je program za ilustracije, softverski alat za izradu vektorske grafike, a proizvodi nastali uz pomoć tog programa su prisutni u velikom broju, na webu, kao logotipovi, ikone, crteži, ilustracije za tisak i slično. *Illustrator* je komercijalni proizvod čije korištenje nije besplatno te je za ovaj projekt nabavljena licenca za uporabu i objavljivanje razvijenih ilustracija. U njemu su izrađeni svi likovi korišteni u igrici, pokreti glavnih likova, ikone, gumbovi i pozadine (*Slika 14*). *Inkscape* je također program za razvijanje ilustracija. Za razliku od *Illustratora*, otvorenog je koda i smije se koristiti za razvijanje proizvoda bez naknada proizvođaču. Pomoću *Inkscapea* je izrađena cijela druga razina i napravljene su skice ostalih razina koje su zatim uređene u *Illustratoru* (*Slika 15*).

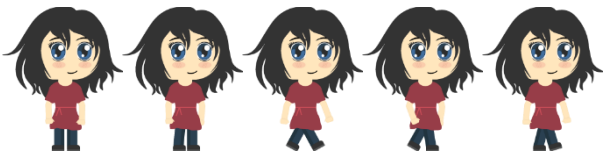
Slika 14 *Glavni likovi u igri*

[3]eng. *game engine* – hrv. program za izradu igrica

Slika 15 *Pozadina za drugu razinu*

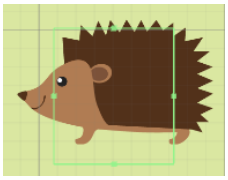
Funkcionalnost igre ostvarena je koristeći *Unity* i programski jezik C#. Svaka razina te uvodni i završni ekran razvijeni su u *Unityju* kao zasebne scene koje su zatim povezane u jednu cjelinu.

Kretanje glavnih likova je ostvareno skriptno; svaki pokret je dizajniran u *Adobe Illustratoru*, potom je napisana skripta kojom se izmjenjuju slike koje tvore kretanje odabranog 2D lika (*Slika 16*).



Slika 16 *Animacija glavnog lika*

Dizajn koji je napravljen u prethodno navedenim programima, dodan je u *Unity* i slikama su dodani *collideri*[4]. *Collideri*su važni elementi unutar *Unityja* koji se mogu iscrtati po dodanim slikama (pozadine), glavnim likovima ili NPC-ovima[5] (eng. *Non-player character*) im se skriptno može odrediti ponašanje.Jedan od primjera je dodavanje *collidera* zidovima i objektima u pozadini kako bi ponašanje lika u prostoru bilo vjerodostojno(lik će se zabiti u njih umjesto da prođe kroz njih).Drugi primjer korištenja *collidera* je dodavanje istih NPC-ovima s kojima glavni lik ostvaruje interakciju. Prilaskom glavnog lika NPC-u (označenim objektima u prvoj razini, kupcima u drugoj, ježevima u trećoj) aktiviraju se njihovi*collideri*, koji se ponašaju poput okidača, te se prikazuje zadatak unutar prozora (eng. *canvas*[6]).



Slika 17 *Collider (zeleni pravokutnik) na ježu*

[4]*collider*–komponenta unutar *Unityja*koja definira oblik objekta u svrhu fizičkog sudara

[5]eng. *Non-player character* - likovi/objekti unutar igrice kojima igrač ne upravlja

[6]eng. *canvas* – hrv. platno; komponenta unutar *Unityja*unutar koje se stavljaju svi UI (eng. user interface – hrv. korisničko sučelje) elementi u igri

Svi odgovori unutar zadataka su oblikovani poput gumbova (eng. *Button* [7]) kojima su pridijeljene odgovarajuće slike s ARASAAC-a i njihovo ponašanje je skriptno određeno.

Kroz cijelu igru se u pozadini mogu čuti glazba i tonovi za točno/netočno kada se odabere odgovor. Na početku svake razine su kratke upute koje upoznaju igrača s pričom i korištenjem potpomognute komunikacije u raznim situacijama. Igraču je omogućeno uključivanje ili isključivanje navedenih elemenata igre u postavkama na uvodnom zaslonu. U Web inačici klikom na gumb za izlaz prikazuje se završni ekran gdje se nudi i mogućnost ponovnog pokretanja igre nakon zatvaranja prozora s informacijama (*Slika 13*), a u Desktop inačici se zatvara prozor igre čime se igra u potpunosti završava.

V. ZAKLJUČAK

Igra *Pričajmo slikama* osmišljena je i dizajnirana na način prilagođen većini korisnika, pogotovo zbog korištenja dodatnih postavki kojima korisnik igru dodatno može prilagoditi sebi. Zbog formata igre ona je pogodna i za djecu mlađeg uzrasta, koja bi trebala samo znati čitati pa tako članove društva možemo educirati od ranog uzrasta. Educiranje u obliku igre zbog svoje interaktivnosti prikladno je i za starije jer im lako može zaokupiti pažnju. Cijela igre osmišljena je i ostvarena iz perspektive osobe koja pomaže osobama s teškoćama kako bi se razvila dodatna empatija korisnika, a naglasak je stavljen na pozitivne emocije kroz svakodnevne primjere i vedre sadržaje. Na početku je bilo potrebno odabrati želi li se utjecati na korisnika pozitivnim ili negativnim emocijama. Iako postoji mogućnost za snažniji utjecaj na korisnika kroz poticanje negativnih emocija i izazivanje potresenosti koje bi posljedično moglo imati i snažniji utjecaj na pamćenje informacija, nije se željelo djelovati na takav način. Upravo zbog naglaska na pozitivno, ali i zbog jednostavnog i lako shvatljivog sadržaja, igra je prikladna za djecu te se može koristiti za edukaciju u osnovnim i srednjim školama kako bi se okolinu pripremilo na učenike s teškoćama koji mogu sudjelovati u svakodnevnoj nastavi pomoću potpomognute komunikacije. Također zbog sažetosti i lakoće upotrebe aplikacija se može koristiti i od strane osoba koje nisu pretjerano vješte s tehnologijom, a od velike bi važnosti bila edukacije osoba koje mogu stupiti u kontakt s osobom s teškoćama u svakodnevnom životu, primjerice osobe iz uslužnih djelatnosti. Nedostatak ovakvog tipa projekta očituje se u zahtjevnosti mjerenja pozitivnog utjecaja na društvo u kratkom vremenu, ali se zbog suradnje sa stručnjacima iz problemskog područja uvelike povećava mogućnost uspješne realizacije projekta te je upravo zato ona od presudne važnosti.

[7]eng. *button* – hrv. gumb; komponenta unutar *Unityja* koja reagira na klik

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[6] Inkscape - vektorsko–grafički program za crtanje distribuiran pod GNU-ovom općom javnom licencom: https://inkscape.org/en/

Unapređenje poslovnih procesa kompanije kroz OHS aplikaciju

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Sažetak – Radom je opisana izrada i implementacija web aplikacije čime je došlo do unapređenja poslovanja i poboljšanja postojećeg procesa praćenja kvalitete rada i ocjenjivanja izvođača radova. Kroz „Occupational Health and Safety“ (OHS) aplikaciju vodi se Ericssonov „Quality Audit System“ (QASIS), odnosno prati se pridržavanje određenih standarda kvalitete izvedenih radova te zaštite na radu i primjena sigurnosti radnika na terenu tijekom obavljanja građevinskih i drugih radova. U radu je pojašnjeno i opisano značenje i važnost implementacije zaštite na radu u organizacijama, Ericssonova načela i način primjene tog sustava u svakodnevnom radu i razlozi zbog kojih se odlučilo ići na izradu aplikacije koja bi omogućila centralizirano upravljanje podataka vezanih za zaštitu na radu i njihovu kasniju lakšu obradu i skladištenje. Naizgled jednostavan proces raspisan je kao koncept - opisan je vremenski slijed, potrebni resursi i ključne kompetencije koje su bitne za izvedbu ovakvog projekta. Opisani su i upotrjebljeni alati (temeljeni na otvorenom kodu) koji su značajno doprinijeli troškovnoj uštedi cijelog projekta, te mogu služiti kao referenca za razvoj drugih projekata ovog tipa. Pokrivena je ukratko i zaštita prilikom implementacije ovakvog rješenja i na koje se sve ranjivosti treba obratiti pozornost. Opisana je i sama aplikacija (izgled, ažuriranje i izvještavanje, razrada rola), te primjena i najbolji izvedeni zaključci iz cijelog projekta i primjene u praksi.

Ključne riječi – zaštita na radu, razvoj web aplikacije

I. ZAŠTITA NA RADU I SIGURNOSTI RADNIKA (OHS) I KVALITETA IZVEDENIH RADOVA (QASIS)

A. Značenje i važnost zaštite na radu

Zaštita na radu je stvaranje, upravljanje i održavanje sigurnog i zdravog radnog okružja, što bi danas trebao biti jedan od temeljnih zahtjeva za svaku kompaniju na tržištu. Sustav osigurava okruženje orijentirano radu na siguran način za svakoga tko radi po zahtjevu određene organizacije.

Cilj zaštite na radu jeste dizajnirati radna mjesta i radne procese kako bi se spriječili loši utjecaji na zdravlje ili ozljede koje se mogu dogoditi za vrijeme radno-uvjetovanog stresa, te zadovoljiti kako zahtjeve kupca, tako i kompanijske zahtjeve poštujući relevantne propise sigurnosti na radu na svim tržištima na kojima kompanija posluje.

Glavno pravilo je primijeniti pristup upravljanja i kontrole rizika kojim se kontrolira i sprječava opasnosti na radu te se na osnovi prijavljenih incidenata analiziraju uzroci i trendovi koji omogućavaju kontinuirano poboljšanje sigurnosti na radu.

Provedba zaštite na radu u kompaniji znači raditi zajedno sa zaposlenicima, klijentima, dobavljačima i drugim zainteresiranim stranama kako bi kontinuirano razvijali radnu okolinu te omogućili razvoj kompetencija i osposobljavanje pojedinačnog i timskog razvoja s ciljem osiguranja odgovarajućih znanja.

Pravodobna i kvalitetna primjena zaštite na radu u organizaciji utječe na:

- moral - svatko ima pravo doći na posao i otići kući bez da bude ozlijeđen tijekom izvođenja svog rada
- pravni aspekt poslovanja – treba učiniti sve potrebno kako bi svakodnevni posao bio u skladu sa svim zakonskim zahtjevima zaštite na radu
- financijsku dobit - postoji realna financijska korist za dobre performanse u pravilnoj provedbi zaštite na radu

B. Zaštita na radu u Ericsson organizaciji

Tvrtka Ericsson uvjerena je da se incidenti, ozljede i izvođenje radova koji mogu loše utjecati na zdravlje mogu spriječiti. Ericssonova vizija je nula teških incidenata. Stoga je zahtjev Ericssona integrirati sustav zaštite na radu s posebnim naglaskom na prevenciju u sve Ericssonove procese koji uključuju prvenstveno građevinske radove, ali i druge radove vezane za gradnju, korištenje, održavanje i razvoj elektroničke komunikacijske infrastrukture i elektroničkih komunikacijskih mreža te geodetskih poslova snimanja infrastrukture i vodova. Na slici 1. prikazan je primjer situacije s kojom se radnici Ericssona susreću prilikom održavanja ili izgradnje.

Slika 1. primjer važnosti implementacije kvalitenog sustava zaštite na radu

Ericsson učinkovito komunicira prema svima u poslovnim procesima pravila nulte tolerancije na ozlijede, tako da zaposlenici, izvođači radova i dobavljači razumiju njihovu svrhu kako bi ih se mogli pridržavati. Odabir ignoriranja pravila nulte tolerancije znači nesuradnju s Ericssonom i gubitak daljnje međusobne poslovne suradnje.

Ericsson organizacija ima interna pravila za vlastite resurse i ima odgovornu osobu za zaštitu na radu i sigurnost i koordinatore zaštite na radu. Internim propisima definirano je da se mora uskladiti standarde zaštite na radu sa svakim ovlaštenim davateljem usluga - „Authorized Service Provider“ (ASP) s kojim ima sklopljen ugovor o izvođenju, odnosno podizvođenju radova. Internim propisima i ugovorima definirani su način praćenja zaštite na radu kroz dio organizacije i osobe zadužene za provođenje internih audita.

C. *Kvaliteta izvedenih radova*

QASIS je Ericssonova metoda za mjerenje i kontrolu kvalitete izrade nakon što su projektne radnje napravljene od strane ovlaštenog davatelja usluga, korištenjem vlastitih djelatnika iz organizacijske cjeline nadležne za zajedničke terenske operacije ili izradom od samog investitora. Metoda je usklađena sa standardima ISO 9001 i TL9000 i dio je procesa u kojem je ova metoda dio svakodnevnog rada u provedbi projekata.

Prednosti metodologije jeste da su rezultati audita usporedivi na globalnoj razini, te da rano sudjelovanje u projektima i brze analize pogrešaka umanjuju troškove, jer je korektivne radnje moguće početi neposredno prije kontrole kvalitete projekta.

Prikupljanje podataka obavlja se na mjesečnoj bazi kako bi mogli napraviti izvještaje do 15. u mjesecu za prethodni mjesec. Pristup globalnoj bazi podataka je ograničen i imaju ga ovlašteni revizori (mogu čitati i pisati u bazu) i menadžeri (samo za čitanje). Na slici 2 prikazan je pregled Ericsson standarda.

Incident Cards	Card Description	Measures – Non Conformance types are depicted in the local audit templates.
	Yellow Card (1st Serious Violation) Major Non Conformance or Continuous Minor Non Conformances (3)	A warning notification with a set time frame to obtain compliance. Agreed 40% Increase in audits at ASP cost for a min of 20 days, with action plan to correct. "Special Measures" at ASP cost may have to be agreed to obtain compliance.
	2 x Yellow Cards (2nd Serious Violation) New or Repeated Serious Violations	2 Yellow Cards are equivalent to a Red Card. Penalties as defined for one yellow card and in addition; 100% Increase in audits at ASP cost for a min of 40 days, with action plan to correct. Supplier exclusion from participating in future bids or tender opportunities for a number of events or time period.
	Red Card (3rd Serious Violation) New or Repeated Serious Violations	Termination rights in accordance with Clauses of the Agreement.

Slika 2. Ericsson standard pri primjeni pregleda

II. IMPLEMENTACIJA APLIKACIJE ZA UPRAVLJANJE KVALITETNOM ZAŠTITOM NA RADU

A. *Misija*

Zbog velike količine odrađenih projekata i velikog broja izvođača s kojima Ericsson surađuje, ubrzo je postalo evidentno da ispunjavanje i prikupljanje upitnika i prateće dokumentacije radi praćenja performansi izvođača radova, odnosno pridržavanja naputaka vezanih za zaštitu na radu neće biti provedivo klasičnim načinom, odnosno ispunjavanjem generičkih papirnatih špranci, te da će se pojaviti problem arhiviranja i obrade podataka i kasnijeg brzoga pretraživanja radi detaljnije analize.

U organizaciji je stoga pokrenuta inicijativa za izradom alata internim resursima s ciljem razvijanja web i mobilne aplikacije koja bi se koristila na terenu u svrhu bržeg odrađivanja upitnika, te skladištenja i obrade podataka u svrhu izvještavanja i donošenja kvalitetnijih odluka.

B. *Hodogram, vremenski slijed i faze projekta*

Proces izrade aplikacije uključuje, osim zainteresiranih strana, i niz drugih stručnjaka u organizaciji koji osiguravaju da se proces odvija sukladno internim propisima i pravilima struke tako da rezultat bude kvalitetan proizvod koji će zadovoljiti standarde kvalitete, sigurnosti, i druge postavljene norme. U tom procesu sudjeluju:

- Poslovni analitičar: snimanje postojećeg procesa, prikupljanje dokumentacije i izrada specifikacije,
- Voditelj projekta: opis projektnog zadatka, vremenskog plana i upravljanje resursima,
- Administrator sustava: kreiranje virtualnih servera, instalacija potrebnog software-a, konfiguracija mreže,
- Administrator baze podataka: priprema baze podataka, verifikacija i uvoz postojećih prikupljenih podataka,
- Razvojni inženjeri: razvoj aplikacije, prilagodba skripti za promjene u bazi podataka, testiranje,

- Upravitelj za sigurnost: testiranje u izoliranom sustavu, instalacija sigurnosnih certifikata,
- Razvojni programer: finalno puštanje aplikacije u rad na produkcijski server
- Voditelj tima: izrada uputa za organizaciju, dokumentiranje novog procesa te preuzimanje odgovornosti za daljnje upravljanje i održavanje alata.

Nakon inicijalne analize potreba, prikupljeni su minimalni zahtjevi koje aplikacija trebala omogućiti:

- prikupljanje podataka o evaluaciji propisa zaštite na radu,
- statistički prikaz unesenih podataka: ukupan broj pregledanih lokacija u odnosu na ukupan broj pozitivno ocjenjenih lokacija, listu najboljih i najgorih podizvođača, ukupno pregledanih u odnosu na pozitivno ocijenjene i za tip gradilišta/terena i obujam poslova,
- automatizirani izračuni: za svakog pojedinog izvođača napraviti sažetak upitnika napravljenih za svaki pregled. Upitnik mora pokazati koliko je negativnih ocjena prema kategorijama na svim lokacijama, i rangirati prema definiranim formulama,
- kreiranje izvještaja: omogućiti izvoz podataka u Excel tablicu, pripremu pojedinačnih upitnika za ispis u pdf formatu,
- osigurati kopiju podataka u formi statičkih web stranica koje će se moći pohraniti na vanjski medij za potrebe daljnje distribucije.

Voditelj projekta je odlučio projekt podijeliti na dvije faze. U prvoj fazi se isporučuje glavni projektni zadatak – upotrebljiva web aplikacija sa svim ispunjenim zahtjevima postavljenim od strane budućih korisnika propuštena na intranet mreži.

- Prikupljanje specifikacija: 2 tjedna
- Konfiguracija sklopovlja, instalacija programa, mrežna konfiguracija: 1 tjedan
- Priprema baze podataka. 1 tjedan
- Razvoj i testiranje: 4 tjedna
- Dokumentiranje: 1 tjedan

U drugoj fazi dodatno se razrađuje administracijsko sučelje, dodatni izvještajni moduli, višejezično sučelje, mobilna aplikacija i propuštanje u internet mrežu.

- Razvoj i testiranje: 4 tjedna
- Sigurnosni penetracijski testovi: 1 tjedan
- Dokumentiranje: 1 tjedan

C. Programi, tehničke specifikacije i sigurnost

Nakon prikupljanja podataka od zainteresiranih strana, odlučeno je da će alati za razvoj, te razvojno i produkcijsko rješenje biti bazirano na rješenjima otvorenog koda, čime se dodatno minimizira trošak razvoja i kasniji trošak održavanja. Prednost takvog rješenja je osim troškovne i široka podrška od strane svjetske zajednice čime je osigurana primjena najnovijih tehnoloških i sigurnosnih rješenja te kvalitetna dokumentacija.

Operativni sustavi na serverima:
CentOS - Linux distribucija koja pruža računalnu platformu podržanu od strane zajednice, a koja je funkcionalno kompatibilna s Red Hat Enterprise Linuxom [2].

HTTP proxy i web serveri:
Apache - HTTP poslužitelj za koji osigurava siguran, učinkovit i proširiv poslužitelj koji HTTP usluge usklađuje s trenutnim HTTP standardima [3].

Baza podataka:
MariaDB - relacijska baza podataka razvijana od strane zajednice kao poseban projekat nastao originalno od strane MySQL relacijske baze podataka sustava, s ciljem da ostane slobodna za korištenje prema GNU GPL licencama [4].

Server side skriptni jezik:
PHP 7 - brzo i robusno rješenje koje u potpunosti zadovoljava sve zahtjeve postavljene pred razvojni tim [5]. Za razvojni framework je odabran sada već široko prihvaćen Laravel - koji uključuje „Object-relational mapping“ (ORM) klasu za kreiranje modela i komunikaciju sa bazom podataka – dostupan kao samostalni paket Eloquent [6]. Inicijalna instalacija frameworka i dodatnih paketa je odrađena pomoću Composera - alata za upravljanje ovisnim paketima u aplikacijama napisanim u PHP programskom jeziku. Pomoću alata Composer moguće je instalirati i ažurirati sve pakete koji su navedeni kao potrebni u aplikaciji koju programer razvija. Sami paketi su povlačeni s najveće baze PHP paketa Packagist.

Javascript i CSS:
Jquery - malena i brza JavaScript biblioteka. Omogućava da stvari poput manipulacije HTML koda, rukovanja događajima, animacije i rad s Ajax zahtjevima budu pisani brže i jednostavne pomoću jednostavnog API-ja koji funkcionira u svim suvremenim web preglednicima [7]. Twitter Bootstrap - biblioteka HTML-a, CSS-a i JavaScript-a, razvijena s ciljem da omogući i olakša razvoj web formi kao i razvoj naprednih web komponenti [8].

Upravljanje verzijama koda i kolaboracija:
Tortoise SVN - jednostavno rješenje za upravljanje verzijama koda u MS Windows okruženju bez potrebe pokretanja naredbenog retka [9].

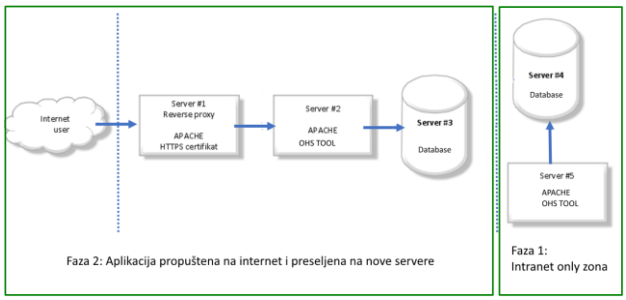
Razvojni uređivač koda:
MS Visual Studio Code - izuzetno brzi i proširivi uređivač programskog koda koji osim samog uređivanja koda podržava i praćenje verzija napisanog izvornog

koda (source control) i upravljanje greškama pri izvršavanju i testiranju (debuging) [10].

Klijentska strana:
Svi suvremeni web browseri s podrškom za HTML 5 i Javascript.

U Ericssonu se mrežnoj sigurnosti i zaštiti podataka pridodaje maksimalna pozornost. Testovi za provjeru sigurnosti aplikacije odrađuju se u alatu Netsparker.

Server za bazu podataka i mrežni server, te redovni backup je osiguran 0-24 od strane Ericsson IT podrške. Slika 3 shematski prikazuje sve komponente koje se koriste u obje razvojne faze.



Slika 3. Faze implementacije i pogled na poslužiteljske zahtjeve

U prvoj fazi projekta, kada je aplikacija u sigurnoj intranet zoni, predviđeno je da korisnici aplikaciji pristupaju preko Ericsson intranet mreže ili zaštićene internet veze. Za pristup moraju upisati svoje korisničko ime i lozinku, za čiju ovjeru je zadužen lokalni imenik kojem se pristupa putem „Lightweight Directory Access Protocol“ (LDAP) protokola.

U drugoj fazi projekta predviđeno je bilo propuštanje aplikacije prema internetu preko zakupljene domene. Komunikacija prema van bi se odvijala preko reverse proxy servera na kojem je instalirani HTTPS certifikat. Aplikacija na proxy serveru je samo maska prema korisniku i šalje kriptirane zahtjeve prema zaštićenoj zoni u kojoj obrađujemo dobivene upite i vraćamo nazad alatu rezultate upita u JSON formatu. Alat će dobivene podatke obrađivati i prema dobivenim podacima generirati prezentacijske poglede.

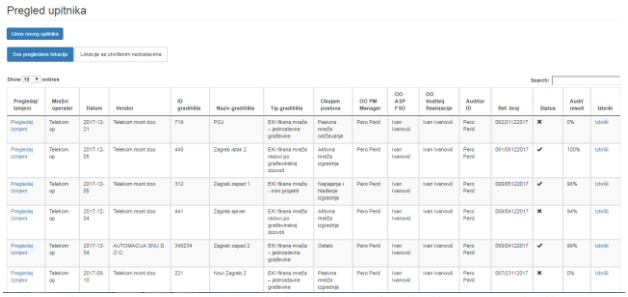
Osim zaštite putem proxy servera i slanja podataka putem HTTPS protokola, obratila se pozornost na implementaciju dodatnih razina zaštita u samoj aplikaciji:

- regeneracija session_id (otežava session hijacking)
- Obrane od Cross-site scripting (XSS)
- Obrane od Cross-site request forgery (CSRF)
- Izbjegavanje SQL injection napada

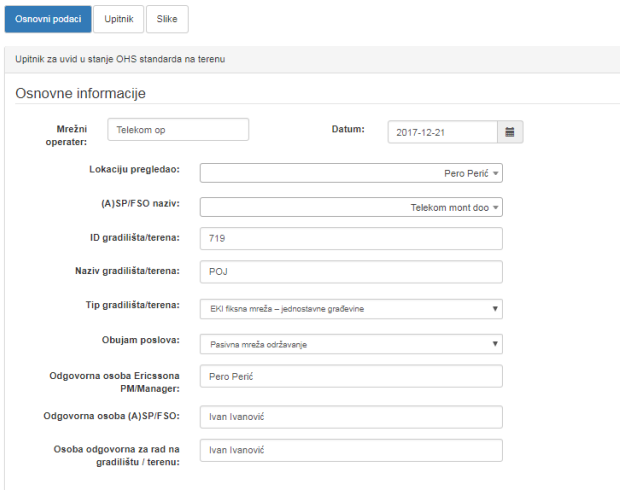
D. Unos i izmjena OHS upitnika

Primarna svrha aplikacije jeste unos, izmjena, automatska evaluacija i kasnija pretraga upitnika i izvoz podataka.

U tu svrhu je razvijen primarni modul aplikacije zadužen za unos, izmjenu i pretragu OHS upitnika. Pretraga i pregled svih upitnika prikazana je na slici 4. Sam upitnik je podijeljen na 3 funkcionalna djela. Prvi dio se odnosi na generalne, odnosno osnovne informacije o ispitaniku i lokaciji i auditoru, što je prikazano na slici 5.



Slika 4. Osnovni pogled na listu odrađenih OHS upitnika



Slika 5. Osnovne infomacije o lokaciji, auditoru, ispitanicima i dokumentu

Drugi dio je unos podataka definiranih sa OHS obrasca, a treći dio je dio za upravljanje dokumentacijom (slikama).

U osnovnom dijelu se unose sljedeće informacije:

- Mrežni operater: Erissonov kupac usluge
- Datum audita
- (A)SP/FSO naziv: predefinirano vrijednostima iz postojeće baze podataka i bira se iz padajućeg izbornika
- ID gradilišta/terena
- Naziv gradilišta/terena
- Tip gradilišta/terena: tipovi su predefinirani vrijednostima iz postojeće baze podataka i biraju se iz padajućeg izbornika
- Obujam poslova: tipovi su predefinirani vrijednostima iz postojeće baze podataka i biraju se iz padajućeg izbornika
- Odgovorne osobe su polja s imenom i prezimenom koji se ručno unose.
- Auditor: polje koje se automatski popunjava prema tome tko se ulogirao u aplikaciju, uz uvjet da ga je moguće po potrebi mijenjati od strane

osoba koje su posebno ovlaštene za unos promjena.

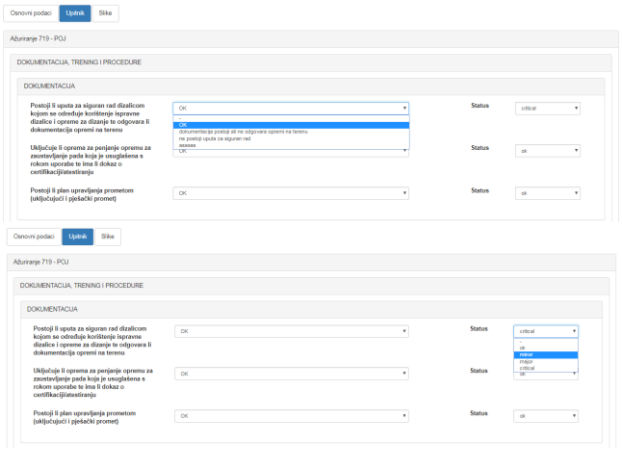
- Referentni broj audita: polje s vrijednošću u formatu BBB/DDMMYYYY i unosi se automatski, uz uvjet da ga je moguće mijenjati. BBB je broj koji predstavlja koliko puta je rađen audit, na njega se dodaje odabrani datum odrađenog audita

Obrazac:

- Upitnik, odnosno obrazac se sastoji od ukupno 22 pitanja podijeljena u 4 grupe, a svaka grupa je podijeljena na podgrupe. Inicijalno stanje je zamišljeno kao da nisu pronađeni nedostaci, odnosno lokacija se boduje po svim pitanjima kao OK, te da je ukupna ocjena lokacije/audita 100%. Ukoliko auditor pronađe neke nepravilnosti unosi ih za točno određeno pitanje (grupu/podgrupu) odabirom iz padajućeg izbornika.

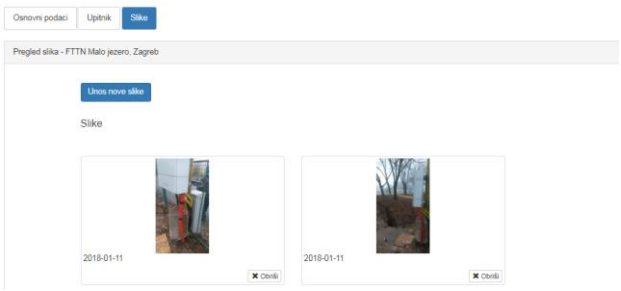
- Nedostatak može biti ocijenjen kao MINOR, MAJOR i CRITICAL (polje "status")

Dio upitnika za unos podataka o nedostacima prikazan je na slici 6.



Slika 6. Unos i izmjena OHS audita

Zadnji tab u dijelu za dodavanje / uređivanje audita omogućava dodavanje fotografija ili drugih priloga s datumom izvršenog audita, uz mogućnost unosa komentara za svaku pojedinu fotografiju. Ovaj dio upitnika prikazan je na slici 7.



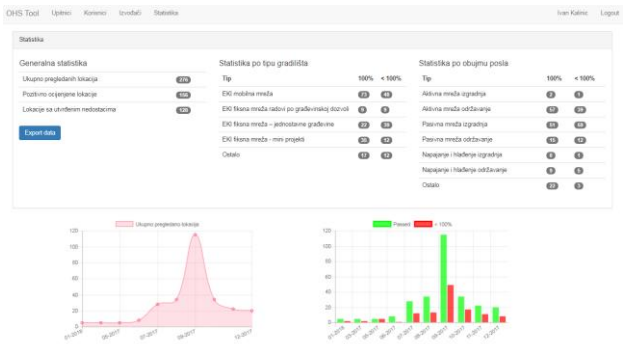
Slika 7. Unos i izmjena pripadajuće dokumentacije / slika

E. *Izvještaji i izvoz*

Nakon unosa upitnika, predviđeno je da se svaki upitnik na osnovu unesenih podataka automatski kategorizira i evaluira ASP ili FSO. Svaka ocjena ima svoju težinu u sukladno težini se oduzima od ukupnog postotka.

Primjer: 1 MAJOR, 2 x MINOR = 100% - 5% - 2x1% = 93%. Ukoliko postoji pitanje koje ima ocjenu CRITICAL ocjena je odmah 0%.

Obrasci/lokacije sa vrijednošću manjom od 95% smatraju se nekorektni i moraju se prikazivati na početnoj stranici pod izbornikom "negativno ocjenjeni upitnici". Primjer izvještaja je prikazan na slici 8. Također, omogućeno je i brzo generiranje izvještaja za pojedinačne upitnike, kao što je prikazano na slici 9.



Slika 8. Primjer generiranog izvještaja u aplikaciji

Slika 9. Piprema za ispis u pdf / štampač

F. *Administracija korisnika*

U aplikaciji su definirane 4 role:

- Admin – korisnik sa apsolutnim mogućnostima upravljanja aplikacije. Može unositi nove

korisnike, upravljati listom ASP-a, upravljati listom upitnika i kreirati izvještaje.

- Superuser – korisnik aplikacije koji može upravljati listom upitnika i kreirati izvještaje, te upravljati listom ASP-a.
- User – korisnik koji može kreirati novi audit ili uređivati postojeći koji je kreirao. Korisniku je vidljiv popis svih obrazaca koje je kreirao i ispunio i ne vidi druge obrasce osim svojih. Nema mogućnosti izvoza podataka niti pristup drugim modulima.
- Manager – pristup izvještajima i pojedinačnim OHS obrascima u načinu čitanja. Nema mogućnosti izvoza podataka niti pristup drugim modulima.

G. Administracija izvođača

Modul u kojem se upravlja listom izvođača nad kojima se obavljaju pregledi pridržavanja zaštite na radu. Baza izvođača je povezana s postojećom Ericsson bazom u kojima su izvođači s kojima je sklopljen ugovor o suradnji. U bazi su upisani svi relevantni podaci vezani za izvođače (podaci o firmi, kontakt osobe i ostali relevantni podaci) iako je zamišljeno da u ova aplikacija prvenstveno služi za pregled, a ne sam unos i izmjenu podataka. Posebnim internim procesom definirano je koje ovlaštene osobe u organizaciji imaju pravo izmjene podataka ili unos novih izvođača u bazu podataka.

H. Administracija baze pitanja i odgovora

Modul u kojem se administriraju grupe, podgrupe, pitanja i pridružuju odgovarajuće korektivne preporuke za slučaj negativno ocijenjenog statusa pitanja. Za potrebe višejezičnog sustava predviđeno je posebno administriranje pitanja i pripadajućih odgovora, odnosno prijedloga korektivnih radnji iz upitnika za svaku pojedinačnu jezičnu grupu.

III. ZAKLJUČAK

Izradom aplikacije za praćenje upitnika i postignutih rezultata ispunjen je strateški cilj koji si je kompanija postavila radi podizanja sustava upravljanja kvalitetom na višu razinu. Uspješno je implementirano rješenje koje je osiguravanjem unosa u centralizirani sustav, izvještavanjem i praćenjem ispunilo sva očekivanja managementa, te doprinijelo dodatnoj vrijednosti poslovanja i unaprijedila postojeći proces cijele organizacije.

Dokumentiranjem procesa pokriveni su rizici, osigurano je bolje i transparentno planiranje, realizacija, optimizacija utroška resursa i dodatno se olakšava buduće planiranje poslovanja i potrebnih resursa.

Na operativnoj razini višestruko je ubrzano prikupljanje i praćenje izvedbe izvođača i vlastite organizacije, te njihovog pridržavanja pravila zaštite na radu, a sama analiza je olakšana automatiziranim praćenja ključnih pokazatelja performansi „Key performance parameters“ (KPI) izračunom.

Ispitivanjem tržišta zaključeno je da primjena modernih i kvalitetnih aplikacija u svim suvremenim organizacijama treba biti sastavni dio sustava upravljanja kvalitetom. Implementacija ovakve aplikacije unutar organizacije donosi brojne uštede – težeći uredu bez papira, te usklađivanju poslovanja i skladištenju podataka sukladno propisanim normama. Razvojem ovakve aplikacije stvoren je preduvjet za komercijalnu ponudu aplikativnog rješenja u budućnosti drugim zainteresiranim stranama – što interno u globalnoj Ericsson organizaciji, što drugim vanjskim partnerima kojima bi ovakav tip aplikacije bio tržišno zanimljiv zbog zakonske regulative i poštivanja ISO standarda u poslovanju.

Ultimativni cilj bi bio skladištenje podataka o izvođačima i njihovoj usklađenosti s normama i kvalitetom u centralizirani oblak, čime bi podaci kasnije bili dostupni svim zainteresiranim te omogućili donošenje kvalitetnijih odluka u svakodnevnom radu, te dodatnim smanjenim brojem ozljeda.

LITERATURA

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Važnost analitičkog pristupa poslovnim procesima u telekomunikacijama

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***Sažetak* – Na temelju navedenih karakteristika poslovnih procesa u telekomunikacijama u radu je istaknuta važnost analitičkog pristupa i rada na definiranju sustavnog praćenja odvijanja poslovnih procesa. Naglašena je potreba za definiranjem tehnika i metodologija koje to omogućuju i na temelju kojih se može pratiti uspješno odvijanje poslovnih procesa. Predložene su tehnike koje uključuju definiranje točki u procesu kroz koje se prati uspješno odvijanje poslovnih procesa te definiranje procesnih koraka čija realizacija ima velik značaj na poslovne procese te definiranje vrijednosti čijim se praćenjem može, kroz analitički pristup, uspješno upravljati s potrebnim promjenama za optimalno odvijanje poslovnih procesa. Dani su primjeri modela poslovnih procesa koji omogućuju primjenu navedenih tehnika.**

Ključne riječi - poslovni procesi; modeli poslovnih procesa; analitički pristup; telekomunikacije

I. UVOD

Poslovni procesi koji se koriste na području telekomunikacijama vrlo su složeni procesi u kojima se, osim slijeda različitih procesnih koraka (akcija), u značajnoj mjeri koristi automatska konfiguracija mrežnih elemenata. Kako se radi o vrlo dinamičnom i konkurentnom tržištu, važnost primjene dobro definiranih i optimalnih poslovnih procesa vrlo je velika. S obzirom da zahtjevi korisnika obuhvaćaju velik spektar različitih usluga i njihovih kombinacija te da se radi o velikom broju korisničkih zahtjeva, vrlo je teško pratiti odvijaju li se poslovni procesi na ispravan i optimalan način, kako u dijelu upravljanja, tako i u operativnom dijelu. Pogled i praćenje procesa kroz ova dva aspekta razlikuju se u detaljima i aktivnostima koje se pokreću nakon uočavanja određenih prostora za poboljšanjima ili promjenama unutar poslovanja. Osiguranje izvještaja na svim razinama upravljanja i pravovremeni dostup do podataka vrlo je bitan i potrebno je definirati stabilne točke unutar procesa za osiguravanje praćenje faza procesa, kao i s kraja na kraj. Zbog toga je, osim efikasnosti u odvijanju procesa i načina dizajna, potrebno voditi računa o fiksnim točkama u procesu na osnovu koji će se raditi buduća analitika i analiza na svim nivoima upravljanja.

Analitički pristup omogućava sustavno praćenje poslovnih procesa te otkrivanje točaka u procesu u kojima se oni ne odvijaju na ispravan način. Jedna od tehnika koja omogućava takav pristup je model procesa u kojem su definirane točke kroz koje je moguće uz određenu metodologiju pratiti ponašanje poslovnog procesa. Na taj se način može pratiti odvijanje poslovnih proces kroz njihove faze. Druga je tehnika praćenje poslovnih procesa čije se odvijanje može dovesti u međusobnu povezanost, a time i uspješnost u njihovom odvijanju. Kod poslovnih procesa gdje je visok stupanj automatizacije potrebno je posebnu važnost, kroz analitički pristup, posvetiti stupnju uspješnosti automatske konfiguracije mrežnih elemenata što odgovara postavljenim kriterijima za određene usluge i tehnologije.

U radu je, kroz primjere određenih modela poslovnih procesa, prikazan način primjene definiranih tehnika za praćenje uspješnosti odvijanja poslovnih procesa. Kako se u telekomunikacijama odvija velik broj poslovnih procesa koji se sa svojim karakteristikama međusobno dosta razlikuju, potrebno je definirati više tipova modela poslovnih procesa na koje se primjenjuju različite tehnike za praćenje odvijanja poslovnih procesa, a time i različiti analitički pristupi.

II. TIPOVI POSLOVNIH PROCESA U TELEKOMUNIKACIJAMA

S aspekta realizacije telekomunikacijske usluge [1] mogu se razmatrati četiri osnovne kategorije poslovnih procesa:

A. Uključenje telekomunikacijske usluge

B. Promjene na telekomunikacijskim uslugama

C. Otklanjanje smetnje na telekomunikacijskoj usluzi

D. Isključenje telekomunikacijske usluge

Navedeni procesi koriste se za realizaciju velikog broja usluga i zbog toga je unutar svake od navedenih kategorija poslovnih procesa potrebno osigurati veliki broj poslovnih procesa koji se međusobno mogu znatno razlikovati po svojim karakteristikama.

Telekomunikacijske usluga kao što su govorna usluga, usluga pristupa Internet mreži i IPTV (IP Television) spadaju u usluge širokog tržišta i karakteristika procesa za realizaciju tih usluga su velik broj pokrenutih procesa, predefinirani slijed akcija, potreba za visokom razinom automatizacije kod aktivacije mrežnih elemenata i potreba za brzom realizacijom usluga [1]. U ovu skupinu procesa spadaju i procesi za realizaciju veleprodajnih usluga reguliranih tržištem. Primjer takvih veleprodajnih usluga su portiranje numeracije drugom operatoru, iznajmljivanje kapaciteta pristupne mreže drugom operatoru (na primjer,

bakrena parica ili optička nit), predodabir operatora i tako dalje.

Telekomunikacijske usluge koje se realiziraju preko podatkovne telekomunikacijske mreže ne spadaju u usluge širokog tržišta i njihova karakteristika su složenost realizacije, nemogućnost potpunog unaprijed definiranja slijeda akcija, niska razina automatizacije kod aktivacije mrežnih elemenata [1]. Primjer takve usluge je uključenje VPN (Virtual Private Network) usluge preko MetroEthernet mreže. I u ovu skupinu se mogu ubrojiti procesi za realizaciju određenih veleprodajnih usluga vezanih uz podatkovne usluge.

I kod procesa otklanjanja smetnji na telekomunikacijskim uslugama karakteristika je ograničena mogućnost unaprijed definiranja slijeda akcija [1]. No, ovisno o usluzi za koju se proces otklanjanja smetnje pokrenuo, u dobroj se mjeri mogu predvidjeti potrebne akcije na temelju različitih parametara kao što je opis greške od strane korisnika ili rezultat mjerenja kvalitete korisničke linije. Ovo se prvenstveno odnosi na usluge širokog tržišta. Za složenije usluge, kao što su podatkovne usluge, mogućnost za ovakvo unaprijed definiranje mogućih akcija u sklopu procesa otklanjanja smetnji znatno je ograničeno.

Složenost telekomunikacijskog tržišta te korištenje različitog spektra usluga uvjetuje potrebu za razvojem složenih poslovnih procesa koji u sebi sadrže kombinacije poslovnih procesa definiranih na početku ovog poglavlja. U tim slučajevima potreba za modeliranjem poslovnih procesa i analitičkim pristupom u svrhu praćenja odvijanja poslovnih procesa dobiva na dodatnoj težini.

III. TEHNIKE ZA PRAĆENJE ODVIJANJA POSLOVNIH PROCESA

Analitički pristup poslovnim procesima u telekomunikacijama važan je kod definiranja načina praćenja uspješnosti odvijanja procesa i određenih procesnih koraka, praćenja učinkovitosti aktera poslovnih procesa, definiranja „uskih grla“ u procesu, …

Neke od tehnika koje se mogu koristiti u sklopu analitičkog pristupa poslovnim procesima jesu:

A. *Definiranje točaka u procesu koje omogućuju lakše praćenje odvijanja poslovnog procesa, kako kroz faze procesa, tako i s kraj na kraj*

B. *Definiranje KPI (ključnih pokazatelja poslovanja) pokazatelja za lakše praćenje učinkovitosti aktera poslovnih procesa i performansi poslovnih procesa*

C. *Praćenje odvijanja pojedinih procesnih koraka koji imaju veći utjecaj na performanse procesa*

Definiranjem točaka u procesu omogućuje se analitički pristup kojim se može pratiti odvijanje pojedinih faza poslovnih procesa. Tako se mjerenjem vremena prolaska poslovnog procesa između određenih točaka u procesu može pratiti efikasnost odvijanja poslovnog procesa. Neke točke u procesu mogu biti postavljene tako da njihovo pojavljivanje znači greške u procesu koje se ne bi smjele često ponavljati. Prolazak poslovnog procesa kroz određene točke u procesu otklanjanja smetnji može definirati učestalost određenog tipa grešaka koji, na primjer, zahtijeva odlazak djelatnika kod korisnika.

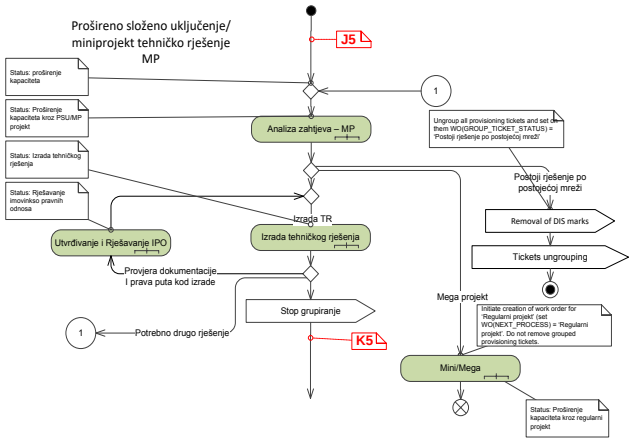
Definirani KPI pokazatelji daju analitičke vrijednosti na temelju kojih se mogu definirati željene te pratiti postojeće performanse poslovnih procesa. Na temelju ovih pokazatelja mogu se vrijednosti koje se dobiju analitičkim pristupom uspoređivati s vrijednostima definiranim na temelju željenog odvijanja poslovnih procesa. Ti se rezultati mogu prikazati kroz različite tipove izvještaja. Dodatno, ponašanje poslovnih procesa moguće je pratiti tijekom njihovog odvijanja što daje mogućnost pokretanja različitih postupka u cilju efikasnijeg odvijanja i realizacije poslovnog procesa. Primjer takvog postupka je prikaz akterima poslovnog procesa koliko je preostalo vremena da se proces odradi unutar definiranog vremenskog okvira za uspješno realiziran poslovni proces ili prikaz uspješnosti odvijanja automatskih aktivacija i praćenja uspješnosti ili određenih nepravilnosti.

Kao što je već prethodno navedeno u radu, jedna od osnovnih obilježja poslovnih procesa za realizaciju usluga širokog tržišta je visokom razinom automatizacije kod aktivacije mrežnih elemenata. Uspješnost realizacije ovakve aktivacije uvelike ima utjecaj na performanse poslovnog procesa. Stoga je vrlo važno definirati model kroz koji se na efikasan način može pratiti razina uspješnosti ovih akcija te uzrok pojave grešaka.

IV. PRIMJERI MODELA POSLOVNIH PROCESA

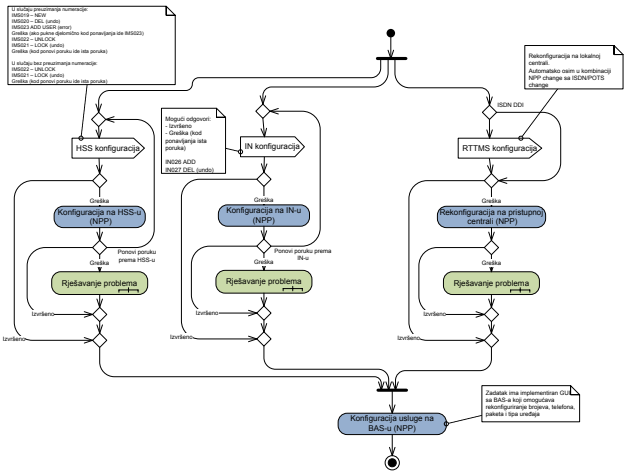
Da bi se definirane tehnike za praćenje poslovnih procesa što uspješnije primijenile potrebno je imati model poslovnog procesa. Model, uz primjenu standardnih elemenata za modeliranje, jasno definira procesne korake i odvijanje poslovnog procesa i kroz njega je moguće na lakši način definirati točke u procesu koje su predmet praćenja kroz analitički pristup. U [1] i [2] predstavljeni su modeli poslovnih procesa korištenjem UML (Unified Modeling Language) dijagrama aktivnosti te modeliranje u alatu Aris korištenjem EPC (Event-driven Process Chain) jezika za modeliranje. Korištenjem ovakvih modela omogućava se razvoj i analiza poslovnih procesa od trenutka ideje i specifikacije poslovnih procesa do same implementacije i korištenja poslovnih procesa kroz sustave za podršku kao što su različiti sustavi za upravljanje tijekom poslova (workflow alati). U [3] i [4] dani su prijedlozi za način specificiranja i modeliranja složenih telekomunikacijskih procesa. Vrlo je bitno da se kod razvoja poslovnih procesa razmišlja o mogućnosti praćenja performansi samih poslovnih procesa što osigurava uvjete za pravovremenom ispravkom u procesnim koracima u slučaju kada se proces ne odvija na željeni način.

Na slici 1 prikazan je model dijela poslovnog procesa modeliranog kroz UML dijagram aktivnosti kroz koji se definiraju točke u procesu (J5, K5) kao kontrolne točke u procesu i kroz njihovu kontrolu provodi se praćenje odvijanja poslovnog procesa. Proces pripada tipu procesa u kojem je puno ručnih zadataka i niska razina automatizacije.



Slika 1: Primjer modela poslovnog procesa s definiranim kontrolnim točkama

Nasuprot modelu prikazanog na slici 1, na slici 2 prikazan je model dijela procesa u kojem je razina automatizacije vrlo visoka. Konfiguracija mrežnih elemenata je automatska i samo u slučaju pojave greške prilikom konfiguracije pojavljuju se zadaci za aktere poslovnog procesa kako bi se konačno realizirala aktivacija. U ovom slučaju je vrlo bitno pratiti postotak uspješnosti automatske konfiguracije mrežnih elemenata jer neuspješna automatska aktivacija ima vrlo negativan učinak na optimalno izvođenje poslovnog procesa i potrošnju ljudskih resursa.

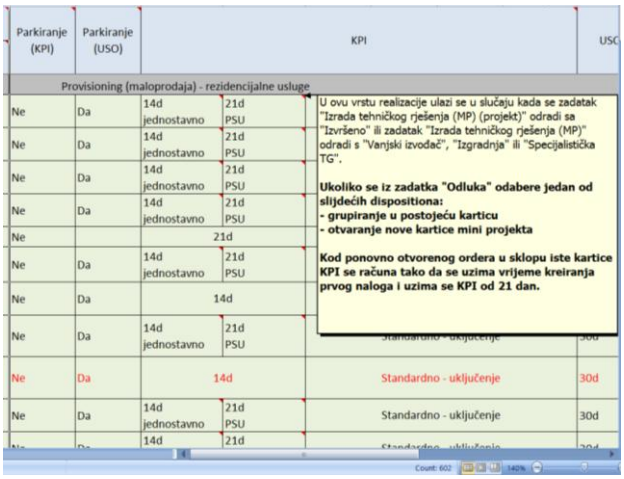


Slika 2: Primjer modela poslovnog procesa s visokom razinom automatizacije

Način modeliranja predstavljen na slikama 1 i 2 uspješno se koristi u HT-u za potrebe implementacije programske podrške u sustavima za upravljanje tijekom poslova. Strukturiranost i jasan prikaz procesnih koraka jedna je od osnovnih značajki i prednosti ovakvog načina modeliranja što je i omogućilo njegovu uspješnu primjenu. No, bez točnosti i ažurnosti uspješnost primjene modela može se narušiti, pa je to jedan od problema s kojima se susreće njegova primjena. Postoji prostor za poboljšanje modela na čemu se radi ovisno o poslovnim potrebama za promjenama. Jedan od primjera poboljšanja je dodavanje poslovnih pravila koja se koriste tijekom odvijanja poslovnih procesa. Trenutačno sva poslovna pravila nisu vidljiva u modelu, a bitna su za usmjeravanje i kontrolu tijeka procesa. Na primjer, definiranje i prikaz kontrola u odabiru opcija za izvršavanje zadatka od strane aktera poslovnog procesa. Ovakav način nadogradnje modela zahtijeva korištenje dodatnih alata za detaljno definiranje zadataka i poslovnih pravila za aktere poslovnih procesa gdje će se definirati izlazne opcije iz zadatka (način izvršavanja zadatka), potrebni podaci za uspješno izvršavanje zadatka, poslovna pravila u izvršavanju zadatka i tako dalje. Ovakav način nadogradnje modela daje dodatan naglasak na potrebi za točnošću i ažurnosti modela.

Modeli poslovnih procesa uspješno se koriste i kao podloga za definiranje KPI pokazatelja jer se u njima lako mogu uočiti točke u procesu između kojih je potrebno definirati mehanizam praćenja uspješnog odvijanja procesa.

Model definiranja KPI pokazatelja prikazan je slikom 3. Zbog preglednosti prikazan je samo segment modela. Za svaki KPI definirani su kriteriji za njihov odabir te parametri na temelju kojih se ti KPI pokazatelji izračunavaju. Ovaj se model uspješno koristi kao podloga za implementaciju praćenja definiranih KPI pokazatelja u sklopu sustava za upravljanje tijekom poslova.



Slika 3: Primjer modela za definiranje načina praćenja KPI pokazatelja

V. REZULTATI PRIMJENE PREDLOŽENIH TEHNIKA I MODELA

Kao rezultat primjene u ovom radu predloženih tehnika praćenja odvijanja poslovnih procesa i modela poslovnih procesa u HT-u se koriste različiti izvještaji i forme za prikaz tijeka odvijanja poslovnog procesa.

Kroz izvještaje prate se različite brojčane vrijednosti kojima se definira uspješnost u odvijanju poslovnih procesa ili uspješnost u radu aktera poslovnih procesa. Primjer su ispunjenost KPI pokazatelja s obzirom na tip procesa, resurse koji sudjeluju u procesima, s obzirom na vremena definirana od strane Regulatora i tako dalje.

Osim tih izvještaja koriste se izvještaji kojima se direktno prate performanse poslovnih procesa. Na slici 4 je primjer takvog izvještaja kroz koji se prati uspješnost automatske konfiguracije mrežnih elemenata što ima značajan utjecaj u odvijanju poslovnih procesa koji su najčešći.

Na slici 5 prikazan je dio forme koji ja na raspolaganju akterima poslovnog procesa i u kojoj je vidljivo koliko je vremena preostalo za zadovoljavanje postavljenih KPI

pokazatelja. U koloni PKPI je navedeno vrijeme preostalo za zadovoljavanje postavljenih KPI pokazatelja za fazu procesa unutar koje se nalazi zadatak, a u koloni KPI se nalazi preostalo vrijeme za zadovoljavanja KPI pokazatelja na razini cijelog procesa. Na ovaj se način omogućava akterima poslovnog procesa da svoje aktivnosti usklade u cilju postavljenih KPI pokazatelja. Primjena ovakvog načina praćenja KPI pokazatelja pokazala se uspješnom u sklopu primjene poslovnih procesa u HT-u.

Razvijeni mehanizmi za praćenje KPI pokazatelja koriste se i u sklopu automatske dodjele zadataka tehničarima na terenu te dodjeli prioriteta u odrađivanju zadataka.

VI. ZAKLJUČAK

Analitički pristup i uspješno upravljanje i praćenje složenih poslovnih procesa kao što su poslovni procesi u telekomunikacijama osigurava se kvalitetnim izvještavanjem i pravovremenim informacijama na svim razinama upravljanja, od operativne do upravljačke razine.

Da bi se ovo postiglo neophodno je u fazi dizajna poslovnih procesa, osim definiranja optimalnog tijeka procesa, voditi računa o jednoznačnom identificiranju točaka i faza unutar procesa koji osiguravaju analizu kvalitete upravljanja procesima

U radu je predstavljena metodologija koja se bazira na primjeni tehnika i modela poslovnih procesa prilagođenih uvjetima i uslugama koje se koriste na telekomunikacijskom tržištu. Rezultati su pokazali da se takvi modeli mogu uspješno koristiti kao osnova sustavnog i analitičkog praćenja performansi poslovnih procesa te upravljanja resursima i osiguravanju sustavnog unaprjeđenja odvijanja procesa.

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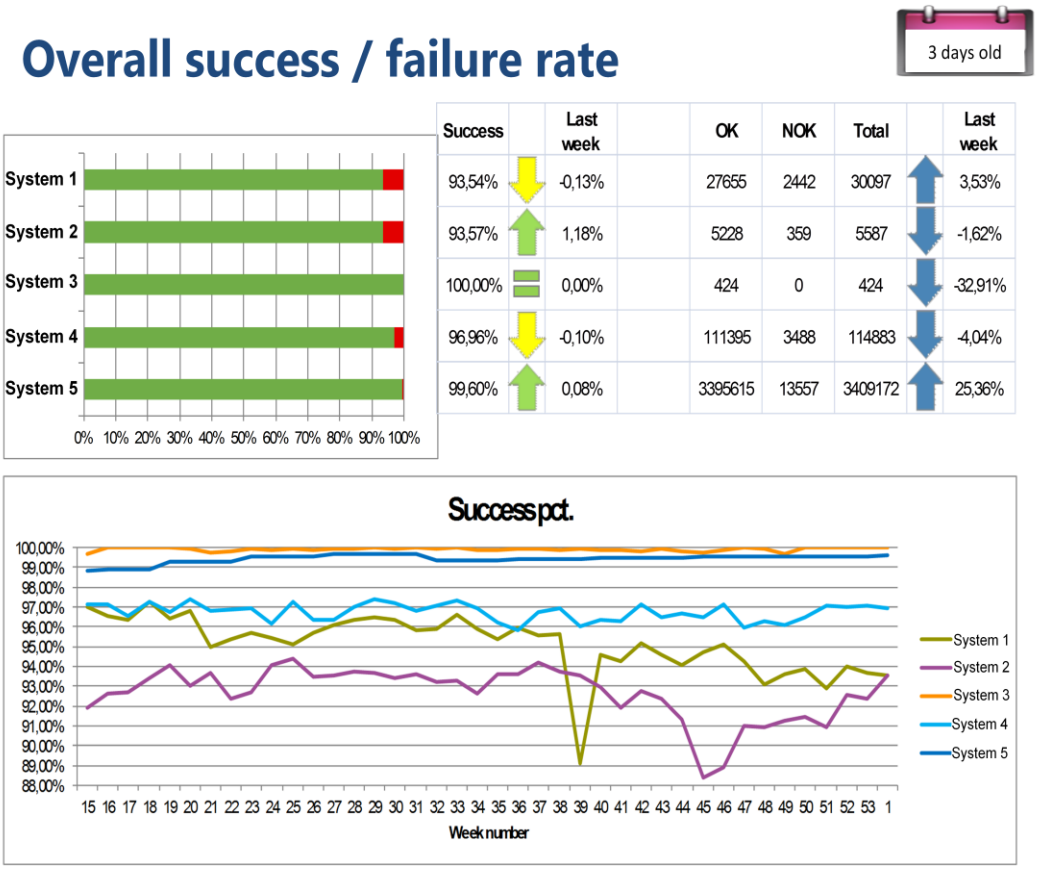
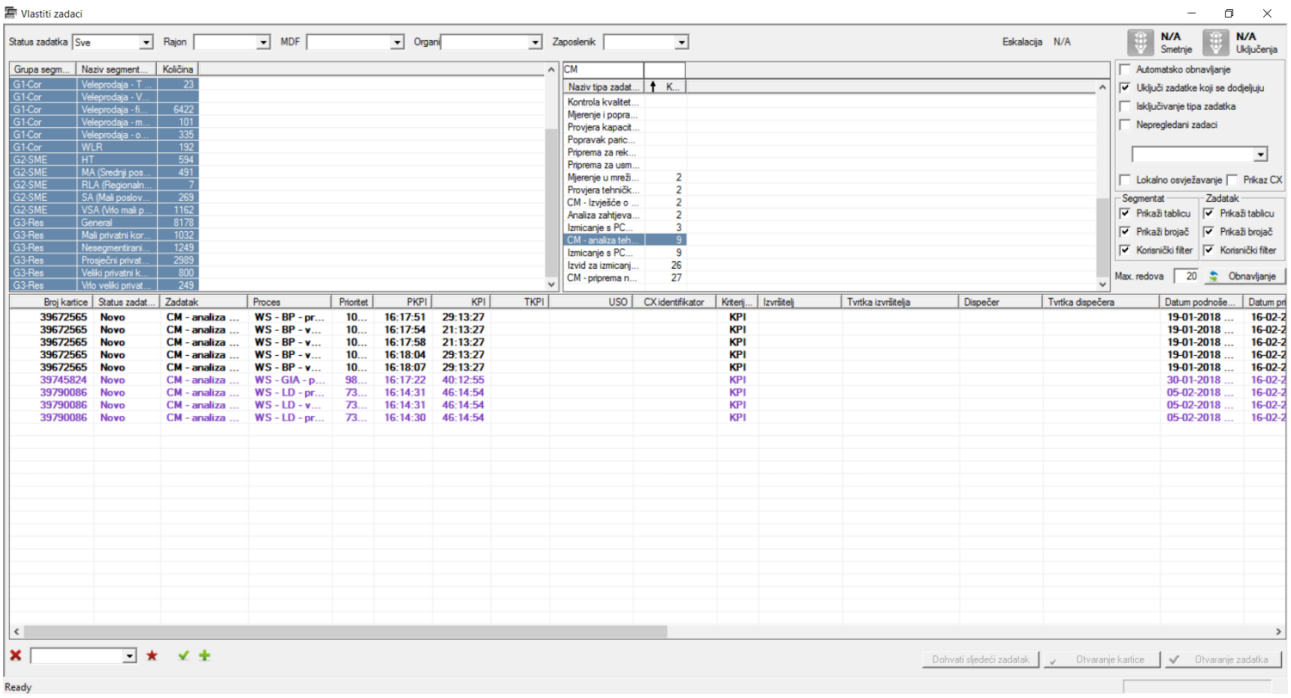


Slika 4: Primjer izvještaja za praćenje uspješnosti automatske konfiguracije mrežnih elemenata



Slika 5: Forma u sklopu koje se prati ispunjenost KPI pokazatelja

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INVITED PAPER

Sretna škola Plave ekonomije
(Osnovna škola Vladimira Nazora, Škabrnja)

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Sažetak **- Projekt OŠ Vladimira Nazora iz Škabrnje „Sretna škola Plave ekonomije“ osvojio je međunarodnu nagradu Ujedinjenih Arapskih Emirata Zayed Future Energy Prize i 100.000 USD u Abu Dhabiju u kategoriji europskih škola. Nagrada je dodijeljena 15. siječnja 2018. godine, tijekom održavanja Tjedna održivog razvoja UAE u kojemu se promoviraju i nagrađuju postignuća u području održivog razvoja, inovativnosti, dugoročne vizije i obnovljivih izvora energije. Projektom „Sretna škola Plave ekonomije“ obuhvaćeni su obnovljivi izvori energije kroz inovativnu PV-T solarnu tehnologiju povezanu s električnim vozilom i mobilnim sustavom baterija; poticanje poduzetništva kroz učeničku zadrugu „Maslina”; učenje o recikliranju i razvrstavanju sedam vrsta otpada kroz program Udruge za održivi razvoj Hrvatske (UZOR) te dijeljenje podataka kroz program GLOBE (Globalno učenje i opažanje za dobrobit okoliša) koji sponzorira NASA. Postavljanjem inovativne PV-T solarne tehnologije na školsko krovište, Škola bi smanjila troškove električne energije i grijanja na loživo ulje jer se mjesto Škabrnja nalazi u najsunčanijem dijelu Hrvatske u Dalmaciji koja se nalazi u mediteranskome pojasu s 2550 sunčanih sati godišnje. Za potrebe školskih nabava i školske kuhinje kupilo bi se malo, dostavno, električno vozilo s mobilnim sustavom baterija, a cjelokupna proizvodnja distribuirala bi se u hrvatski energetski sustav. Projektom je obuhvaćena lokalna, tradicionalna kultura uzgoja maslina i poticanje poduzetništva kroz učeničku zadrugu „Maslina” te povezivanje školske zadruge s Dolinom maslina pokraj Škabrnje u kojoj se nalaze ekološki nasadi 7000 mladih stabala maslina. Kultura uzgoja maslina seže od starih Liburna i svrha poduzetničkog dijela projekta je inspirirati nove naraštaje eko poduzetnika. Pored suradnje s lokalnim maslinarima radit će se na produbljivanju suradnje s ostalim školama koje imaju učeničku zadrugu, a cilj je ostvariti suradnju i sa srednjom Poljoprivrednom školom u Zadru. Kroz UZOR program, koji je dobio nagradu Sozial Marie u Beču 2014. g., učenici bi učili prepoznavati i razvrstavati sedam vrsta otpada kroz dječji eko otok i dječje eko radionice s pomoću „Dječjeg priručnika za održivi razvoj – prepoznavanje i razvrstavanje otpada” koji podržava Ministarstvo zaštite okoliša i energetike i Hrvatska agencija za okoliš i prirodu (HAOP). Osim prepoznavanja i razvrstavanja otpada, učenici bi učili o održivom gospodarenju otpadom s posebnim naglaskom na ZAŠTO je važno odvajati i reciklirati otpad te koje su posljedice neodgovornog postupanja s otpadom.**

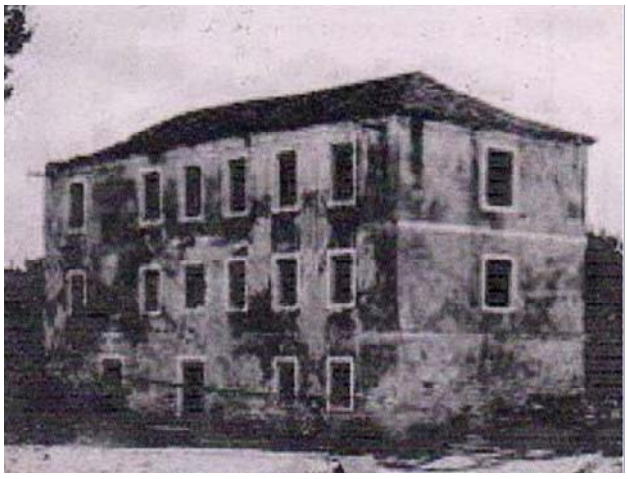
Ključne riječi - održivi razvoj, inovativnost, poduzetnost, vodstvo, vizija

I. KRATKA POVIJEST ŠKOLSTVA U ŠKABRNJI

Početci školstva u Škabrnji sežu u daleku 1876. godinu o čemu svjedoče najstariji sačuvani dokumenti u Povijesnom arhivu u Zadru Školski dnevnik i Razrednica razredne pučke škole Škabrnja. Prvi je učitelj bio don Blaž Cvitanović [slika 1], tada župnik u Škabrnji, a nastava se izvodila u privatnoj kući Ivana Milankovića .

Slika 1. Opis: don Blaž Cvitanović, prvi učitelj u Škabrnji

Nastava je trajala samo godinu dana i školu su pohađala samo muška djeca. Godine 1893. otvara se prva javna škola s obvezom pohađanja nastave za svu doraslu mušku i žensku djecu. Škola je i dalje bila jednorazredna i nosila je naziv „Jednorazredna mješovita pučka škola“ [slika 2], a nastavu su pohađala djeca iz Škabrnje, Prkosa i Zemunika Gornjeg.



Slika 2. Opis: Zgrada Jednorazredne pučke škole u Škabrnji

Završetkom Prvog svjetskog rata i propašću Austro-Ugarske Monarhije 1918. godine škola je prestala raditi, a svoja je vrata ponovno otvorila u novonastaloj državi

Kraljevini Srba, Hrvata i Slovenaca. Godine 1935. škola je, zbog velikoga broja upisane djece, dograđena novim katom i učiteljskim stanom te je prerasla u četverogodišnju školu. Početkom Drugog svjetskog rata i talijanskom okupacijom Dalmacije 1941. godine, škola je u Škabrnji prestala s radom. Završetkom Drugog svjetskog rata 1945. godine započeo je redovni rad škole prema školskom zakonu NR Hrvatske (u sastavu FNRJ). Od 1945. do 1958. godine škola je radila kao četverogodišnja škola, a od školske godine 1958./59. uveo se peti, šesti, sedmi i osmi razred. Školu je u to vrijeme pohađalo 386 učenika podijeljenih u 10 razrednih odjela. Iste godine, osnovana je, rješenjem Narodnog odbora Općine Zadar, Osnovna škola Vladimir Nazor Škabrnja, u čijem su sastavu i područne škole: Prkos, Galovac i Gorica. Za upravitelja škole imenovan je učitelj Zvonimir Troskot. Početkom 70-ih godina u Škabrnji započinje izgradnja nove školske zgrade koja je dovršena 1974. godine. Školu su te godine pohađala 403 učenika. Od 1980. do 1990. godine uočljivo je opadanje broja učenika u Škabrnji. Početkom Domovinskog rata školu je pohađalo 257 učenika u 13 razrednih odjela. Zbog izražene ratne opasnosti, 13. rujna 1991. godine, nastava je prekinuta nakon samo tjedan dana rada. Dana 18. studenoga 1991. godine Škabrnja je doživjela okupaciju i bestijalan napad i masakr od strane tadašnje JNA-a, četnika i pobunjenih lokalnih Srba. Mjesto je postalo veliko zgarište i masovna grobnica za 86 nedužnih škabrnjskih civila i branitelja, a školska je zgrada zapaljena i razorena. Oslobođenjem Škabrnje u vojno-redarstvenoj akciji „Oluja“ u kolovozu 1995. godine. stvoreni su preduvjet za povratak prognanih mještana i obnovu razrušenih domova i škole. Razrušena i spaljena školska zgrada obnovljena je 1996. godine, a nastava je započela 8. rujna 1997. godine s 97 učenika u šest razrednih odjela. Danas školu pohađa 205 učenika u 12. razrednih odjela.

II. ZAYED FUTURE ENERGY PRIZE

Zayed Future Energy Prize dodjeljuje se u Ujedinjenim Arapskim Emiratima u Abu Dhabiju od 2008. godine. Tijekom World Future Energy Summit 2008. godine, princ Sheikh Mohammed bin Zayed Al Nahyan najavio je Zayed Future Energy Prize u spomen na svoga oca, osnivača UAE Sheikh Zayed bin Sultan Al Nahyana (1).

Nagrada se dodjeljuje u pet kategorija: globalne srednje škole, kompanije, osobe godine, male i srednja poduzeća te udruge. Finalisti se biraju kroz ekspertne skupine stručnjaka iz cijeloga svijeta kojima predsjeda bivši predsjednik Islanda Olafur Ragnar Grimsson.

Zayed Future Energy Prize nagrađuje inovativna rješenja u području obnovljivih izvora energije i inovativnih rješenja u veću energetsku održivost.

Projekti se boduju na temelju: utjecaja, inovacije, vodstva i dugoročne vizije. Ove godine obilježava se deset godina Zayed Future Energy Prize i sto godina rođenja osnivača UAE Sheikh Zayed bin Sultan Al Nahyana. Svake se godine tijekom Tjedna održivog razvoja u Abu Dhabiju na ceremoniji dodjele nagrada proglašavaju pobjednici u pet kategorija.

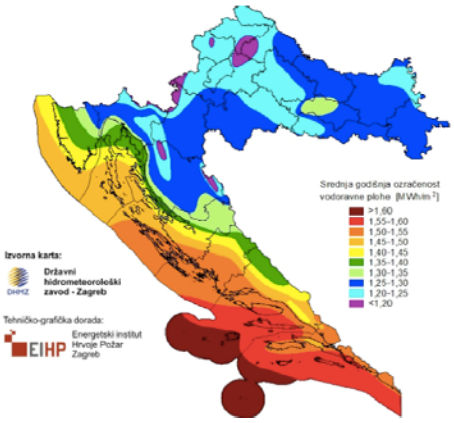
Ove godine nagrada je dodijeljena:

- Google, korporacija godine,
- Shuji Nakamura, osoba godine za izum LED svjetlosti za koju je dobio i Nobelovu nagrade iz fizike 2014 godine,
- Sunna Design, malo poduzeće koje proizvodi solarne ulične svjetiljke na bazi NiMH (niklovog metal hidrida) koji je otporan na niske temperature i traje deset godina za zemlje u razvoju,
- SELCO, fondacija koja svojim djelovanjem želi podići tri milijarde ljudi iznad granica siromaštva kroz decentralizirane obnovljive izvore energije koje imaju socijalni učinak,
- srednje škole u Polinezijskim otocima, Bahrein, Maroko, Hrvatskoj i Paragvaju [slika 3].

Slika 3. Opis: Dobitnici Zayed Future Energy Prize 2018. g.

III. POBJEDNIČKI PROJEKT „SRETNA ŠKOLA PLAVE EKONOMIJE“ OŠ VLADIMIRA NAZORA U ŠKABRNJI

Cilj projekta bio je ponuditi nova, inovativna rješenja iz područja obnovljivih izvora energije koja su kompatibilna s karakteristikama podneblja u kojem se škola nalazi. Energetska bilanca škole opisana je u Izvješću o energetskom pregledu zgrade iz rujna 2014 g. [1]. Izvješćem je opisana potrošnja električne energije na godišnjoj razini od 20.000 kWh. Na školsku rasvjetu udio potrošnje iznosi 50 %. Grijanje škole rješava se lož uljem na koje Zadarska županija godišnje troši 75.000 kn i svake godine kupuje 14.500 l lož ulja. Ukupna bilanca troškova za režije iznosi cca 150.000 kn. Prema energetskom certifikatu nestambene zgrade, škola spada u energetski razred D. [2]. Ovim projektom cilj je bio ponuditi inovativnu solarnu tehnologiju na svjetskoj razini koja bi na jednom kolektoru proizvodila električnu energiju i toplu vodu, smanjila potrošnju električne energije na minimum kao i ovisnost o lož ulju. Prema Institutu „Hrvoje Požar“ kao što je vidljivo na [Slici 4.] ozračenost teritorija RH se kreće od 1,2 do >1,6 MWh/m2. [3]. Od svih područja u Hrvatskoj, Dalmacija i područje otoka i priobalja pokazuje najveći solarni potencijal. Najveću ozračenost od 1,50 MWh po četvornom metru imaju dalmatinski otoci (Dugi otok, Ugljan i Pašman). Zadarska županija je vrlo pogodna za razvoj projekata koji se temelje na solarnoj energiji zbog 2550 sunčanih sati godišnje.



Slika 4. Opis: Srednja godišnja ozračenost vodoravne plohe Hrvatske

Hrvatska ima dobre preduvjete za korištenje Sunčeve energije, trenutno se nalazimo na samom dnu Europe po instaliranim sustavima za korištenje Sunčeve energije. Stoga se može reći da u Hrvatskoj nije iskorištena komparativna prednost u pogledu uporabe Sunca kao obnovljivog izvora energije. Upravo smo od ove pretpostavke pokrenuli naš projekt i dodali mu tradicionalnu vrijednost Ravnih kotara kao prehrambene hraniteljice Dalmacije i učeničkih aktivnosti koje se već provode u školi. Pobjednički projekt „Sretna škola Plave ekonomije“ temelji se na četiri stupa djelovanja [Slika 5].

Prvi i najosnovniji dio je inovativan pristup energetskoj samoodrživosti škole što je i temeljna smjernica Zayed Future Energy Prize i osnova za bodovanje projekta. Inovacija proizlazi iz Plave ekonomije [4] koja predlaže najnoviju tehnologiju koncentriranog kombiniranog solarnog kolektora na svjetskom tržištu. Inovacija se bazira na solarnom kolektoru [5] koji na istoj površini proizvodi električnu energiju i toplu vodu te na iskoristivosti plohe od 70% koristeći konkavno ogledalo koje usmjerava sunčeve zrake na fotoćelije. Hladna voda hladi solarnu ćeliju i preuzima toplinsku energiju kroz zagrijavanje vode. Vezano uz solarni kolektor predložena je zamjena starih žarulja s LED rasvjetom i električno dostavno vozilo snage 14 kWh za novoootvorenu školsku kuhinju. Cijeli je sustav zamišljen kao „on grid“ sustav koji bi tokom ljetnih praznika zarađivao novac za školu kroz otkup električne energije. Cijena otkupne električne energije za solarne elektrane kao jednostavne građevine snage 10 kW je 1,91 kn/kWh dok je cijena za integriranu solarnu elektranu s ugrađenim sustavom za toplinsku energiju na istoj građevini 2,29 kn kn/kWh [Slika 6].

Integrirane sunčane elektrane instalirane snage ≤ 300 kW			Korekcija poticajne cijene za integrirane sunčane elektrane instalirane snage ≤ 300 kW	
Grupa	Tip postrojenja	Poticajna cijena C (kn/kWh)	Korektivni koeficijent za korištenje toplinskog sustava k1	Korekcija poticajne cijene Ck=(C x k1)
1.a.1.	sunčane elektrane instalirane snage do uključivo 10 kW	1,91	1,2	2,29
1.a.2.	sunčane elektrane instalirane snage veće od 10 kW do uključivo 30 kW	1,70	1,1	1,87
1.a.3.	sunčane elektrane instalirane snage veće od 30 kW do uključivo 300 kW	1,54	1,03	1,59

Slika 6. Opis: HROTE otkupne cijene za Integrirane sunčane elektrane instalirane snage ≥ 5 MW

Samim time ova inovativna tehnologija povećava otkupnu cijenu za 20% [6].

Drugi dio proizlazi iz školskih aktivnosti učenika u školskom masliniku na temelju čega je i osnovana učenička zadruga „*Maslina*“ u lipnju 2017 godine. Cilj zadruge je proizvodnja ekološkog maslinovog ulja, edukacija učenika o poduzetništvu i ekologiji te kreiranje proizvoda na bazi vrhunskog maslinovog ulja za prodaju. Nastavno na učeničku zadrugu kroz projekt se nastoji povezati lokalni ekološki maslinar iz *Doline maslina* kako bi prenio znanje na buduće ekološke poduzetnike Škabrnje. Ujedno je i maslinarstvo poveznica s tradicijskom kulturama podneblja koje sežu 2500 g u prošlost i predantički period.

Treći dio projekta temelji se na postojećim školskim aktivnostima sakupljanja i recikliranja otpada u školi. Učenici su tokom 2016. godine sakupili 1 tonu starog papira i plastične boce. Učenička aktivnost želi se proširiti kroz program udruge UZOR HR iz Koprivnice koja je dobila nagradu Sozial Marie 2014. godine u Beču za socijalnu inovaciju [7]. U okviru edukativnog programa učenicima će biti podijeljeni *Dječji priručnici za održivi razvoj* – prepoznavanje i razvrstavanje otpada koje je podržalo Ministarstvo zaštite okoliša i energetike i Hrvatska agencija za okoliš i prirodu; solarni ruksaci za punjenje mobitela te ekološki otok za sedam vrsta otpada prilagođen dječjem uzrastu. Također, u sklopu programa održat će se edukativne radionice o hijerarhiji gospodarenja otpadom, kružnom toku otpada i razumijevanju važnosti zaštite okoliša.

Četvrti dio projekta odnosi se na implementaciju GLOBE programa sponzoriranog od strane NASA-e koji povezuje osnovne i srednje škole u 112 država svijeta [8]. Učenici će sakupljati podatke o klimatskim uvjetima i bilježiti proizvodnju električne i toplinske energije iz obnovljivih izvora energije.

Slika 5. Opis: Pobjednički projekt "Sretna škola Plave ekonomije"

IV. UČENIČKA ZADRUGA „MASLINA“

U sklopu učeničke zadruge „Maslina“, osim brige o masliniku, estetskom uređenju Škole te školskog dvorišta, uvrstili smo kreativne radionice, koristeći isključivo materijale koje pronalazimo u našoj okolini (borove šiške, kamen, cvijet lavande, listove masline, grančice masline,

drvo, kamen, tkaninu idr.), za izradu različitih suvenira [Slika 7].

Slika 7. Opis: Radionica rukotvorina učeničke zadruge "Maslina".

Radionice ne služe samo kao izvannastavne aktivnosti, već se njima nastoji poticati učenike na rad, motivaciju i razvijanje osobnih interesa. Cilj je omogućiti lakše učenje i povezivanje nastavnih sadržaja u svim nastavnim predmetima te bolju integraciju u društvu kroz multifunkcionalni sklop znanja, vrlina, vještina i nadarenosti kao što su kreativnost, logičko razmišljanje, komunikativnost, snalažljivost, samoinicijativnost, disciplina, dosjetljivost, spretnost, inovativnost. Prije svega treba imati viziju, planirati i stvarati ideju, realizirati ideju, uvažava se svako individualno mišljenje. Nemotiviranost, nespretnost, sramežljivost, slaba komunikacija brzo nestaju iz malih glava. Mogućnost da oni mijenjaju nešto nabolje, da zajednica cijeni njihov trud i rad jača njihovu odlučnost i upornost. Nema više blokada, samopouzdanje raste unatoč sposobnosti prepoznavanja i svjesnosti svojih vrlina i mana. Jednom riječju kod djece razvijamo poduzetništvo. Prepoznali smo priliku i ostvarujemo ideje tako da svakog 18. studenoga (Dan stradanja Škabrnje u Domovinskom ratu, 18. studenoga 1991.)), kada je najviše posjetitelja u mjesto, prodajemo naše rukotvorine. Svaki posjetitelj želi ponijeti nešto sa sobom što ih podsjeća na mjesto u kojem su bili. U svakoj rukotvorini nalazi se duh Škabrnje. Ne nose sa sobom samo sjećanje na bol i tugu mjesta, već i nadu u jednom malom suveniru, koji odiše optimizmom, strašću, energičnošću i pozitivnim promjenama. Iz nečega stvaraju nešto novo i korisno. Baveći se stvarima koje vole, pronalazeći prave ideje koje vode do uspjeha, djeca postaju mali poduzetnici. Svako dijete je talentirano za nešto, pružena im je prilika da otkriju svoj talent, za koji možda nisu ni znali i pokažu ga. To nipošto ne znači da će se jednog dana baviti korporativnim poduzetništvom, niti je svrha radionica razvijati korporativno poduzetništvo već socijalno, koje priprema ove mlade ljude za život. Sve komponente koje su satkane u socijalnom poduzetništvu omogućava im napredak i pozitivan razvoj njih samih kao neovisne, komunikativne i inteligentne individue, koji će se sa svojim razvijenim sposobnostima, koje pruža takav vid poduzetništva, izboriti u životu, ali i što bezbolnije prihvatiti odgovornost za svoje postupke.

V. ZAKLJUČAK

Zadarska županija kao vlasnik osnovnih i srednjih škola troši velika financijska sredstva na uvoz lož ulja za postojeće sustave grijanja u školi (7.647.120,00 kn u 2016 godini.) i potrošnju električne energije [9]. Kroz predloženi projekt „Sretna škola Plave ekonomije", županija bi uvelike mogla smanjiti svoje troškove koristeći Sunce kao Bogom dani obnovljivi resurs Dalmacije koji je potpuno neiskorišten.

Ovaj projekt isto tako predlaže put održivog razvoja kroz edukativni sustav škola u Hrvatskoj koji povezuje tradiciju, poduzetništvo, suradnju i brigu o okolišu s najmodernijim tehnologijama.

Plava ekonomija počela je kao projekt pronalaženja 100 najboljih prirodom inspiriranih poslovnih modela koji bi mogle utjecati na ekonomiju svijeta te pružiti ljudske osnovne potrebe na održiv način - pitku vodu, hranu, posao, energiju i dom. Prof. Gunter Pauli začetnik je i vizionar te nove ekonomije. Osnovao je ZERI Fondaciju u Tokyu kao uvod u Kyoto protokol 1997. godine gdje je trebalo predložiti poslovne modele koje ne zagađuju okoliš a ekonomski su isplative. Plava ekonomija dostupna je i na hrvatskom jeziku od 2012. godine, izdavača „Katarina Zrinski" iz Varaždina [10].

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PAPERS

Applicability of knowledge: Motivational factor for beginning learners of programming

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Abstract - **Knowledge of programming, basic algorithmic structures and planning using algorithms is the literacy of the 21st century. Learning such knowledge is not easy and requires complex thinking and the dedication of time and effort. To attract students to the study of programming, we should not turn to the traditional method of imparting knowledge but rather teach such knowledge in parallel with other topics to build subject-related programming knowledge and to motivate students to apply such knowledge to other topics. Writing, reading and mathematics are taught at the initial stages of schooling (up to a certain point), but programming has generally only been applicable when students have acquired a certain level of knowledge. So, early departure from opportunities to teach programming creates problems in this respect and later results in a potentially small pool of programmers.**

The present research deals with how to increase students' initial motivation to learn programming through the use of robotics, automation, electronics programming and block programming (without encoding). This research is based on two hypotheses: Students are motivated to learn knowledge with relevant applications (H1). And, showing the applicability of programming increases the short-term motivation of students to learn programming (H2). The examination of students' motivation was done through self-assessment using a Likert scale before and after students received an in-class demonstration of the applications of programming.

Keywords: motivation, programming, robotics, short-term motivation.

I. WHY DO WE RESEARCH MOTIVATION?

Motivation is a key factor of school success. Many sub-areas of motivation are unexplored in motivation research, although much time and effort have been devoted to understanding student motivation. The applicability of learned knowledge is one aspect (one factor) that increases motivation for learning. One of the main criticisms of modern schools is that students are not taught applicable knowledge, i.e. students are taught knowledge that is highly theoretical (factual knowledge) and has little applicability to real world contexts where specific skills, critical thinking, and critical knowledge are required to excel.

Three of the most important influences on student motivation in the classroom are as follows:

- external motivation,
- internal motivation,
- and expectation of success [1].

External (extrinsic) motivation is strongly influenced by rewards and punishment. Such motivation is of low intensity and short-term leads to stress and anxiety because the reward (punishment) is a factor in stimulating these (extrinsic) motivations. [2]. Overall, work that promotes extrinsic motivation is associated with non-creative assignments, awards and penalties, memorised skills and repetitive tasks [2].

Contrary to extrinsic motivation, internal (intrinsic) motivation is reflective of student engagement in activities that satisfy their own curiosity and students' interest in an educational context, which may be interpreted students' desire to develop competencies or abilities to respond to the demands placed upon them or for their own sake [1]. Internal motivation is a desirable, long-lasting motivation that can be developed by creating meaningful school experiences, by making knowledge relevant to students and by making learning entertaining [2]. In this research, we examine initial, short-term motivation and place an emphasis on intrinsic motivation. We do not focus on prizes or punishments but rather aim to explore approaches that would make school (and programming) more meaningful, relevant and fun. In doing so, we examine why students are motivated to learn, simulate real industrial processes to which programming knowledge is applicable and encourage learning by playing with robots and automatic systems. Most of all, we emphasise the meaningfulness of learning, i.e. the applicability of programming to a real-world context.

A. Applicability

In Bloom's taxonomy, the applicability of high level knowledge requires a certain capacity for assessment (i.e. the ability to revise, hypothesise, experiment and judge) and for creation (i.e. the ability to design, construct, plan, invent, design, etc.). These tasks are difficult for students, and students may struggle to see the applicability of knowledge. Also, teachers face a difficult task in reinforcing the applicability of imparted knowledge or groups of knowledge. Not every scientific field (e.g. history) may be applicable in ways that students perceive as applicable.

The applicability of knowledge should not be repetitive. In other words, the same knowledge should not be applied to different problems. Rather, students must be able to examine how new knowledge applies to distinct problems. In this context, the applicability of knowledge must then be partly built on creativity. Creativity is the mental process involved in creating new ideas or products, in obtaining certain achievements or in combining knowledges in a new way [3]. To apply knowledge in creative ways, a teacher must also be creative. In addition

to intellectual and cognitive abilities, which are an important foundation of creativity, on an individual level, personality traits and motivational and emotional characteristics are also important [4]. The creative individual is open to both interior and exterior experiences and often follows illogical solutions or pathways during problem solving. In this sense, the creative individual is not solely driven by achieving the correct solution according to the proper steps. Creative individuals often make use of all their senses, are persistent, see order in chaos, are not dominating, do not impose opinions, accept ambiguity and are inclined to changes, often asking the following question: 'Why?'

B. Problem and possible solution

Programming as a skill is difficult to teach, and learning programming is painstakingly hard for beginners regardless of their age [5]. The popularisation of programming has failed to attract a large number of interested students even though relatively well-paid jobs in this field are nearly guaranteed. Accordingly, the IT industry does not grow at the rate at which it might because it is experiencing a major workforce shortage. The biggest shortage of workers in the IT sector is in programming. To rectify this problem, various aids and methods have been developed to teach programming. All methods and aids can be accommodated in two large groups: (a) methods that encourage the cognitive part of the brain responsible for abstract thinking and (b) methods and aids that appeal to the abstract part of the brain by, in some cases, representing concepts more simply and concretely. There are problems associated with both approaches. In the first approach, it is difficult to constantly use teaching methods and processes that trigger certain cognitive centres of the brain; also, it is difficult, if not impossible, to determine a unique method for the whole class and to plan ahead. In the second approach, research is lacking on the success of related methods. This is the approach that has been traditionally used to teach programming and much programming knowledge would not have been imparted without these associated methods. The use of robotics, electronics and automation relies on both approaches, but more emphasis is placed on visualisation of the task and the solution (b). Furthermore, robotics, electronics and automation in this research will be exclusively used as a method of motivating students and demonstrating the applicability of programming. The research will aim to assess the effects on students' motivation to learn programming (in the short term) of an in-class demonstration showing the applicability of programming to robotics, electronics, and automation.

II. DESCRIPTION OF THE STUDY GROUPS

The research was performed in May 2017 in several classes of a Gymnasium programme. The groups were divided into a focus group (FG) and a control group (CG). Both groups contained 38 students and were created from two classes: FG from 1. a and 2. b and CG from 1. b and 2. a classes. The members of the groups did not differ by age, knowledge or amount of information received in prior classes (computer science classes). A preliminary test was conducted with 40 students using a self-assessment based on a Likert scale. Some students were unavailable because of other obligations or illness. However, the selection of students was completely random, so the results for the groups were unaffected. The self-assessments were applied using the cloud application in GoogleDocs for simplicity. In the preliminary test, the groups were confirmed to be equivalent according to a Mann-Whitney non-parametric test (Table 1). The test showed that all questions has a significance level greater than $p > 0,05$; thus, it was concluded that the groups were not statistically different. In addition to checking whether FG and KG were statistically equal, several questions that were not relevant to this particular research but were related to motivation for studying certain specific subjects were excluded, including the reasons that students listed for their level of motivation. The questions examined in this study addressed students' short-term and long-term motivation (intrinsic and extrinsic motivation) to learn programming. As noted, no statistically significant differences were identified in (basic) motivation, so the students were divided into two groups: the FG and the CG.

III. HYPOTHESIS AND RESULTS

Two hypotheses were proposed and used to guide the research study in regard to whether teaching the applicability of programming increases initial, short-term motivation among students to learn programming. If this is the case, both hypotheses must be accepted. The first hypothesis (H1) was that students are motivated to learn knowledge upon understanding its applications. H1 was simple to verify in the first test in which the groups were determined to be statistically equivalent. The results of a

TABLE 1

TEST STATISTICS

	I have a lot of knowledge about programming.	I have low level of knowledge of the applicability of programming.	To get involved in the application of knowledge, it is not essential to have prior knowledge.	My hobbies require me to continue learning new knowledge and skills.
Mann-Whitney U	178,000	191,500	187,500	191,500
Wilcoxon W	454,000	344,500	340,500	344,500
Z	-0,497	-0,113	-0,225	-0,112
Asymp. Sig. (2-tailed)	0,619	0,910	0,822	0,911
Exact Sig. [2*(1-tailed Sig.)]	0,645a	0,914a	0,829a	0,914a

TABLE 2

STATEMENT: APPLYING KNOWLEDGE MOTIVATES ME TO LEARN NEW KNOWLEDGE.

	Frequency	Valid Percent	Cumulative Percent
I completely disagree	1	2.5	2.5
I partially disagree	3	7.5	10
nor do I agree or disagree	5	12.5	22.5
I partially agree	14	35	57,5
I completely agree	17	42,5	100
Total	40	100	

3simple frequency analysis are shown in Table 2. Of all students, a large percentage of students (77,5%; Table 2) claimed to be more motivated to learn new material if the applicability of the material is also presented. Notably, only four students (10%) did not perceive the applicability of knowledge to influence their motivation. These results confirmed H1, and the further research was based on this condition.

The second hypothesis (H2) was that showing the applicability of programming increases the short-term motivation of students to learn programming. This hypothesis was explored in the FG group. During a class session, the applicability of robotic, electronic and automated research was demonstrated to the students of the FG, who were shown simple block programming and its direct application to robotics and mobile devices. For the electronics, an Arduino Uno (microcontroller) and its associated elements were used to demonstrate the operation of a robot by remote control. The Arduino programming approach was also explained, and the creation of an Android application was demonstrated using the App Inventor from MIT. At the end of the class, a survey was conducted to check the level of motivation and whether it differed from the CG. A classical coding session was administered to students in the CG, including information on the applications and complexities of coding, the types of programming languages and the level of knowledge required to master coding.

The data obtained from the surveys administered at the end of the class sessions was analysed to understand students' subsequent motivation. A self-assessment along a Likert scale was used to measure students' level of agreement with respect to several statements related to motivation. The results were analysed by a non-parametric Mann-Whitney test (Table 3).

A. Analysis

The analysis shows that the responses of the groups were significantly different as the Asymp. Sig. (2-tailed) was less than 0,05 (considering that the initial test determined that the basic motivation of students in both groups was the same). So, it can be concluded that the presentation of rapid (block) programming (programming without encoding) and its applicability in programming robots, electronics and automation leads to initial, short-term increases in motivation. The H2 hypothesis was proven at a 0,05 level of statistical significance. The aim of this research was not to examine long-term motivation or the duration of motivation but solely to increase short-term motivation after presenting the applicability of programming to students. The research was based on two hypotheses wherein the second hypothesis was dependent on the confirmation of the first hypothesis. Both hypotheses were accepted, confirming that presenting the applicability of programming increases students' short-term motivation to learn programming.

IV. CONCLUSION

The present work contributes to the understanding of students' motivation to learn programming. Similar research among other groups in additional schools should be carried out to test whether the findings of the present study can be generalised. The next step should be to check the duration of this motivation (to confirm whether it is short term) and to find methods to extend the duration of this motivation. In addition, it would be interesting to test the degree of motivation (whether small or large) and to research additional reinforcement methods and their success. Further methods may or may not be reliant on self-evaluation. Specifically, different learning materials should be explored and evaluated for their effects on motivation.

However, caution should be taken in generalising the findings of the present study: 1) It should not be assumed that this method is the only means of increasing initial/short-term motivation. Also, 2) further studies should confirm that this method leads to increased short-term motivation. Until further testing, the results are only applicable to the present school environment and students.

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TABLE 3

MOTIVATION AFTER EXPERIMENTAL CLASS

	I'd like to know more about programming.	Programming does not seem overwhelming.	I was motivated to continue learning programming.
Mann-Whitney U	523,000	35,000	97,500
Wilcoxon W	1264,000	776,000	838,500
Z	-2,372	-7,314	-6,704
Asymp. Sig. (2-tailed)	0,018	0	0

Information literacy as a conceptual outline

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Abstract

Understanding libraries and their past and present role has shed light on the relationship between modern education and the existing ICT paradigm. The role of technology in education, especially in the production of knowledge and the influence of internet, conditions the transformation of libraries in this new digital context and virtual reality. This new reality requires a new kind of literacy. Information literacy is a crucial factor in modern communication. It implies a whole range of modern education directed towards research work. Thus the interest for the role of libraries has never really ceased. The role of information technology in education has not been sufficiently analyzed, despite the fact that the programme of information literacy is a conceptual basis of the librarian's activity in a school. The aim of this paper and research is to analyze the connection of information literacy and the education phenomenon as well as the changes in educational outcomes in order to establish the main issues information literacy is faced with in the context of education through research work.

Key words: Information literacy, modern communication, information technology in education, educational outcomes

I. INTRODUCTION

School libraries have always been the fundamental infrastructure of education. With its fund, they have improved the educational process, developed services and today, considering globalization, fast technological development and economic and social factors, school librarians should develop competences necessary to implement information literacy, the use of ICT, in order to adapt to the new pedagogical paradigms.

Information literacy as one of the fundamental literacies of today has an important role in education and what is considered lifelong learning. This paper presents the results school libraries have obtained so far in the programmes of information literacy in the Istrian County. A further step should aim at determining the mutual interconnection between information literacy and the phenomenon of education and, based on an analysis of changes in educational outcomes, determine the main issues and topical areas of information literacy in the context of education through learning as research work.

The Istrian County is very interesting in terms of educational programmes. The educational model comprises the programmes of Croatian schools and the programmes of Italian schools as national minority programmes.

School libraries are conceived as basic support to education within their schools. The changes that occurred in society generally affect the changes reflecting in education and the sourced the libraries used as their own resources for education. A new era brought about the demand for new literacies… It is not possible to speak of the new role of libraries in education, the new model of library and its work, in the information society without new literacies that make up literacy for the 21st century.

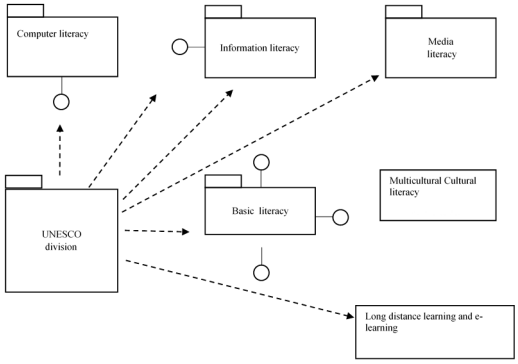
II. NEW LITERACIES

The appearance of new literacies and new media sees the need to master these new literacies. Information literacy as a set of skills ranging from the awareness and understanding of information needs, strategies for the location and finding of information, their takeover, evaluation, usage and ethical handling to the creation of new information and their transformation in new knowledge, is becoming a literacy without which there is no active involvement of the student in education.

Libraries have always been places where literacy was stimulated and developed through the use of sources, reading and comprehension, demanding a constant education of librarians so they could accomplish their

mission which is also determined by the times in which the libraries operate.

UNESCO lists 6 kinds of literacy:



- Basic literacy
  The knowledge of reading, writing and computing necessary to function in everyday life
- Computer literacy
  Encompasses tool using skills
- Media literacy
  Access to media, understanding media, critical approach to content, ability to understand hidden messages, creating media messages
- Multicultural literacy
  Interpreting and understanding of others and the different with the aim to establish a dialogue between cultures
- Long-distance learning and e-learning
  A set of skills necessary to learn in an online surroundings; the ability to use electronic systems for long-distance learning
- Information literacy
  Contains elements of all the previous; skills included in previous literacies necessary for the development of information literacy

In the book *Information literacy: theoretical framework and starting points*, the authors Špiranec and Banek describe in a detailed and straightforward way what it means to be an information literate individual and give importance to the spreading of information literacy. Numerous programs in school libraries are developed on these grounds.

An information literate individual is a person who knows how to learn because they know how knowledge is organized [1].

Libraries have always had an infrastructural position in education, offering an answer to the mentioned challenges in education through the offer of information literacy [2] that is seen as the starting point of lifelong learning.

In order to realize and implement information literacy it needs to be integrated in the school curriculum. In that context there is need to publish an information literacy standard which gives a framework for its systematic inclusion in the curriculum.

Standards are usually directed to the definition of characteristics of information literate individual or student, with a taxative listing of properties, attributes, processes, knowledge, skills, attitudes or beliefs that such an individual needs to build. By far the most influential standard that has been translated into several languages is the American *Information Literacy Competency Standards for Higher Education* of the ACRL (Association of College and Research Libraries).“ [3]

The translation of the ACRL standard may be the first step towards the conceiving and publication of own, local (national, regional, institutional) information literacy standards. For the school libraries these are guidelines for the making of education programmes for teachers and students.

As early as in 1989 the American Librarian Society pointed out the close connection between information literacy and education.

In this definition information literate individuals are defined as: “those that have learned how to learn… because they know how knowledge is organized, how to find information and how to use them in a clear way… these are people prepared for lifelong learning”. [4]

This definition includes a list of competences according to which an information literate person should possess the following:

- awareness to recognize when information is needed;
- ability to define the need for information when there is a problem to be solved or decision to be made;
- ability to find out whether the needed information exists or not;
- ability to locate the needed information if it exists;
- ability to create the needed information if it exists;

- ability to create information that is needed but is not available;
- comprehension of located information or knowledge about where to find help;
- ability to organize, analyse, interpret and evaluate information as well as to evaluate the source;
- conduct in case information is no longer needed or how to protect information from misuse;
- knowledge to use information efficiently

In that context, it was of interest to find out whether there are information literacy programmes in national minority libraries in Istria County, how they are carried out and who implements them.

Information literacy programmes

There is no need to elaborate on the importance of information literacy. Librarians were the forst to accept this task as part of their work with library users. However, hte education programme depends on the readiness and knowledge of thel ibrarian to embark on the task of education of users. In the context of the curricular reform, the issue of information and media literacy comes into the focus of interest of education institutions and their employees. The author was, before all, interested in analyzing the situation in schools and seeing to what extent the management of the school, thus also the librarian, it aware and willing to plan and implement an information literacy programme.

In Italy, information literacy through school libraries started with the discussion on the need to introduce the new literacies in the core curriculum. In order to be able to participate in the oncoming changes and the current discussions, especially in the country of origin of the national minority covered by the school with its programme, it was necessary to research whether there was sufficient knowledge on what is information literacy, if there were information literacy education programmes and who implemented them in schools and in what way.

Sample and methodological approach

The research focused on Italian minority schools active in Istria. The quantitative and qualitative method was used for the analysis. The table below presents information on schools, number of students and teachers and information on whether the school has a librarian or not. The data used for this paper are part of the data collected within a doctoral research [5].

The questions were integrated with some questions from the questionnaire set up by the Ministry of Education of the Republic of Italy in order to get relevant answers.

A decisive factor in choosing schools was the County's territorial map. The selected schools are primary and secondary schools which carry out education according to Model A.

In the Republic of Croatia, members of national minorities exercise their constitutional right to education through the implementation of one of three suggested models of education. Model A stands for education in the language and script the national minority is using.

There are 15 schools chosen.

- A sample of 15 schools, 325 students, 463 teachers, 15 principals, 15 librarians and 15 pedagogists is defined as a target group for the research.

The first question posed in the research of programmes and their implementation was whether students and school management knew what information literacy was.

Results and interpretation

The responses to the introductory question showed that the perception on what information literacy is and the evaluation on whether a person is information literate and if they can tell information literacy education programmes is very varied. The students usually take information literacy as knowledge and skills in computer use. Teachers are more cautious but they also fail to see the difference, though they are not prone to saying they are not information literate. Librarians have a good knowledge of the term and its contents.

- It was necessary to collect all the data for statistical analysis and the willingness to cooperate was low because some colleagues do not like surveys. However, some information was finally gathered after written correspondence and oral communication.
- There is also the spreadsheet which shows the schools which participated in the survey.
- In 15 schools, according to the data presented on their web pages and additional interviews that were organized, it has been identified that some libraries do not have a librarian at all, some have part-time librarians and some schools do not have a link for libraries on their web page, with materials presenting the schools containing discording information and where the concept of bilingualism has not been met. Therefore, the research was based on the given data.

TABLE I. PRESENTATION OF SCHOOL SURVEY RESULTS

Ord. No.	School	No. of surveys for students	No. of completed surveys for the students	No. of surveys for teachers	No. of completed surveys for teachers	Surveys for school principals	Surveys for librarians	Surveys for pedadogists	Surveys for psychologists	Total
1.	Elementary School-SE Dolac Rijeka	18	16	30	17	-	-	1	Hasn't got one!	34
2.	Elementary School-SE Gelsi Rijeka	18	18	34	22	1	1	Hasn't got one!	1	43
3.	Elementary School-SE Belvedere Rijeka	9	8	25	19	1	1	1	Hasn't got one!	30
4.	Elementary School-SE San Nicolo' Rijeka	18	16	30	13	-	1	Hasn't got one!	-	30
5.	Italian Secondary School in Rijeka	38	17	34	19	1	1	Hasn't got one!	1	39
6.	Elementary School-SE G. Martinuzzi Pula Pola	31	27	50	22	-	1	1	-	51
7.	Italian Elementary School -SEI Bernardo Benussi Rovinj Rovigno	23	23	25	22	1	1	Hasn't got one!	1	48
8.	Italian Elementary School -SEI Galileo Galilei Umag Umago	20	20	25	11	1	1	1	-	34
9.	Italian Elementary School -SEI Novigrad Cittanova	8	8	30	12	1	1	1	-	23
10.	Elementary School --SE Vodnjan Dignano	9	8	20	8	1	*	-	-	17
11.	Italian Elementary School -SEI Edmondo de Amicis Buje Buie	13	12	34	17	1	Substitute teacher	Hasn't got one!	1	31
12.	Italian Elementary School -SEI Bernardo Parentin Poreč Parenzo	15	13	19	14	1	1	Hasn't got one!	1	30
13.	Italian Secondary School in Rovinj Rovigno	32	29	30	23	-	1	1	Hasn't got one!	54
14.	Italian Secondary School Leonardo da Vinci Buje Buie	32	28	37	24	1	1	1	Hasn't got one!	55
15.	Italian Secondary School Dante Alighieri Pula Pola	41	38	40	34	1	1	1	Hasn't got one!	75
	Cumulative results		281		277	11	12	8	5	594
	Total number of surveys	325		463		15	15	15	15	848

* survey completed in Buje where she works as a substitute teacher in Italian language)

The students mainly answer that they don't know what information literacy is or if the answer is yes, they consider it to be an IT class; also, they do not differentiate the term information from informatic.

The school principals answer that the school has information literacy programme carried out by librarians according to their curriculum.

The librarians from all 15 schools answer that they have an information literacy programme implementing it partly through classes and partly through certain workshops for students or teachers when required and whenever there is a problem to be solved. Answering the question about the implementation of information literacy in obligatory curriculum, all of the librarians agree that it would be the best and the most complete education for the 21st century. They also consider that teaching information literacy should be provided in their vocation as an information and pedagogical expert. [6]

New technologies have made it possible to access information and knowledge in an easier and faster way. The development and the employment of Web 2.0 technologies and the Internet in general have facilitated the access to countless contents; moreover, these steps forward in technology have made it possible to contribute to knowledge and to share it within the users' communities.

Communication uses various channels, such as blogs, wikis, various social media such as Facebook, spaces for the publishing of pictures and movies, podcast systems and similar aids have widened the librarians' communication range aiming at satisfying their users' needs.

Like in the case of basic literacy, it is important to know when the student interacts with information in an unreasoned way, and practices instead a mere mechanical collecting of facts; at such a point, the role of information literacy and the whole literacy program is of huge importance, for it is an element of modern teaching methods such as problem-solving, research or project teaching and learning.

Within the field of lifelong learning, contemporary learning models and strategies are a basic necessity both for students and for teachers.

A question which a school librarian can be asked is when to begin information literacy.

Špiranec and Banek suggest starting a systematic development of competences as soon as children enter the system of formal education: thus, it will be possible for them to think critically and autonomously, bearing on the analysis and comparison of topics, resources, as well as using information and the Internet in a responsible way, and being safe online.

A literacy model for teachers and students should be prepared together with its future users. Elementary information literacy consists of a level of information and computer literacy which is appropriate for a certain status or age. It is the librarian who helps develop suitable activities in accordance with the contents, the structure and the educational program of a certain school.

III. FINAL CONSIDERATIONS

The concept of information literacy was first outlined in the USA in the 1970s, as a reaction to the development of a type of information society influenced by new educational paradigms. Information literacy includes finding, assessing as well as using and applying information (learning how to learn, problem solving, critical thinking, independent learning).

At present, information literacy is a major issue in Croatia; Italian schools existing on the territory of the Republic of Croatia are expected to and try to coordinate their programs both with literacy programs in Croatian schools, as well as with similar programs in schools in Italy. The results of the survey show that problems and questions relating to information literacy are indeed a necessity within the field of education, pertaining to the times we live in. There is clear evidence that different methods are being used, whereas the introduction of standards setting the tasks would ease the librarians' work.

After primary school, further education is one of the most important developmental aspects for the proper functioning of each community, town, region and country. Hence, general and vocational education at secondary school level has to be considered as part of the development strategy contributing to meeting all needs for professional and educated personnel in the economy and the welfare sector of a certain area: for such a development, information literacy programs are of prime importance and their implementation within the core curriculum is the best solution.

In order for the program to be realized, it is necessary to know diverse types of sources and possibilities to access information so as to develop a good program together with students and teachers: all participants should be satisfied with it because this program will affect the quality of education. Thus, the role of the library will be more visible, too. In this way, information literacy as well as a teacher/librarian educated in this field will take over the role of reform leader in education. Information literacy is a prerequisite for lifelong learning and for what is called "learning how to learn".

In order to accomplish the aforesaid tasks, an education manager, above all a school principal as member of the school leading team, is expected to take over much more responsibility than earlier. Managing a school

means also bearing responsibility for managing all its sectors, as well as understanding the task of each participant involved in this process. The question whether this understanding is the librarian's task, who in spite of good guidelines and standards is somewhere on the margins, is dealt with in this research paper, which puts forward a need for changes based on best practice.

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Moving teaching from blackboard to the Learning Management System – helping absent students learn from home

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Abstract - With the emergence of various Learning Management Systems (LMS), online and distance teaching and learning has steadily grown in popularity among teachers and students. Moving teaching and course content away from blackboard to the LMS can help teachers create a more dynamic learning environment and can also help students focus their learning and master learning objectives although they are unable to attend their classes. This paper will explore how to move teaching from blackboard to the Schoology learning management system in order to help absent students learn from home.

Keywords – Learning Management System (LMS), distance teaching and learning

I. INTRODUCTION

A Learning Management System (LMS) is a software application for the administration, documentation, tracking, reporting and delivery of electronic educational technology (also called e-learning) courses or training programs. [1] Learning Management Systems promote a learning environment that leads to achieving the expected learning outcomes through encouraging student participation.

There are many learning management systems available on the market; platforms offer a wide range of features for diverse users. The most popular LMS services among teachers are Edmodo, Moodle and Schoology.

With the emergence of various Learning Management Systems (LMS), online and distance teaching and learning has steadily grown in popularity among teachers and students. Moving teaching and course content away from blackboard to the LMS can help teachers create a more dynamic learning environment and can also help students focus their learning and master learning objectives although they are unable to attend their classes. Moreover, such LMS platforms can help teachers to easily collaborate with other educators in the community.

This paper will explore how to move teaching from blackboard to the Schoology learning management system in order to help absent students learn from home.

II. SCHOOLOGY

Schoology [2] is a learning management system that provides a number of various collaboration tools and enables teachers to share e-learning courses, administrate classes, keep gradebooks and communicate with other teachers and students.

TABLE I. SCHOOLOGY - ADVANTAGES AND DISADVANTAGES [2]

Schoology	
Advantages	**Disadvantages**
– User-frendly interface – No messaging between learners – Advanced configuration for assessment and quizzes (such as time limitation, retakes, etc.) – Cloud-based functionality for sharing assignments (similar to DropBox) – Notifications by email – Synchronized with Google Docs – Online distribution and submission of assignments – Web-based gradebook and attendance monitoring – Paper grading and annotation feature – Large database of guidelines, instructions and best practices from teachers – Mobile application	– Students have to enroll themselves in the system in order to start receiving assignments and checking up on their own performance – No messenger for students

Schoology offers the possibility to create course media albums in order to organize photos, videos and/or audio files for different courses. Teachers can allow comments on each item within an album. Students can have an option to upload and tag media.

By using Schoology, teachers can create an interactive discussion for students. Students can respond to any post by another student. The students' comments can be moderated, which requires a teacher to approve each post before it is published.

Schoology can be used to create quizzes/tests and offers elaborative reports and statistics on students' improvement via the Gradebook. Teachers can grade assignments, quizzes/tests and discussions directly in the Gradebook, and students can easily view these grades under their Grades tab. Moreover, the students' progress can be evaluated against specific instructor-defined objectives [2].

III. FLIPPED TEACHING

The best way for moving teaching and course content away from blackboard to the learning management system is to start implementing a flipped classroom.

Flipped teaching (or flipped classroom), also known as backwards classroom, reverse instruction, flipping the classroom and reverse teaching is a teaching technique in which students are encouraged to study course material online before class using readings, pre-recorded video lectures or research assignments. Class time is reserved for interactive activities, exercises, illustrating concepts, projects, discussions, etc.

Instead of lecturing, teachers offer students personalized guidance through learning materials and more interaction with course topics.

The main objective for implementing a flipped classroom is the change from a passive to an active learning model. Basic differences between traditional and flipped teaching are given in Table II [3].

To successfully implement flipped classroom teachers first need to identify what course content that can be reversed. Flipped classroom method can be used for courses that teach computer science such as Java programming, working with databases and SQL, Server operating systems, creating web pages etc. Students already have in-class computer based activities and have worked on different tasks from home, for that reason transitions from traditional to reversed teaching can be easier.

Reversed teaching creates engaging class environment and can be completed with different instructional approaches such as peer instruction, case-based learning (CBL) and process-oriented guided inquiry learning (POGIL).

The main objective of Flipped teaching is to engage students in various learning activities that allow them to explore course content by themselves and allow them to attain course outcomes at their own pace. Teachers need to create appropriate evaluation task to check whether students have mastered learning outcomes for a particular teaching unit. Online platforms that can be used for implementing reverse teaching are Schoology and Edmodo. Those platforms offer wide range of different possibilities in organizing course content and creating comprehension assessments for students. Course content needs to be organized into three groups according to what students need to experience before, during and after the class. For organizing created course materials in addition to specific LMS platforms, both teachers and students can use Google Drive storage. Using websites such as TED-Ed, YouTube, Vimeo, SchoolTube, KhanAcademy and OpenCulture can help teacher to find various already created content that can help them in planning a specific teaching unit.

TABLE II. TRADITIONAL VERSUS FLIPPED TEACHING [3]

	Traditional teaching		**Flipped teaching**	
	Teacher	Students	Teacher	Students
Before class	- prepares lectures, presentation and homework assignments	- mostly do no work - explore course materials - do homework assignments	- prepares reflective web-based lecture materials such as video/audio recordings, content- rich websites, blogs, quizzes, personalised projects, problem based learning , simulations, etc.	- complete interactive learning materials, prepare to participate in class activites, - work on gaining necessary knowledge or skills - explore new topics on their own
During class	- present learning materials, usually using presentation or using the blackboard - repeats what was in the lecture and assigns homework assignements	- listen to a lecture, - follow guided instruction, - take notes	- guides the learning process, gives students support as needed - offer additional explanations for specific topic	- practice skills - via quizzes and polls students provide immediate and anonymous feedback for teachers about course outcomes and content
After class	- grades past work	- memorize notes, - try to do homework	- posts additional resources and explanations as necessary	- continue applying their knowledge and skills, - extend learning to more complex tasks

The main advantage for using reversed teaching is that teachers can devote more in-class time to helping students and can easily identify students' incomprehension. Also, teachers can further expand concepts discussed in the class assigning additional problem tasks for students to explore after class. Students can access learning materials at home, learn and examine course material at their own speed. The main problem when trying to implement reversed teaching is that both teachers and students need to have access to the required technology, computer with access to the internet and necessary software, at home and school.

IV. WORKING WITH ABSENT STUDENTS

When using LMS portals teachers can start to implement reversed teaching which allows non-attending students to explore course content and master necessary learning outcomes at their own pace.

A. Course materials

All course materials, such as learning materials (textbooks in pdf format) or video instructions need to be available for absent students. Teachers can use one of the LMS portals such as Edmodo or Schoology or Google Drive to share course materials. Also, absent students need to have access to all course activities. LMS portals offer a great way for absent students to easily track both in-class activities and additional problem tasks and to do them from home. If they have a problem with a given task, student can easily contact teacher via e-mail or LMS portal.

B. Assignment submission

Students can submit their work in various ways depending on the assignment activity. For example, they can send their assignments via e-mail (Google Mail can be used) or via the Schoology portal. Also, student can create a folder on the Google Drive that is shared with the teacher. In that way teacher has all the students' assignments in one place for review. Created folder can be used as a student portfolio for that specific subject. In this way, the teacher can easily evaluate students' progress.

C. Evaluation

Evaluation of absent students' work is possible through an on-line test using one of the LMS portals such as the Schoology or Edmodo portal or by examining the students' portfolio on the Google Drive. The teacher can obtain additional explanations on the tasks performed by the student using a video conferencing tool such as Skype.

D. Empower classmates to help absent students

Absent student can name their trusted friends among classmates, teacher than asks and supports them to share notes from class. To avoid overburdening one student, responsibility can be spread among several students. Or each student can have a responsibility to share their notes for one time period for example one week. These classmates can also support the absent student by filling them in on what they missed socially and by checking in via phone or social media platforms. If a class has a WatsApp or Viber group already created than interaction between absent students and their classmates can be daily. Teacher can also schedule one-on-one time (for example once a week) to communicate with the absent student via phone or one of the online platforms.

Teacher can include absent students on in-class computer based activities, in that way absent students can collaborate with their classmates during school hours.

V. CONCLUSION

Moving teaching from blackboard to the specific learning management system can be quite difficult. Teachers need to completely change their approach to teaching. Various platforms and software can help, but teachers need to have technical literacy, time and will to become familiar with the necessary tools and platforms. Students and teachers need to have necessary material conditions (computer and access to the internet, smartphone, tablet, etc.), both at school and at home. Once the adjustment phase is over, teachers will have a learning management platform with course content that can help students learn even if they are absent from class.

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Tracking the evolution of scientific collaboration networks

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Abstract - In this paper we perform a network based analysis of scientific collaboration networks. The analysis of the collaboration networks provides an insight into the quality of the relations among participants in the collaboration network. It may identify leaders and crucial participants in the network, domains of interest, closely related communities and future links. This is all of great importance for studying knowledge sharing among participants. We describe a set of network measures and algorithms chosen from the standard complex networks methodology, which are suitable for the research of scientific collaboration networks. The focus of this study has been placed on the scientific communities and linking. Communities can provide information about how collaboration is evolving over time. More precisely, the analysis of collaboration communities tells us about how well the participants are connected and how well they communicate. Next, the paper describes a case study in which the selected measures are applied to the collaboration networks that have emerged from STSMs (short-term scientific missions) on the KEYSTONE COST Action (semanticKEYword-based Search on sTructured data sOurcEs).

Keywords **- collaboration networks; social networks analysis; community detection; link prediction.**

I. INTRODUCTION

High quality collaboration is an important prerequisite for achieving good results in science and education. It can be stimulated by introducing collaborative tasks and projects in educational and scientific domains. Supporting projects strengthens the collaboration among actors. The project's organisation and financing are important steps. However, this does not guarantee the significant benefits and outstanding outcomes as results of a collaboration. Tracking and evaluating the collaboration is another important step. One aspect of tracking the collaboration is analysing the collaboration networks. Collaboration networks are a special case of social networks in which nodes represent actors/individuals who collaborate in certain projects, jobs or scientific publications [20]. Thus, there is a wide range of methods and approaches from the field of social network analysis (SNA) [26] that can be applied on the collaboration networks.

The analysis of collaboration networks will provide a better insight into the hidden rules of collaboration. By possessing this knowledge one can improve collaboration, find a domain of interests, find the crucial actors and leaders in the collaboration network or provide an insight into the quality of the relations among the actors in the network. Moreover, it may also identify closely related communities, domains of interests, and knowledge flow. Thus, the analysis of the collaboration networks is important because it can give us information based on which it is possible to predict future steps and actions in a collaboration.

Collaboration networks can represent collaborations on different levels: between individuals, between institutions or between countries as project participants. Special case of collaboration networks are co-authorship networks in which collaboration is realised as joint publication. Collaboration networks can be (but not necessarily) weighted and/or directed. Weights (if they exist) may denote the number of interactions, projects or publications. Directions (if they exist) may denote the direction of communication, institutional exchange, knowledge sharing, etc.

SNA in general offers a wide range of metrics for data analysis on the global, middle and local network level. A variety of these measures has been applied to various research of collaboration networks such as co-authorship networks [1,2,6,7,9,11,12,13,17,19,20] and project collaboration networks [3,8,22,23,24]. Still, there has been no standardised/universal methodology nor framework proposed for the scientific collaboration networks analysis. Each study proposes its own set of measures and approaches.

In this paper we present a preliminary study in which we experiment with the set of standard complex network measures. Special focus has been placed on the identification of communities and future linking. This study is an extension of our previous work [16], however here the aim is to get a deeper insight into the communities and linking rules of collaboration networks.

The rest of the paper is organised as follows. In the second section we present state of the art. Next, in the third section we give an overview of the standard complex network measures that we use in our experiment. The fourth section describes a network construction based on the STSM data. In the fifth section we present the results of the network based analysis. The last section provides concluding remarks and plans for future work.

II. STATE OF THE ART

Collaboration networks have received much attention in research for at least the past forty years. The first attempts of the analysis of collaboration networks were focused on the networks based on scientific publications because this data was always freely available to the public. Newman [19] was one of the first who intensely studied the structure of scientific collaboration networks in terms of social network analysis. Following his approach many authors have combined various network measures in order to analyse the structure of the collaboration (co-authorship) networks constructed from scientific publications.

A. Co-authorship networks

The co-authorship networks remain the most commonly analysed collaboration networks in the last decade.

In [9] authors analyse the structure of scientific co-authorship networks in Scientometrics. They combine SNA, co-occurrence analysis, cluster analysis and frequency analysis of words to reveal microstructure of the collaboration network on scientists' aspects of scientometrics. They study major collaborative fields of the whole network and of different collaborative subnetworks and collaborative center of the collaboration network in scientometrics.

Morel and his group use co-authorship network visualization and analysis to improve design and strategic planning in the health domain [18]. The results of their research enable project leaders to identify network components by area of work, find institutions and authors that are central hubs or located at critical network cut-points and detect authors or institutions participating in large international scientific collaborating networks.

De Stefano et al. describe different phases of the analysis of co-authorship networks [6]. They illustrate and discuss certain issues: use of different data sources, definition of network boundaries; various weighting schemes and interpretation of network analysis results.

In [2] authors analyse the structure of co-authorship networks in three different fields in Spain over period 2006.-2008. and explore the relationship between the research performance of scientists and their position in co-authorship networks. The number of co-authors and the strength of links show a positive relationship with the g-index in the three fields. No clear advantages from intermediary positions or from being linked to well-connected authors can be interred from that analysis.

There are various papers focused on the dynamics of co-authorship networks.

Abbasi and his group [1] analysed collaboration network of scientists in the field using author affiliations extracted from Scopus between 1970 and 2009. They compared and analyzed a number of properties of these networks (i.e., density, centrality measures, the giant component and clustering coefficient) for presenting a longitudinal analysis. They show that the scientific collaborations network structures were central considering the closeness centralization while betweenness and degree centralization were much lower. In general networks density, connectedness, centralization and clustering coefficient were highest in marco-level and decreasing as the network size grow to the lowest in micro-level.

In [13] authors model the dynamics of co-authorship networks. They identify two types of links between authors: social links and links that indicate common professional interests. and detect that the links are based on the social and professional interactions. Based on their model they conclude that professional link does not guarantee future joint authorship between the two authors. However, a strong social link yields high probability of a future joint publication.

Kronegger et al. analyze the dynamics of co-authorship networks constructed from the national Slovene Research Agency [11]. They use blockmodeling framework to identify similarity across nodes and other substantively interesting patterns in the group of nodes. This way they get more information that using standard community detection algorithms. The same authors investigate networks of Bibliometric data for Slovenian researchers in [12]. They apply hierarchical clustering procedure in order to identify main scientific disciplines. Their findings are partly in line with traditional science classification, however their findings suggest that this classification is not strict. Similar analysis is performed for Croatian authors in [17].

Recently Guan and his group [7] develop a new method of construct the knowledge network using article keywords. In the collaboration network, the structural holes of authors have positive but non-significant effects on the papers citations, while the authors centrality has inverted effects on the paper's citations; in the knowledge network, the structural holes of knowledge elements are positively related to the paper's citations, and the knowledge elements centrality has an inverted relationship with the paper's citations.

B. Project collaboration networks

Scientific project collaboration networks such as FP7 or ERASMUS have been analysed much less [3,22,23].

Balland et al. [3] analyze data from R&D collaborative projects, funded under the European Union 6th Framework Programme. They model network dynamics and show that geographical, organizational and institutional proximity improve collaboration, however cognitive and social proximity do not have significant impact to collaboration.

Roediger-Schluga and Barber describe the construction collaboration networks based on the data collected from EU Framework Programmes [22]. They examine data properties and network patterns and provide economic interpretations from the economic point of view. They find stable core of interlinked actors which consists mainly of universities and research organisations.

In [23] authors analyse the network of ERASMUS staff and student exchange agreements between academic institutions involved in FETCH project. They use standard metrics and techniques of social network

analysis. They show that network is in a mature phase of the development and has a clear core-periphery structure.

Furthermore, collaboration networks are of great interest in organisations. For example in [8,24] the authors explored how the structure of the collaboration network can influence innovation.

Guan and his group use multilevel networks to construct inventor collaboration networks on the two levels: city level and county level [8]. at city and as well as country levels. Their findings show that show that country-based collaboration network structure moderates the relationships in the city-based collaboration network structure and that affect the innovation performance. innovation performance are enhanced when country's centrality and structural holes are high.

In [24] authors claim that structure of alliance networks influences their potential for knowledge creation. They present a longitudinal study of the patent performance in 11 industry alliance networks. Their findings suggest that communication and cooperation are better when network has dense local clustering and that high clustering and short average path lengths to provide better inovation.

III. COMPLEX NETWORKS ANALYSIS

In this section we describe some of the standard network measures that we used in our experiment, the detailed descriptions and equations are given in [21,27].

A network or graph $G = (V, E)$ is a pair of a set of nodes V and a set of edges E. N is the number of nodes and K is the number of edges. A network is directed if the edges have a direction associated with them. A network is weighted if there is a weight function w that assigns value (real number) to each edge. In weighted networks, S denotes the sum of all weights in the network; that actually refers to all realised relations.

A. Global network measures

There is a wide set of network measures on the global level; here we explain the measures that we use in presented study.

The degree of a node i, k_i is the number of edges incident to the node. In a directed network, in/out-degree of a node is the number of incoming and outgoing links. Average degree, ($<k>$) is the sum of the degree over all nodes divided by the number of nodes.

Weighted degree is called strength. The strength of the node i is the sum of the weights of all the links incident with the node i. The average strength, ($<s>$) is the sum of the strength over all nodes divided by the number of nodes.

Network density, (*dens*) represents a fraction of existing connections and the number of all possible connections. In directed networks it is calculated as:

$$d = \frac{K}{N(N-1)}.$$

The number of connected components is denoted by ω. When a network has a property that it has no disconnected parts, we say it is connected; otherwise it is disconnected.

The clustering coefficient is a measure which defines the presence of connections between the neighbours of a node. The clustering coefficient of a node, c_i is a fraction between the number of edges (E_i) that exist between that node and the total possible number of links:

$$c_i = \frac{2E_i}{k(k-1)}.$$

The average clustering coefficient C of a network is defined as the average value of the clustering coefficients of all nodes in a network:

$$C = \frac{1}{N}\sum_i c_i.$$

For the next two measures, if a network contains more than one component, we consider the largest component. The average shortest path length between every two nodes in a network is:

$$L = \frac{1}{N(N-1)}\sum_{i \neq j} d_{ij}.$$

And the maximum distance results in the network diameter, D:

$$D = max_i d_i.$$

Network modularity (m) measures the quality of the network partition in the communities. The modularity of a network partition is a scalar value between -0.5 and 1 that measures the density of links inside communities as compared to links between communities.

Some of these measures used in network tracking during various periods provide information about network tendency to growth. More precisely, the average degree, strength and density give an insight in network size. The distance measures (average path length and diameter) can show how far nodes are from each other, or how well is network connected. The clustering coefficient is an indicator of clustering nodes in the group of three nodes. Modularity is important for the interpretation of the communities. Networks with modularity greater than 0.7 have a tendency to form communities, while a modularity of less than 0.3 indicates that there is no grouping into communities.

B. Network substructures

In the second step we identify communities by the means of the Louvain algorithm [14]. The identification and visualisation of communities provide knowledge about sets of nodes (participants) such that each set of nodes is densely connected internally.

In some projects it is preferable to have a collaboration network with a community structure while

in other projects it is not. The information about communities in the project is valuable and cannot be directly identified from the project data. Communities can be directly detected by analysing the whole network.

Here we have to point out that, besides communities, on the there exist some other structures that indicates denser connections between nodes. More precisely, on the middle level we can analyse other interesting substructures such as cliques, clans, clusters, blockmodels [12]. However, in this preliminary research we stay focused only on communities.

C. *Link prediction in the network*

There are various link prediction algorithms. The most popular and simple link prediction algorithms are: Resource Allocation Index, the Jaccard Coefficient, the Adamic Adar Index and the Preferential Attachment. Link prediction is important and helps to model the network evolution and it is an important task in project tracking.

Most of these measures can be applied to the directed and weighted networks, but some of them are suitable only for undirected and/or unweighted networks and in that case of analysed collaboration networks the directions and/or weights are omitted.

IV. STSM NETWORKS CONSTRUCTION

COST is the European framework supporting transnational cooperation among researchers, engineers and scholars. Short-Term Scientific Missions (STSMs) are one of the COST networking tools that allow participants to visit an institution or laboratory in another country. The main objective of the Action is to launch and establish a cooperative network of researchers, practitioners, and application domain specialists working in fields related to semantic data management, the Semantic Web, information retrieval, artificial intelligence, machine learning and natural language processing, that coordinates collaboration among them to enable research activity and technology transfer in the area of keyword-based search over structured data sources. To build a successful, unified and effective solution – due to the multifaceted nature of the problem – the Action "semantic KEYword-based Search on sTructured data sOurcEs" (KEYSTONE) proposes to create synergies between several disciplines, such as semantic data management, the Semantic Web, information retrieval, artificial intelligence, machine learning, user interaction, service science, service design, and natural language processing. [5].

For the purpose of this experiment, a collaboration network is constructed, based on the data collected from the STSMs on the KEYSTONE (semanticKEYword-based Search on sTructured data sOurcEs) COST Action [10]. There were 62 STSM grants during the 5 grant periods (GP1, GP2, GP3, GP4 and GP5): 11 in the first grant period (year 2014), 14 in the second grant period (year 2015), 8 in the third grant period (year 2016), 24 in the fourth grant period (years 2016 and 2017) and 5 in second half of 2017 in the fifth grant period.

In an STSM network, countries are nodes and a directed link between two nodes X and Y exists if there was an STSM application from country X to country Y. The weight denotes how many STSM applications were realised between these two countries.

Based on this principle, five STSMs networks are constructed from five grant periods. The final result is five directed and weighted networks: STSM1, STSM2, STSM3, STSM4 and STSM5. These networks are further examined in terms of growth, communities and linking.

V. RESULTS

In this section we present the results of our experiment in three steps. Firstly we analyse how to perform global network measures during the network growth. Secondly we identify communities and how they change in each period.

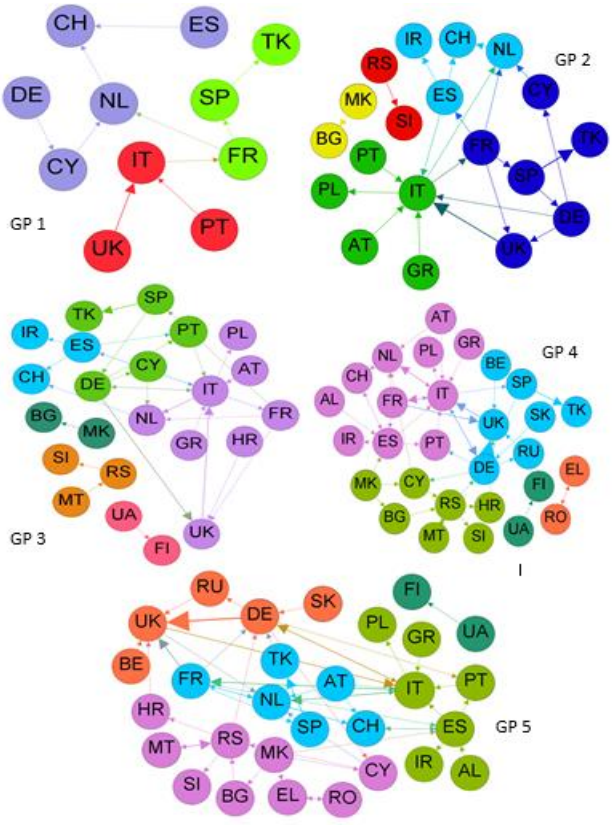
And lastly we evaluated the four most used link prediction algorithms.

A. *Basic analyses*

First, for the purpose of network evolution analysis on the global level we use several measures: number of nodes, number of links, sum of all weights, average degree, average strength, density, number of connected components, average clustering coefficient, average path length, network diameter and network modularity.

In Figure 1 the network growth visualised is shown using Gephi [4]. In Table 1 we present how the values of the global network measures change during the five grant periods.

Figure 1. Growth visualisaton of Grand Period 1, 2, 3, 4, 5



As expected, the average degree, average strength and density increase over time. The tendency of the growth of the number of connected components varies over time. It increases during the first three grant periods and then decreases. This means that the actors tend to connect into a connected component, and after some time we can expect to have a connected network. The clustering coefficient is low in the beginning due to the small number of nodes, but increases very quickly.

B. Communities detection

In the next step we analyse communities in the networks and how they change during the five grant periods. A precise analysis of the communities is presented in Table 2. The number of communities increases during the first three periods and then it stops at five communities. This is a relatively small number of communities. This can be interpreted in a way that project participants tend to collaborate with various network members and there is a slight tendency to be isolated in separate communities. This assumption has already been indicated because of the low values of modularity. In the case of a COST project this is a positive result because the main goal of the project is collaboration across all the countries without grouping and isolation. Understanding the communities can improve knowledge sharing among the participants.

In addition the Louvain algorithm in Gephi visualises the communities in the way that nodes in one community are all the same colour. The visualisation of community dynamics during the five grant periods is shown in Figure 1.

C. Link prediction

In the third step we apply various link prediction algorithms in order to capture new links that appear between two grant periods. More precisely, we apply the Resource Allocation Index (RAI), the Jaccard Coefficient (JC), the Adamic Adar Index (AAI) and Preferential Attachment (PA).

TABLICA I. GLOBAL NETWORKMEASURES FOR NETWORKS BASED ON THE STSM AGREEMENTS, N IS NUMBER OF NODES, K IS NUMBER OF LINKS AND S IS TOTAL NUMBER OF WEIGHTS

Network	***N***	***K***	***S***	**<*k*>**	**<*s*>**	***dens***	***ω***	***C***	***L***	***D***	***m***
STSM1	11	10	11	0,909	1	0,091	1	0	2,172	4	0,445
STSM2	19	23	25	1,211	1,316	0,067	3	0,042	2,57	5	0,379
STSM3	23	30	33	1,304	1,435	0,059	4	0,078	2,405	5	0,372
STSM4	29	47	57	1,621	1,966	0,058	3	0,099	3,111	6	0,412
STSM5	29	52	61	1,793	2,198	0,064	2	0,107	3,01	6	0,390

TABLICA II. COMMUNUNITIES DETECTION IN GP PERIOD

STSM	**GP1**			**GP2**					**GP3**						**GP4**					**GP5**				
Number of communities	**3**			**5**					**6**						**5**					**5**				
Community	1.	2.	3.	1.	2.	3.	4.	5.	1.	2.	3.	4.	5.	6.	1.	2.	3.	4.	5.	1.	2.	3.	4.	5.
Country	CH ES NL CY DE	TK SP FR	UK IT PT	FR UK CY TK SP DE	IT PT PL AT GR	ES IR CH NL	MK BG	RS SI	UK HL GR HR IT AT FR PL	DE CY PT SP TK	RS SI MT	IR ES CH	UA FI	MK BG	GR PL AT NL IT CH AL FR PT ES IR	MK CY BG MT RS SI HR	BE SP TK SK UK RU DE	EL RO	UA FI	HR RS MT SI BG MK EL CY RO	PL IT GR PT AL ES IR	FR NL AT CH TK SP	BE UK RU SK DE	FI UA
Sum	5	3	3	6	5	4	2	2	8	5	3	3	2	2	11	7	7	2	2	9	7	6	5	2
Percentage	46	27	27	31	26	21	11	11	35	22	13	13	7	7	37	24	24	7	7	31	24	20	17	7

We use these algorithms in the task of predicting new links for every new grant period: GP2, GP3, GP4 and GP5. Then we evaluate the predicted results using real links in a way that we count how many links are correctly predicted among the first *Z* links where *Z* is the number of new links in the original network.

The evaluation results are shown in the Table 3. The results of prediction are very poor. Only for the second grand period were some links correctly predicted and the best results give a PA algorithm. spremnih za tisakPoor results can be explained by the assumption that scientific project collaboration networks may have different linking rules from other social networks.

TABLICA III. LINK PREDICTION BASED ON FOUR ALGORITAMS IN PHYTON

STSM	RAI	JC	AAI	PA
	hit/predict	hit/predict	hit/predict	hit/predict
GP 2	2/14	1/14	2/14	5/14
GP 3	0/8	0/8	1/8	0/8
GP 4	0/24	0/24	0/24	0/24
GP 5	0/5	0/5	0/5	0/5

VI. Discussion and Conclusion

In this paper we presented how scientific project collaboration can be analysed by means of complex networks. We report results based on the preliminary case study in which we analyse the collaboration in STSM projects within the KEYSTONE COST Action.

The main objective of this study is to use complex networks in order to better understand the nature of collaboration in the scientific project. This may be of potential interest in academic and education communities in a sense that results may be applied to direct further steps in project management.

The global network measures show how fast participants connect among themselves. According to the values of the connected components all nodes (participants) tend to group into one component. The clustering coefficient indicates that grouping into triangles increases over time. However, the modularity values are lower which means that there is no strong tendency from the participants to group. In fact, this characteristic is desirable in COST networks because there should be no isolated communities.

The selected set should be extended with additional global networks measures. Moreover, the selected SNA measures and approaches should be further tested on other scientific or educational projects.

In the second step we analyse how communities and new links are formed during five grant periods. While communities are easy to identify by using the fast and efficient Louvain algorithm, future linking cannot be detected with standard algorithms (Resource Allocation Index, Jaccard Coefficient, Adamic Adar Index and Preferential Attachment). This means that we should find new link prediction algorithms that better suit the growth of collaboration networks and we plan to investigate that in our future work.

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Guidelines for development of application for procedure implementation of public procurement

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Abstract - This paper includes analysis of public procurement law and individual procedures of procurement from that Law. The analysis is a fundamental preparation for developing the application that will enable enforcement of the public procurement law. Based on conducted analysis a set of user entities has been defined, its attributes and relationships between entities which all together defines relational database model. After defining relational database model, a functional application has been made that works according to the defined process flow. Process flow has been defined in analysis of procurement procedures.

This paper presents the use of web technologies and object-oriented programming to create a functional application. The application was created at the University of Applied Sciences Velika Gorica for the courses Object Programming Application and ASP Web Programming. This paper represents educational case for implementing the procedures of the of public procurement law.

Keywords - Public Procurement Law; analysis; process; ASP.NET; MVC; SQL Server; relation model; procurement process; diagram; entity; application logical model

I. INTRODUCTION

Today for business organization the work without the use of information systems is almost unimaginable. All business processes that can be supported by information system are computerized to a greater or lesser extent and with the development of technology there are increasingly more processes that can be computerized. The need for computerization process stems from several important reasons such as data storage and creation of a knowledge base on data from the past for the better future business decisions, to standardize processes and reduce human errors at the lowest possible minimum, quickly and adequately respond to changes, real-time, quick and easy access to information when needed, increase employee productivity, and more.

The aim of this paper is to illustrate and explain the methods and guidelines for the development of applications for the implementation of public procurement procedures under the Public Procurement Law NN 90/11 and to create a functional module for the implementation of procurement procedures.

II. PUBLIC PROCUREMENT LAW NN 90/11

On July 15th 2011, the Parliament of the Republic of Croatia confirms the Public Procurement Law and on 20 July 2011 the President of the Republic of Croatia issues a decision on the proclamation of the Public Procurement Law. Subsequently, the Law on Changes of the Public Procurement Law was passed by the Parliament of the Republic of Croatia on June 21st 2013, and the President of the Republic of Croatia decided on the amendments on June 24th 2013. The Law on Amendments to the Public Procurement Law was passed in the Parliament of the Republic of Croatia on November 22nd 2013.

This paper is based on the clarified text of the Public Procurement Law NN 90/11, 83/13, 143/13 and 13/14 (PPL) [1].

The PPL regulated the procedures for concluding contracts and framework agreements for the procurement of goods and services, legal protection in these proceedings and the competence of the central state administration body. It is divided into seven parts:

- general provisions,
- concluding a public procurement contract for public purchasers,
- concluding a public procurement contract for sectoral purchasers,
- legal protection,
- the central state administration body responsible for the public procurement system,
- misdemeanor provisions,
- transitional and final provisions.

General provisions prescribe the basic concepts on which the PPL has been set up and the subjects to which it relates and who must act in accordance with the PPL, the principle of preventing discrimination in public procurement procedures, procedures for implementing public procurement, definitions of procedures.

PPL contains important articles that define the types of procedures, the concepts that are relevant to the application's work, the way of calculating the estimated value and part of the reserved contracts.

PPL stipulates the course of a particular procedure, the obligations of the contracting authority conducting the public procurement procedure and defines the cases in which the proceeding may be initiated [2]. The contracting authority may not initiate certain procurement procedures without the fulfillment of certain conditions.

III. GUIDELINES FOR CREATING AN APPLICATION BASED ON AN ANALYSIS OF PUBLIC PROCUREMENT PROCEDURES

Prior to the creation of a public procurement application, it is necessary to define the types of processes and their phases in the life cycle. Each procedure has its beginning and end.

Life phases of the process are essential to the work of the application because of the activities that are performed within them, allowing the user to better manage within the application. Within each stage of the process, certain types of documents and data are generated. Also, entered data should be validated to confirm that all the requirements are fulfilled. If any of the requirements is not fulfilled, the application should remind the user what to do.

Before designing the application, it is necessary to design and define the database structure. To define the entities and attributes, it is necessary to analyze the entire PPL, to study the documents that are generated and discuss with the procurement person to obtain the overall picture.

In addition to the entities and attributes that are related to the procurement process, other entities that are not defined in the PPL are required for the work of the application. An example of such an entity is user information, which at least includes the first name, last name, username and password that serves to authenticate the user. Depending on what the system designer wants to achieve and how he wants to authenticate and authorize the user, this entity may have more attributes.

There are also binding entities derived from PPL core entities, which serve to automate and control the flow of the application to make it easier for the user to use the application. An example of such entity is the derivative of the basic entities, the types of procurement procedures and the status of the process. This entity defines the exact course of the public procurement process.

When constructing a relational model, entities will be supplemented with attributes "Last Changes Date", "User", and the Primary Key. Entities that are important to keep historical data will be created with historical tables and the attribute "Version" will be added to the basic table. The basic table will have the "Deleted" attribute that will be used as a delete indicator and thus avoids physical data deletion from the database.

After the creation of a relational model of data, it is possible to start creating application. The first step is to choose development technology. Which development technology to use depends on several factors. The first factor is the desired environment in which the application will work, and it can be desktop, web, or mobile. This factor is important and choosing a wrong platform could cause that the user will not be able to use application.

The desktop application is a good choice for large systems where there is a very strong response rate towards end users and is easier to develop. The drawback of desktop application is that their work depends on the user's computer. Upgrading is more difficult because it requires user action and is related to the type of operating system it is designed for. Also, desktop applications can work offline, and later synchronize with the main database, enabling application continuity.

A Web application is a good choice if we want to cover more than one platform with a single development. The user needs Internet access and one of the web browsers to use a web application. Another benefit of web applications is easier maintenance. All changes are made in one place and are visible to all users at the same time. The web design itself is more complicated in terms of designing the user interface and may be slower than desktop applications. When the Internet connection is lost, the application does not work and the continuity of work is lost.

Making large and demanding mobile applications today is possible although it is not a practice. For mobile devices, most often only a part of the functionality used in field work is done. For example, if we have a post office or employee to maintain the functionality of an application to open a work order or download a new order, it may be via a mobile device. This functionality on the mobile device takes precedence because the worker does not have to go back to the base to take over the work order. It can download it over the mobile device and do the job and confirm the execution.

For this project, we have decided to create a web application, since the application can be used by several different users who can be dislocated throughout the Republic of Croatia.

IV. THE LOGICAL MODEL OF THE APPLICATION

The logical model of the application serves to generalize the functionality of the application and does not dependent on development technology. By creating a logical model, developer gains insight into the main application functionality and its interaction with other systems and participants.

The procurement support application consists of several basic functionalities:

- maintaining the base data,
- user administration,
- conducting procurement procedures.

Each of the functionality consists of a group of activities that the user can trigger depending on the rights assigned to the user. Figure 1 shows a context-specific case diagram that specifies the main application capabilities.

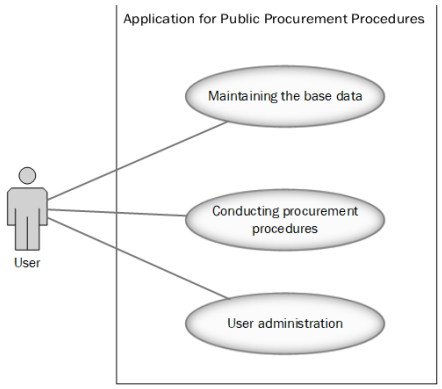

Figure 1. Use case diagram

Maintaining the base data consists of the following activities:

- maintenance of actions,
- maintenance of items,
- maintenance of Common Procurement Vocabulary (CPV)
- maintenance of suppliers,
- maintenance of employee functions,
- maintenance of procurement groups,
- maintenance of units,
- maintenance of locations,
- maintenance of contracting authorities,
- maintenance of procurement subgroups,
- maintenance of procurement plan status,
- maintenance of type of proclamation,
- maintenance of types of procedures,
- maintenance of the connection status of the procedure – procedure,
- maintenance of the connection procedure – status of the procedure – type of disclosure.

Each of these activities has several possible actions: create, update, and delete.

User administration consists of the following activities:

- maintaining the menus,
- maintaining context menu actions,
- maintaining the context menu by role,
- maintaining the user,
- maintaining connections user – role,
- maintaining roles,
- maintaining simple roles,
- maintaining links user – menu,
- maintaining connections user – simple role.

The conduct of procurement procedures consists of the following activities:

- conducting competitive dialogue,
- conducting an open tender,
- conducting a restricted tender,
- conducting a restricted procedure,
- conducting an open procedure,
- conducting a negotiated procedure with prior notices,
- implementing the procurement procedure from the framework agreement.

A case-diagram of use is made for each of the above functionalities and activities.

V. DEVELOPMENT TECHNOLOGIES

Several technologies and programming tools were used in web application development.

A. Microsoft SQL Server

Microsoft SQL Server is a Relational Database Management System (RDBMS) whose primary function is to store and retrieve data for other applications whether they are running on the same computer or on another computer on the network (including the Internet) [5].

It also manages the data for the developer by restricting the kind of data that can go into the system and facilitating getting data out of the system [5].

B. .NET Framework

.NET Framework is a collection of classes that can be used when creating any kind of application. For example, the .NET Framework includes classes for working with the file system, to access the database, to create images and more [3].

.NET Framework provides multilinguality and interoperability, i.e. the ability to use classes created in one language in another language. This feature is possible because programs written for .Net Framework are executed within the Common Language Runtime (CLR) program environment, which represents the virtual machine within which the programs are run.

.NET Framework is responsible for correct execution of programs that uses .NET classes. For example, .NET Framework is responsible for allocating and freeing memory, security data in the memory, allocating resources for applications, and more.

C. Visual Studio

Visual Studio is an Integrated Development Environment (IDE) intended for development of various kinds of applications for the Windows operating system. With Visual

Studio, it is possible to develop Windows applications, web applications, Windows services and mobile applications [6].

As a tool for creating web applications Visual Studio is far more than a simple editor designed for writing the source code.

Continuous development of the Visual Studio positioned it as a comprehensive tool for developing web applications. Features such as JavaScript IntelliSense, debugging, CSS editor, CSS IntelliSense, HTML editor are the key benefits of Visual Studio when developing web applications.

Visual Studio comes with a built-in web server which allows quick and easy way to test web applications. It allows the development of web applications without the need to install any additional web server. The embedded web server has the basic features common to all web servers.

Visual Studio allows the use of external web server installed on the development computer or on a server on the Internet.

During development, it is recommended to use unit testing. Unit testing is a set of repeatable automated tests that are used to test and verify individual components.

D. ASP.NET MVC

ASP.NET MVC is a set of classes that allows web application development. The web application architecture is divided into a model-view-controller (MVC) and allows for independent development of individual application parts [4].

The model contains data. The view defines the appearance of the user interface and how the data is displayed. The controller contains program logic and receives the input requests from the user [4].

E. JavaScript

JavaScript is an object-oriented scripting language that runs on the user's side within the web browser. Along with HTML and CSS is the core technology in web content production. The code written in JavaScript is not compiled before, but the commands are loaded into the interpreter that then executes them [7].

JavaScript enables programmers to make asynchronous calls from the web browser. Asynchronous call enables to dynamically retrieve data from the database or execute part of the code on the server, which alters all or just part of the content on the web page [7].

JavaScript captures HTML elements that can be used to define desired visual properties. JavaScript can also capture certain events in the elements themselves, and in combination with visual properties define a dynamic view. In addition to fetching JavaScript elements, programmer can also create program logic, manage dates, run calculations, perform operations with texts, lists and define own classes and functions.

F. DevExpress

DevExpress is a collection of user interface (UI) controls for Visual Studio. In addition to visual features, DevExpress controls allow programmers for easier administration of the application and facilitate the creation of specific functionalities [8].

DevExpress controls are executed on the server side, which is very important in terms of security [8]. When generating control on the server side, it dynamically generates and includes JavaScript and CSS code to be executed on the client side.

G. DHTMLX

DHTMLX controls are also user interface controls. Unlike previous controls, those client controls are written in JavaScript and CSS to be executed exclusively on a client computer within the web browser [9]. Controls are modularly made so that individual JavaScript and CSS files can be used for a particular control. Data and control attributes can be defined in the code or forwarded from the code in XML or JSON format. When creating XML or JSON formats, programmer should pay attention to the control attribute names so that the data can be loaded correctly.

VI. WEB APPLICATION

Using the methods and guidelines outlined in the previous chapters, an application model has been developed, with the functionality for implementing public procurement procedures, base data maintenance and administration.

To use the application, the user must first enter a user name and password. After a successful login, the user is transferred to the home screen with the menu according to the defined user rights. Selecting action from the menu in the center of the view displays data. At the same time, the header shows an additional action menu with possible actions according to the defined user roles.

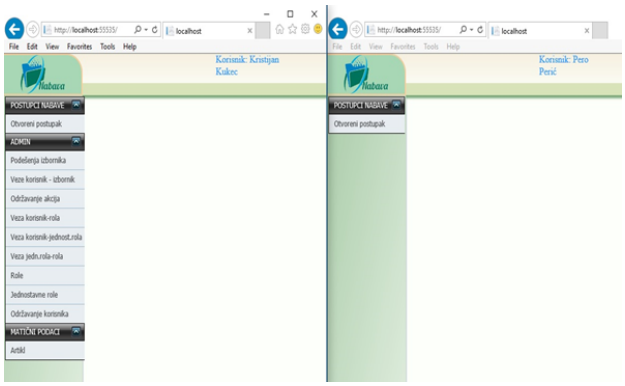

Figure 2. Home page for different roles

The concept of the application in the part of the procurement procedure is designed in such a way that the superior worker assigns procedures to the procurement reference and the referent processes the procedures assigned to it. Each new process that a referent gets in the view is highlighted in bold. After opening the process this feature is

removed. By selecting "Update" action, a popup window opens with details of the procurement procedure. Depending on the status of the procedure and the type of procedure, certain actions can be executed. If a certain action is obligatory (legally prescribed) system does not allow the transition to the next status until it is done.

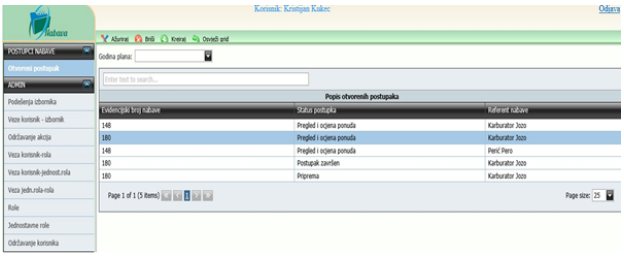

Figure 3. Web application with data display

Context menu of forms for procurement procedures changes depending on the status of the process, and thus leads the user through the procurement process. When a procurement procedure is under preparation, it is possible to add a procurement reference, decision to initiate a procedure, publication or an internal document and the reasons for the exclusion through the context menu. When initiating the procedure, depending on the group bidding indicator, in the background, necessary sets of data and cost-scaling based on the planned items are generated. In the review status and the evaluation of the bidding it is necessary to make an analysis of the bids where all submitted bids are presented and depending on the documentation it is necessary to confirm the correctness of the bidding.

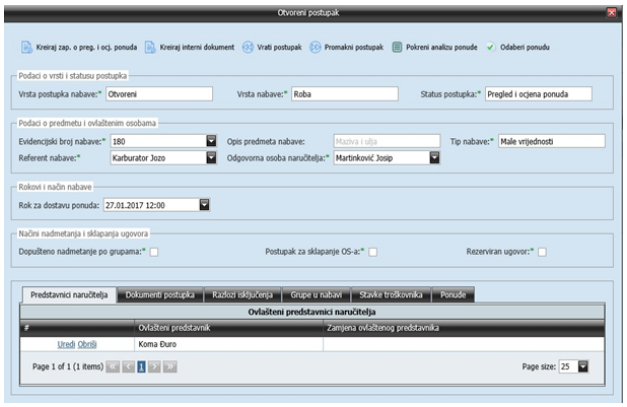

Figure 4. Form for starting the procurement procedure

After the analysis of the bids, it is necessary to select the offer. If there are more bids that meet the conditions, the system allows a manual selection of bid that meets the conditions of the analysis.

The next status is status completed, and the user has the option to load the scanned contract.

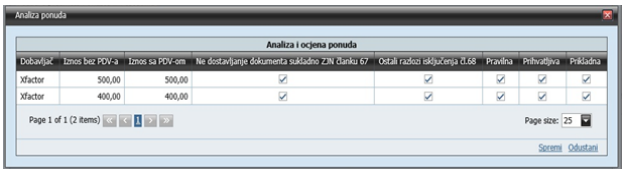

Figure 5. Form for bid analysis

VII. CONCLUSION

The analysis of the Public Procurement Law is a prerequisite for making quality applications. When analyzing the Public Procurement Act, it is essential to systematically write down all necessary parts to obtain the overall picture, create entities and their attributes. When defining an entity, it is necessary to take account of their relationship to properly define the relationships between them.

If procurement processes and entities are well-defined when system analysis is done, the application itself does not pose a problem. The quality of the application depends on the input data. If the input data is poor or insufficiently specified, application development will take a long time and the desired result will not be obtained.

Choosing a technology for development depends primarily on the individual or team responsible for development. Today, one cannot say that some technology is better or worse, although each one has its own flaws and advantages. When choosing technology, it is important for an individual or team to know how to use it. Good practice in developing is to stick to the agreed mode of naming variables, at the end of each working day or several times a day, store the code on a code version management system, put descriptive comments on the functions to make it clear to others what the function is doing.

By following the rules and methods outlined in this paper, an application for the implementation of public procurement procedures was developed.

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Comparative analysis of QR code generators

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Abstract - The goal of this paper is to describe ASP.NET application for comparative analysis of QR code generators. The application includes the implementation of existing solutions of QR code generator provided by the third parties over which the research was conducted and the results will show us which solution is best in terms of consumption of computing resources and speed of execution.

This paper explains the technology and development tools that are necessary for the development of the application and the way of implementation of existing solutions QR code generator provided by third parties.

Keywords - QR code; ASP.NET; web application; .NET Framework; comparative analysis

I. INTRODUCTION

QR codes are a newer way of distributing information to end users. QR code provides quick access to information through image scanning using the appropriate optical reader.

Comparative analysis is a method of research that compares the same or related facts and determines their similarity in behavior and intensity and differences between them.

Comparative analysis allows us to compare the performance and quality of individual QR code generators. A web application has been created to enable comparative analysis. A web application enables the end user to test individual generators through an interactive interface and to view the results through the tabular display and graphs. It enables end user to see which of the implemented QR code generators has better or worse performance.

On the server side web application uses .NET Framework and SQL technologies and on the client side HTML, CSS and JavaScript.

II. COMPARATIVE ANALYSIS

A web application developed for comparative analysis allows end users to perform tests related to program execution speed, processor and memory usage versus generator QR code, output image type, iteration number, error correction level and QR code version.

Each test result is recorded in the database and the same data is aggregated when displaying the results to the end user, which enables user to view the quality and performance of a single QR code generator.

III. QR CODE

QR code (Quick Response Code) is a trademark for a two-dimensional barcode. The barcode contains information about the subject and it is readable by an optical reader.

The QR code has become popular because of its reading speed and the data capacity. It can store more data than standard barcodes. QR code can serve in product tracking, time tracking, subject identification and marketing.

QR code consists of black modules (cube points) in a cubic table on a white background in the form of an image that can be read with an optical reader (camera, scanner, etc.). After reading the image, the data is read out through the patterns that are presented in the horizontal and vertical image components.

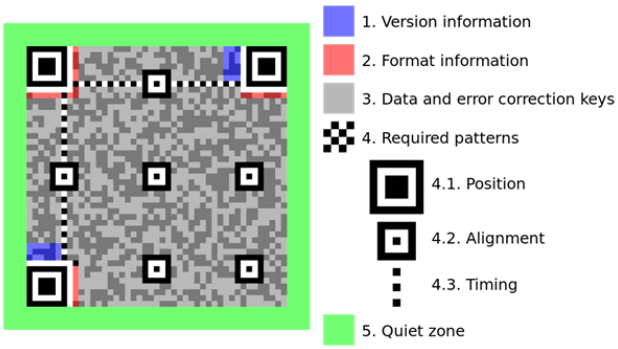

Figure 1. QR code structure with marked functional elements

QR codes are read by a two-dimensional digital scanner and then digitally analyzed with a pre-programmed processor. The processor locates three distinct squares in the image and uses small squares near the fourth corner square to read off the image size, orientation, and alignment. After reading the small squares that are in the QR code, they are converted into binary values and checked by the algorithm to test the error correction.

The amount of data that can be stored through the QR code depends on the type of data, version and error correction. The keywords are long 8 bits and use the Reed-Solomon algorithm to examine the error correction.

In larger QR codes, the message is broken into smaller Red-Solomon blocks. The size of the block is determined so that each block can eliminate up to 15 errors but that limits the complexity of the decoding algorithm.

TABLE I. ERROR CORRECTION AND MAXIMUM PERCENTAGE OF DATA RECOVERY

Error correction	The percentage of recreation of keywords
Level L (Low)	7%
Level M (Medium)	15%
Level Q (Quartile)	25%
Level H (High)	30%

Format information contains two items, the error correction and pattern for masking the QR code. Masking is used to prevent the appearance of patterns that could potentially confuse the scanner, such as large white surfaces or misleading features used to identify location characters.

The masking pattern is defined on the grid that is repeated to fill the entire QR code. Format information is protected of error with the BCH code and two copies are included in each QR code.

The information is set from the right to left using a zig-zag pattern. In larger QR codes, the process is difficult because of the use of positioning samples and the use of multiple blocks with the error correction.

IV. DEVELOPMENT TECHNOLOGIES

Two application development tools were used to develop a web application:

- Microsoft Visual Studio - business logic and application layout
- Microsoft SQL Server - data storage

A. Microsoft Visual Studio

Microsoft Visual Studio, a product of Microsoft Corporation, is a software development tool. It allows the development of various applications such as web, desktop, mobile, etc. The most commonly used programming languages within the tool are Visual Basic and C#. Visual Studio contains HTML/CSS editor for easier development of HTML pages [14].

HTML and CSS are standards for web pages. HTML is a markup language which is used for creating web pages. HTML consists of elements used to create a web application interface [14]. Cascading Style Sheets (CSS) is the standard for the visual presentation of web pages and web applications [13].

Visual Studio allows debugging execution of the web application which makes it easier to find errors in the application [10]. To make development of web application easier Visual Studio features an embedded Web server [10]. It enables to develop web applications without installing an additional web server. Also, Visual Studio allows usage of external servers such as Internet Information Services or an external server at a particular IP address.

B. Microsoft SQL Server

Microsoft SQL Server, a product of Microsoft Corporation, is a relational database management system.

The primary function of the database is to store and retrieve the data. It allows data storage of various types, such as numeric, textual, and multimedia data [11]. The programming language for database management is Structured Query Language (SQL) [11]. At the request of other web applications using the SQL, it is possible to manipulate the database in terms of obtaining and storing data, changing or deleting the existing data.

Data security in the database is of great importance, therefore it is necessary to take certain measures and methods of data protection [11]. The basic method of data protection is to restrict database access that is controlled by the database administrator. The main recommendations are the constant upgrading of software packages, the separation of the database on secure network segments, the use of encryption for transferring and storing data, and the use of authentication and database access roles.

C. Dynamic-Link Library

The Dynamic-Link Library (DLL) is a Microsoft implementation of libraries that can be used in the context of Windows operating systems. DLL files contain extensions .DLL, .OCX or .DRV.

The Dynamic-Link Library provides a code distribution mechanism that enables a developer to update code or data without compiling the entire application.

Dynamic-Link Library contains code, data and resources in combinations (16bit, 32bit, 64bit). Data files with the same format as a Dynamic-Link Library but with a different extension and containing resource sections are called resource dynamic-link libraries.

Web application developed for the comparative analysis uses the following third-party dynamic-link libraries to generate QR codes:

- Aspper (trial version) [1],
- BarcodeLib (trial version) [2],
- BusinessRafinery (trial version) [3],
- KeepAutomation (trial version) [4],
- OnBarcode (trial version) [5],
- ThoughtWorks (open source) [6],
- KeepDynamic (trial version) [7],
- Aipsys (trial version) [8],
- Tarcode (trial version) [9].

D. ASP.NET

ASP.NET is a web platform that enables the creation of dynamic web sites, web applications and web services based on the .NET platform [10]. It allows to write software using any of

the technologies that are compatible with Common Language Runtime (CLR). Common Language Runtime is a run-time environment which runs the code and provides services that make the development process easier.

ASP.NET supports 3 different development models: Web pages, MVC and Web Forms.

Web application developed for the comparative analysis uses Web Forms development model.

V. WEB APPLICATION

Web application generates a unique key for each user who accesses the web application. Generated unique key is used during the user session and it is written in the cookie variable to connect the user to his data in case of loss of session or for later work. The same key is used to retrieve and enter data into the database.

Web application consists of four modules:

- module for review of created tests,
- module for adding new tests,
- module for reviewing test results,
- module for running tests.

Module for review of created tests shows users tests with all parameters and their results. The data is presented in tabular form.

Module for adding new tests consists of the form for entering the data. Form allows the user to choose:

- generator for testing,
- output image type,
- error correction level,
- number of iterations,
- the QR code version.

QR code generators can create a result in four different image types. The user can choose between PNG, JPEG, GIF and TIFF image types.

Error correction level can have four different values as shown in Table I.

The number of iterations allows the user to repeat the selected test several times. Therefore, the user does not have to create the same test multiple times. It is enough to choose one of the offered values. The user can choose between one, five, or ten iterations.

The QR code version specifies the size of the output image in the pixels and the amount of data that can be saved. The QR code versions are integer values ranging from one to forty. A higher version of QR code allows creation of a larger output image and can contain more data.

The data recorded in the QR code itself cannot be changed to provide the exact results of the QR code generator comparative analysis and consists of a series of characters: "University of Applied Sciences Velika Gorica, Croatia (Europe)".

After the user adds a new test, the test data is transmitted to the server and logged into the database. After entering the data in the database, the test is added to the queue where it awaits further processing.

Module for running tests is responsible for executing created tests and storing results into the database. For each test a new thread is created. Module for running test allows maximum two tests to be executed at the same time (two threads can be active at the same time). When one test is finished, module for running test executes the next test from the queue.

For each test a new thread is created for the purposes of getting the most accurate results. For each thread it is possible to monitor all three observed parameters (execution time, CPU usage and memory usage).

The web application is limited to two threads because of the possibility of blocking the server's normal operating status if multiple tests are run simultaneously. Since a new thread has been created for each test, it may be possible to consume all available server resources. In this case the results obtained would not have been valid.

To ensure as accurate results as possible and enable smooth server operation, the web application is limited to two threads.

Module for reviewing test results displays test results as graphs. Users are enabled to filter results by:

- types of output image,
- error correction level,
- QR code version,
- number of iterations.

The module for reviewing test results displays 2 types of graphs:

- user data,
- global data.

User data are the test results that the user generated and that are related to his session, while the global data includes all test results from all users that are executed and found in the database.

The module for reviewing test results displays a total of 3 graphs:

- Duration (milliseconds)
- Processor (CPU) usage (percentage)
- Memory usage (megabytes)

Library chart.js is used for generating graphs. Library chart.js requires an HTML canvas drawing element and data retrieved from a database that is sent in JavaScript code [12].

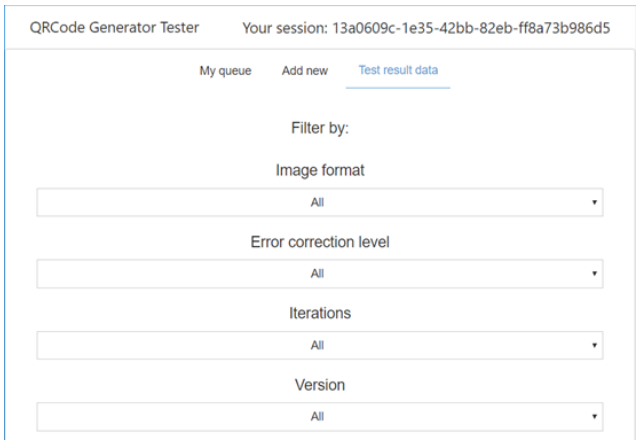

Figure 2. Graph filters

VI. Comparative Analysis Results

By creating a web application, we give the end user an insight into the performance and quality of nine QR code generators. The results displayed through the web application can give existing owners an insight into the quality of their QR code generators and can also check the quality of the competing QR code generators. It can serve as an incentive to improve existing solutions or create new and better than existing ones.

Through the conducted research, nine existing QR code generators were processed. Each of the generators is created with every possible instance of the test whose final number is 17.280, i.e. each generator can be tested in 1.920 different ways (number of possible instances of test = number of output image types * number of possible iterations * number of error correction levels * number of possible versions of QR code).

Results are subject to change and will become more detailed over time and with new test results.

Following results were obtained after completion of the performance testing:

- Duration – best result: KeepDynamic
- Duration – worst result: Aspper
- CPU usage – best result: KeepDynamic
- CPU usage – worst result: BarcodeLib
- Memory usage – best result: ThoughtWorks
- Memory usage – worst result: Aspper

The following figures show test results in the form of graphs.

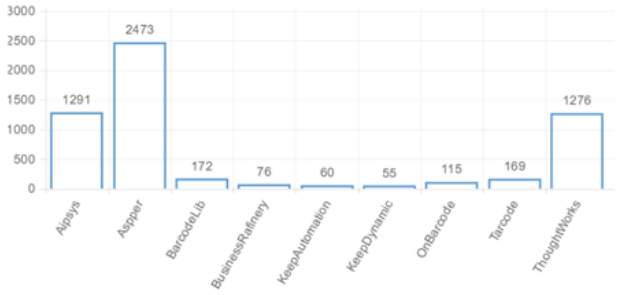

Figure 3. Test results – duration (miliseconds)

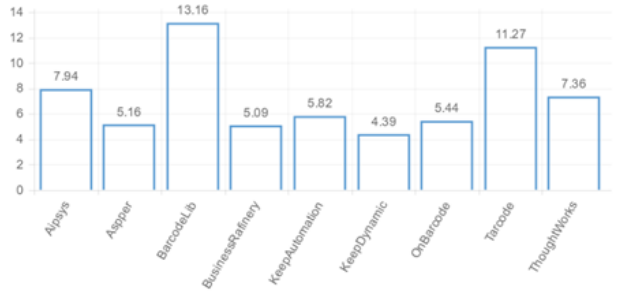

Figure 4. Test results – CPU usage (percentage)

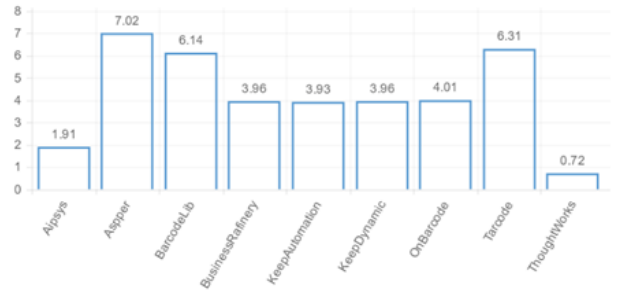

Figure 5. Test results – Memory usage (megabytes)

VII. Conclusion

Based on the results obtained, there are many differences between the selected QR code generators.

The differences in the results is the outcome of different ways how to generate QR codes. Because DDL files are protected, it is not possible to see the internal structure and the source code for each QR code generator. Only thing that is visible is a list of methods they contain and which can be used in other programs.

The four QR code generators are approximately equal by their performance, namely BussinessRafinery, KeepAutomation, KeepDynamic and OnBarcode. The QR code generator KeepDynamic has in two of the three observed parameters achieved the best result. The author's

recommendation is to use the QR code generator KeepDynamic in other programs.

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Evaluation of the impact of changing the number of test tasks on successful completion for automated LMS

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Abstract - Based on the directions for time criteria optimization obtained by previous research related to LMS automated assessment, the task corpus was increased to ensure better class material coverage. In actual academic year on Personal Computer Applications (PCA) course in professional study of electrical engineering at Zagreb University of Applied Sciences, results from exams with the new parameters, were obtained. Statistical data analysis was carried out with the focus on the following explanatory parameters: number of students solving test, number of successful attempts, characteristic duration of test and overall test duration. Results of abovementioned analysis, presented in the paper, give the possibility for quantitative estimation how the changed parameters affect the test dynamic solving and the success of passing the exam.

I. INTRODUCTION

Knowledge transfer, laboratory exercises and the whole assessment system of the Personal Computer Applications (PCA) course in professional study of Electrical Engineering at Zagreb University of Applied Sciences are based on the Moodle e-learning system for the last ten years. Generally speaking, the teaching system (i.e. course organization) and assessment system is a combination of a classical and technology mediated learning [1]. That combination is often called blended learning environment, as well as hybrid learning. LMS assessment systems are beneficial for both, students and lecturers. It helps to reduce the time spent in preparation and execution of exams, as well as to minimize errors in their evaluation and grading, especially when quick grading is required. Additionally, they considerably reduce the administrative tasks (e.g. class attendance tracking system for obligatory laboratory exercises, benefits of centralized grade database). The automated knowledge and skill tests eliminate the teacher's subjectivity during the evaluation phase of the exam and offers students to check the results of the exams in real time i.e. immediately after its completion [2]. In addition, the statistical results of automated knowledge and skill exams can be used to assess the existence of questions or tasks that are either too easy or too complex. Consequently, the questions or tasks can be then reformulated or replaced with new ones without altering the structure of the existing test [3].

With all that in mind, setting of time criteria for assessment in LMS is the challenge. References dealing with assessment in LMS mainly provides qualitative recommendations for test time duration, without quantitative solutions [4]. Possible directions of LMS time criteria quantitative determination and/or optimization from log files is given in [2]. The adjustment of time criteria is in direct correlation with the number and complexity of tasks in each individual exam. Primarily, the optimization is not focused on saving the time (i.e. overall test duration) but on the adequate number of tasks increase in existing time period framework. The increase in the number of tasks ensures better class material coverage, enables implementation of more specific tasks as well as improvements in cognitive linkage of knowledge and skills. Therefore, the leading idea is to examine how the possible increase of number of tasks reflects on overall successful attempts as well as identification for ending time that is suitable for students.

In the current academic year, the task corpus was increased to ensure the better class material coverage. Consequently, the number of tasks in each exam increased, keeping the existing duration of test. Results from midterm exams with new parameters were obtained. Statistical data analysis was carried out with the focus on the following explanatory parameters [2]:

- Number of students solving test M [#],
- Number of successful attempts M_{SA} [#],
- Overall test duration t_e [s]
- Characteristic duration of test Δt [s] is the remaining time for the v [%] of students after fastest (100%-v) students completes the test for all attempts.

  Notes: defined level of v [%] in all analysis is set to 90%; detailed explanation of Δt parameter is given in [2]
- Characteristic duration of test for successful attempts Δt_{SA} [s]
- Slope gradient g [%], i.e. level of rush at the end of test solving; $g = 1 - \Delta t / t_e$
- Slope gradient g_{SA} [%] for successful attempts.

Results of abovementioned analysis, presented in the paper, give the possibility for quantitative estimation how the changed parameters affect the test dynamic solving and the success of passing the exam.

In Section II, input data obtained from LMS Moodle tests' logs are graphically presented, explanatory parameters are calculated, and their change is discussed. In Section III procedure for test solving dynamics modeling is described. Finally, in Section IV results from modeling are presented and the impact of changing the number of test tasks is evaluated.

II. INPUT DATA REPRESENTATION AND ANALYSIS

Initially, the duration of the exams was determined by having the teaching staff of the course solving exams and obtained average measured time were tripled for students. After initial phase, exams and time needed for their solving were improved / adjusted in the period of four years. Finally, the stable phase is achieved and it was unchanged for the next five years. Statistical data from this stable phase were used for previous research, which was focused on principles for determination of time criteria for assessment in learning management systems [2]. Based on conclusions and directions from [2], in the current academic year, the number of tasks increased from 20 to 22 (+10%) with keeping passing threshold level at 50% (which is increase in needed number of tasks to be solved correctly from 10 to 11) as well as keeping the existing time duration of test (30 min). For comparison, in previous paper [2] skill test data were analyzed where passing threshold level is 33%.

New test solving dynamics data were obtained by analysis of LMS Moodle tests' logs processing. In this Section, results of statistical analysis are presented tabular and graphically. In Table 1, overview of explanatory parameters stated in Section I are given. In Fig. 1 and Fig. 2 comparison for dynamics of the first and second midterm test solving (successful attempts only) are given respectively in normalized form. Normalization is carried out on *x*-axis for time (0 s - 1800 s => 0% - 100%) and on *y*-axis for number of students:

- First data point (test starts): 100% students are solving tests i.e. nobody has completed the test yet;
- Last data point (test ends): 0% students are solving tests i.e. all remaining tests are automatically submitted

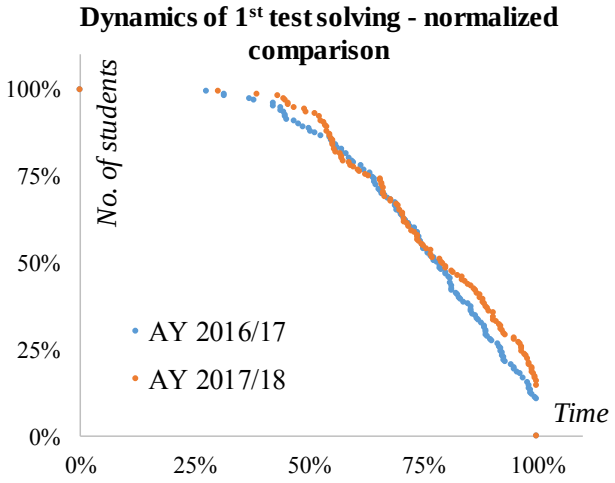

Fig. 1 Normalized comparison for dynamics of the first midterm test solving (AY = academic year) – successful attempts

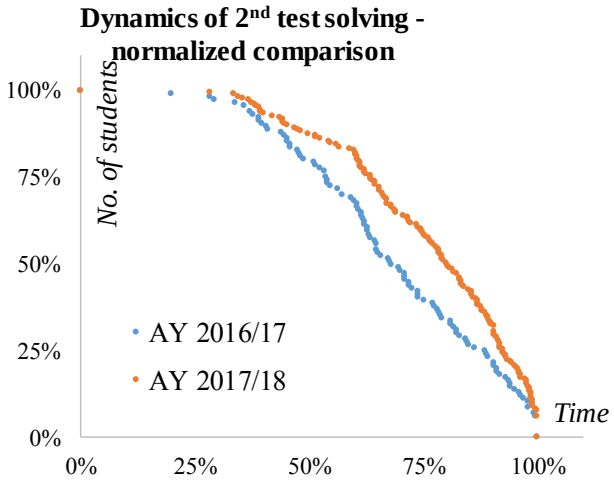

Fig. 2 Normalized comparison for dynamics of the second midterm test solving (AY = academic year) – successful attempts

Table 1. Overview of explanatory parameters

	1st Midterm exam 2016/17	1st Midterm exam 2017/18	2nd Midterm exam 2016/17	2nd Midterm exam 2017/18
Number of students solving test M (all attempts)	181	202	177	205
Number of successful attempts M_{SA}	150	155	117	178
Success ratio [%]	82.9	76.7	66.1	86.8
Characteristic duration of test (all attempts) Δt [s]	923	832	1067	964
Characteristic duration of test (successful attempts) Δt_{SA} [s]	942	837	1069	986
Overall test duration t_e [s]	1800	1800	1800	1800
Slope gradient g (all attempts) [%]	48.7	53.8	40.7	46.4
Slope gradient g_{SA} (successful attempts) [%]	47.7	53.5	40.6	45.2

By comparing values of explanatory parameters stated in Table 1, it is possible to conclude the following:

- **Success ratio** varies in interval from 66% to 87%. Regardless the fact that in academic year 2017/18 number of tasks and the passing threshold in number of correctly solved tasks were increased by 10% (keeping the existing time duration of test), success ratio for 2nd midterm exam 2017/18 is significantly higher (86.8% vs. 66.1%);
- **Characteristic duration of test** Δt_{SA} (time needed for $v = 90$ % of students to finish test) for successful attempts shortened in case of 1st midterm exam for 11% and 8% in case of 2nd midterm exam. This decrease is comparable to the task number increase (for each exam 10%);

- **Slope gradient** for successful attempts g_{SA} increased in case of 1st midterm exam for 12% and 11% in case of 2nd midterm exam. Again, this increase is comparable to the task number increase.

The previous conclusions show the impact of changing the number of test tasks is comparable to analyzed explanatory parameters change. In other words, there is no step change among above mentioned explanatory parameters that can be used as a clear warning that the new test is overwhelming for students. Consequently, by modeling the dynamics of test solving it will be tried to find additional conclusions. It is important to note that collected data for new test regime is only available for current year, so results should be taken with caution. For example, presently it is not clear is the success ratio increase in the case of 2nd midterm exam result of 'new easier tasks', 'better prepared students' or 'better generation of students'.

III. Test Solving Dynamics Modeling

The model introduced in [2] suitable for modeling the dynamics of test solving, named **Doubled Declining Bass Model** (**DDBM**), has the following form:

$$DDB(t) = DB_1(M_1, p_1, q_1, t_1; t) + DB_2(M - M_1, p_2, q_2, t_2; t) =$$
$$= M_1 \frac{1 - e^{-(p_1+q_1)(t_1-t)}}{1 + \frac{q_1}{p_1} e^{-(p_1+q_1)(t_1-t)}} + (M - M_1) \frac{1 - e^{-(p_2+q_2)(t_2-t)}}{1 + \frac{q_2}{p_2} e^{-(p_2+q_2)(t_2-t)}} \quad (1)$$

The DDBM is based on the Bass diffusion model (2) which is defined by four parameters: M – market capacity (upper asymptote) M; p – coefficient of innovation, $p > 0$; q – coefficient of imitation, $q \geq 0$ and t_s – time when service is introduced, $B(t \leq t_s) = 0$:

$$B(t; M, p, q, t_s) = M \frac{1 - e^{-(p+q)(t-t_s)}}{1 + \frac{q}{p} e^{-(p+q)(t-t_s)}} \quad (2)$$

In the first step, the initial Bass model [5] is converted into declining form to encompass the nature of test solving: customers (students) are leaving service (test solving) and after overall test duration (t_e) there is no customers left on market (knowledge assessment). In the second step, declining Bass model is doubled gaining the DDBM. This complex model is capable to identify two groups of students – one better prepared that will successfully finish test in the first wave (in (1) - parameters indexed with 1) and other one that will finish test in the second wave (in (1) - parameters indexed with 2).

Modeling procedure is chosen as follows:

- All data except the last point $(t_e, 0)$ are used for modelling. The reason for dropping the last point lies in the fact that it is the consequence of the LMS system. In other words, at a time when 1800 seconds passed, the test automatically turns off. All other test solving dynamics data points come from the users (students) and describes their behavior.
- There are seven free model parameters in (1): M_1, p_1, q_1, t_1, p_2, q_2 and t_2 which are obtained by ordinary least squared method. Parameter M (number of students solving test) is fixed to values from the first row of Table 1.
- Initial values for parameters are prepared as follows $t_1 < t_2$ and $M_1 < M$.

According to all abovementioned, parameter t_2 corresponds to the overall test duration parameter, but obtained from the user behavior as opposed to t_e which is determined through the LMS. Namely, parameter t_2 obtainable by ordinary least square method (OLS) from user data dynamics represents the ending time that could be suitable for students.

IV. Results

Results of test solving dynamics modeling performed by OLS method are presented in tabular and graphical form.

Modelling of the first midterm test solving dynamics is presented on Fig 3 and Fig 4, values of parameters are given in Table 2.

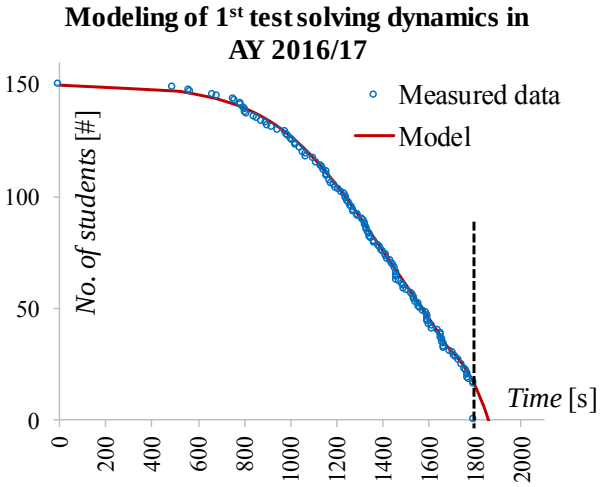

Fig. 3 Dynamics of the first midterm test solving modeled by DDBM for academic year 2016/17, successful attempts only

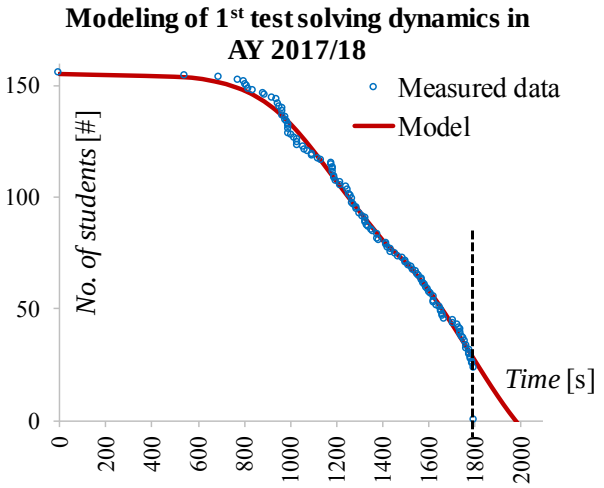

Fig. 4 Dynamics of the first midterm test solving modeled by DDBM for academic year 2017/18, successful attempts only

Table 2. Overview of modelling results for the first midterm test

	Academic year 2016/17	Academic year 2017/18
M =	150	155
M_1 =	99	57
p_1 =	0.00076	0.00080
q_1 =	0.00373	0.00607
t_1 =	1679.6 s	1418.3 s
p_2 =	0.00693	0.00133
q_2 =	0.00263	0.00357
t_2 =	**1855.7 s**	**1978.0 s**
Correlation Coefficient r	0.9996	0.9983

Modelling of the second midterm test solving dynamics is presented on Fig 5 and Fig 6, values of parameters are given in Table 3.

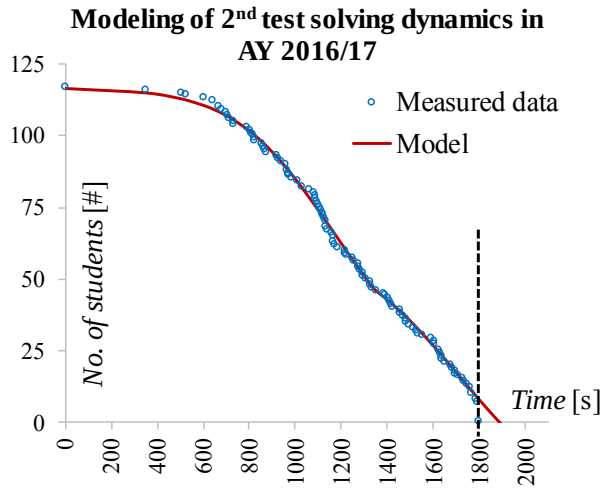

Fig. 5 Dynamics of the second midterm test solving modeled by DDBM for academic year 2016/17, successful attempts only

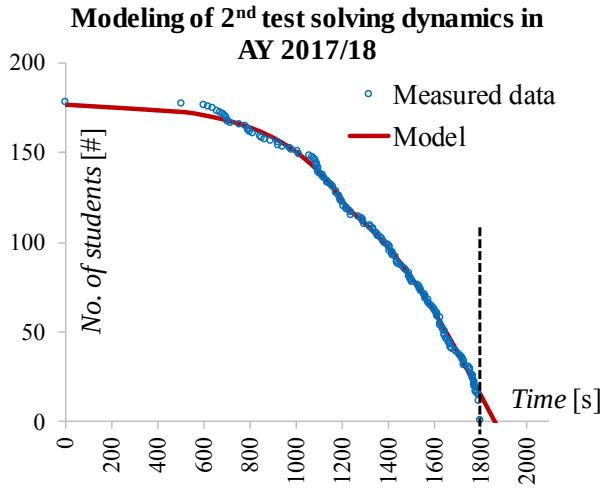

Fig. 6 Dynamics of the second midterm test solving modeled by DDBM for academic year 2017/18, successful attempts only

Values of parameter t_2 obtained by OLS in comparison with t_e (overall test duration parameter – defined through LMS), are as follows:

1st midterm exam AY 2016/17: $\boldsymbol{t_2 = t_e + 56s}$

1st midterm exam AY 2017/18: $\boldsymbol{t_2 = t_e + 178s}$

2nd midterm exam AY 2016/17: $\boldsymbol{t_2 = t_e + 83s}$

2nd midterm exam AY 2017/18: $\boldsymbol{t_2 = t_e + 60s}$

According to this comparison, parameter t_2 (ending time that could be suitable for students) is at least 56 seconds higher than t_e (even in cases when the number of tasks is not increased). The only case when t_2 is much higher than t_e is for 1st midterm exam in academic year 2017/18, when the number of tasks is increased by 10%. The possible conclusion is that for the 1st midterm exam overall test duration time t_e should be increased for 120 seconds and for the 2nd midterm exam t_e could remain the same.

Number of better prepared students (M_1) decreased in the academic year 2017/18 when increased number of tasks were introduced ensuring better class material coverage. Note that parameter M_1 is obtained via data modelling, so it is not an integer number. In Table 2 and 3 M_1 is presented as integer one because it represents number of students.

Table 3. Overview of modelling results for the second midterm test

	Academic year 2016/17	Academic year 2017/18
M =	117	178
M_1 =	52	24
p_1 =	0.00104	0.00540
q_1 =	0.00425	0.00204
t_1 =	1337.1 s	1215.0 s
p_2 =	0.00132	0.00160
q_2 =	0.00258	0.00163
t_2 =	**1883.4 s**	**1860.2 s**
Correlation Coefficient r	0.9990	0.9992

V. CONCLUSION

The analysis shows that the percentage change of test tasks number is comparable to the absolute percentage change of *Success ratio*, *Characteristic duration of test* and *Slope gradient* parameters. Because there is no step change in mentioned parameters, none of them can be used as a clear warning that the new test is overwhelming for students.

Nevertheless, it is shown that value for ending time $\boldsymbol{t_2}$ obtained by modeling user data dynamics represents the test duration time that could be suitable for students. In all modeling cases, achieved correlation coefficient is higher than 0.998 which proofs that Doubled Declining Bass Model (DDBM) is appropriate for this purpose.

Future research will be focused on verifying the stated conclusions with a large number of samples and/or for different courses to evaluate proposed concept for test time duration time in more general cases. In addition, numerically determined time parameters should be appraised by students, too. The specific questionnaire for that purpose will be proposed.

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Using Analytic Hierarchy Process to Select the Most Appropriate Tool for Learning Programming

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***Abstract* - Introductory programming courses around the globe are sharing the common issue of high dropout rates that are mainly caused by the lack of prior knowledge and experience in developing algorithms for the purpose of solving problems as well as the perception of programming concepts as something that is too abstract and therefore very difficult. Literature offers a number of tools that are encouraging students to adopt good programming habits but testing them in order to select the most appropriate one is resource-consuming procedure for both teachers and students. With an aim to address the aforementioned issue, a taxonomy of tools designed for learning programming is proposed in this paper. As a follow up, an analytic hierarchy process (AHP) has been employed in order to facilitate multi-criteria decision-making related to choosing the tool that is most suitable for acquiring programming skills.**

Keywords: Tools for Learning Programming, Taxonomy, Analytic Hierarchy Process

I. INTRODUCTION

In the last few years we are witnessing an exceptionally rapid development of technology and the emergence of new technological trends. As a result, new devices have been developed not only for personal use but also for the employment in all aspects of human endeavor, including education. In order to be able to consume those devices, computer skills that represent the prerequisite for active participation in an information society are required. The set forth is particularly true for programming skills, a specific facet of computer literacy that is essential for individuals operating in the ICT field.

Current studies (e.g. [1]) dealing with learning programming revealed that lack of prior knowledge, fear of programming, and perception of programming language as something that is very hard are strong drivers of programming anxiety in programming novices. Literature in the field suggests several solutions for overcoming these issues. For instance, Bubica [2] found that choice of teaching strategy which can be customized to the characteristics of programming novices affects the development of their programming skills. The same author emphasizes that the customization itself is not sufficient for programming novices to achieve success but is necessary to provide an environment that will encourage their work and their desire to advance. The afore mentioned motivated us to initiate a research on selecting the most suitable tool for learning programming. For that purpose, an empirical study was carried out in which field experts served as respondents. The collected data was analyzed by means of analytic hierarchy process (AHP) method.

The remainder of the paper is structured as follows. Taxonomy of tools designed for learning programming is presented in Section 2. AHP method is briefly explained in Section 3. Employed research methodology is outlined in Section 4. Study findings are presented and discussed in Section 5. Conclusions are drawn in the last section.

II. TAXONOMY OF TOOLS FOR LEARNING PROGRAMMING

Taxonomy is a scientific technique that based on similarities and differences, classifies taxonomical units into groups. Tools for learning programming can be, with respect to their features, purpose, and current application, categorized into following four groups [1][3][4][5]:

A. Web Integrated Development Environments (Web IDEs),
B. Game-Based Learning Environments,
C. Visualization Tools,
D. Tools for Learning Higher Order Programming Languages

A. Web IDEs

The main representatives of this group of tools are CodeBoard [6], Rextester [7], Ideone [8], Codepad [9].

Codeboard was introduced in 2014 as a research project at ETH in Zürich. Its goal was to equip teachers in computer science schools, universities, and polytechnics as well as Massive Open Online Courses (MOOCs) with powerful, yet lightweight tool that would support them in creating interesting and practical programming lessons. Although MOOC platforms offer hosting services with lectures, videos and simple quizzes content, they do not enable teachers to make sophisticated, automatically ranked programming exercises. Codeboard fills that gap by allowing teachers to provide exercises in which students are not required to download any folders nor install any new software but they still immediately get feedback about the correctness of their work. Findings of recent study [5] have shown that CodeBoard is the most efficient Web IDE for learning programming.

Rextester is an online programming environment meant for writing snippets of code in wide variety of programming languages including C++, Java, C#, Python,

PHP, Javascript, Haskell, Erlang, Kotlin, R, Lua, Ruby, Node.js, etc. While writing the code, one can collaborate with his/her peers in solving a problem at hand. Once the code has been saved, a user can provide an access to it by granting various privileges.

Ideone is an online debugging tool that enables compiling and executing code in more than 60 programming languages. With an aim to get feedback and improve both correctness and efficiency of written code, one can share it on a number of social media applications.

Codepad is a simple online compiler/interpreter for 13 most popular programming languages. It supports collaboration in a manner that it generates short URL for particular snippet of code which one can share through an e-mail or chat.

B. Game-Based Learning Environments

Games are proved to be relevant trigger for developing creativity and curiosity in children. In that respect, if teaching process is organized in a way it stimulates children's imagination and curiosity in the same way the games do, then children will acquire estimated knowledge and skills in a very short period of time. The same holds for students which is supported by findings of recent study on gaining programming skills by playing games [10]. In literature one can find a lot of game-based learning environments of which some are more suitable for junior (such as Tynker [11], Waterbear [12], RoboMind [13], and Kodable [14]) whereas some are more appropriate for senior (such as CodeCombat [15], Code Hero [16], Code Hunt [17] and LightBot [18]) programming novices.

Tynker is a system for learning programming based on a simplified visual programming language. For executing actions, it is not necessary to be familiar with the syntax yet just connect the combinations of code blocks.

Waterbear is similar to Tynker in a way that is also draws on visual syntax and employs drag and drop of code blocks in order to make attractive projects. Users can share their own projects or learn programming concepts from the projects shared by other users. Every single element has clear description which makes understanding their purpose much easier.

RoboMind is a tool based on ROBO programming language that learns users how to solve science and industry related problems thus developing logical thinking. The main goal is to lead the robot through a two-dimensional world and solve multiple problems encountered on the way.

Kodable is an online game that introduces programming concepts such as variables, sequences, conditional statements, loops, functions, strings, arrays, and classes, to pre- and elementary school children in an entertaining way thus providing a foundation for critical thinking, communication, creativity, collaboration and solving complex problems.

CodeCombat is an online game designed for learning programming concepts in Python language. The game is played in a manner that players write the programming code in order to beat game levels. To complete a certain level, player has to make his/her avatar move, avoid or attack their opponent. Some of the more important features of this game are learning programming concepts such as variables, loops, if-else statements, etc., providing feedback so that the player can better understand the logic of the code, and motivating the player to learn the syntax of the programming language.

Code Hero is an educational game in which players learn how to make a game. It is a first-person coding puzzle platformer in which players design game by writing a code in C# programming language within the Unity editor toolset.

Code Hunt is an online game designed for acquiring programming skills in Java and C# programming languages. The objective of a player is to discover a secret algorithm and write code for it. Based on the difference between the code the player wrote and the secret algorithm, the game provides clues thus helping a player to reach a solution.

Lightbot is a programming puzzle game in which players program a robot using icons where each of them represents a specific movement a robot can take. In that manner, Lightbot teaches player coding constructs such as sequential control flow, procedures, loops, and debugging which are common to many programming languages.

C. Visualization Tools

Visualization tools designed for learning programming can be divided into four sub-groups: mini languages such as Guido van Robot [19], flowchart-based environments like RAPTOR [20] and Flowgorithm [21], virtual worlds such as Alice [22], and simulation tools like ViSA [23].

Guido van Robot is a minimalistic introductory programming language equipped with instant visual feedback thus facilitating understanding programming concepts such as sequencing, conditional branching, looping and procedures. The players' objective is to write a code and in that way guide a robot around the world made up of walls and "beepers" which Guido can set or collect.

RAPTOR stands for Rapid Algorithmic Programming Tool for Ordered Reasoning, a flowchart-based programming environment designed with an aim to help students visualize algorithms thus avoiding logical errors in them. The most important RAPTOR features are as follows:

- Syntax required to create the program is minimized.
- Tracing the execution through the flowchart allows users to examine the correctness of their algorithms.
- Error messages are designed in a way they are clear and understandable to programming novices.

Flowgorithm is a visual programming environment which allows the users writing and executing the program using flowcharts. The tool is invented with an objective to focus users' concentration on the logic underlying the algorithm rather than on the syntax of the programming language. Flowgorithm enables conversion of flowcharts to 15 most popular programming languages. When programming concepts are concerned, Flowgorithm

supports arrays, loops, recursion, user-defined functions, etc.

Alice is an innovative puzzle-based coding environment that enables users to make 3D games, build interactive narratives, and create animations. It is designed with an aim to encourage learning fundamental programming concepts as well as aspects of object-oriented programming through creative exploration. Studies [24][25] on the employment of Alice in educational ecosystem have shown that it positively affects students' outcomes in computer science courses and facilitates transfer to object-oriented programming languages such as Java.

ViSA is a tool designed for the visualization of eight most popular sorting algorithms. Its main feature is that it displays and explains every step in executing a particular sorting algorithm which facilitates their understanding by programming novices. In addition, ViSA supports simultaneous visualization of selected sorting algorithms and their analysis and comparison in terms of efficiency.

D. Tools for Learning Higher Order Programming Languages

This group of tools can be further decomposed into educational environments such as Verificator [1] and code analyzers like QAPlug [26] and Prospector [27].

Verificator is an educational environment designed for learning programming concepts in C++ programming language. It is based on Dev-C++ integrated development environment and has following important features:

- Program personalization. Before they can even start writing a code, students have to provide their personal information (academic ID, first and last name) which are then embedded in a programming code in the form of a comment so that it can be later verified if the code was actually written in the Verificator.
- Time limit. Students have to complete a program in the given time frame. After the time runs out, the program can be executed, but it cannot be changed.
- Code authenticity. Verificator prevents inserting and copying code from any external source.
- Adoption of good programming habits. Verificator expects from students to check the logic and correctness of their code after every ten new entries which is indicated by specific integrated module in the form of traffic lights. This feature encourages students to correctly structure the code and to think logically.
- Module for testing logical correctness of the code which shows how many correct programming blocks does the code consist of.
- Tutor that clarifies the cause of certain errors and warnings returned by compiler and linker.

QAPlug is a plugin fully integrated with IntelliJ IDEA that facilitates managing the quality of the code. It supports several different code quality tools such as:

- Programming Mistake Detector (PMD) is a source code analyzer designed for finding most common programming flaws such as declared unused variables, created unnecessary objects, empty catch blocks, etc.
- CheckStyle assists programmers to write code that adheres to Java coding standard. It can verify many aspects of written code such as class and method design problems, code layout and formatting issues, etc.
- FindBugs employs static analysis to discover bugs in Java code.

Prospector is a tool designed for analyzing Python code and returning feedback about errors, potential problems, convention violations and complexity. It offers some default profiles and adapts the output depending on the libraries particular project uses.

All of the above indicates that there are a number of tools for learning programming and accordingly choosing the most suitable one is a time-consuming process. In order to facilitate the teachers to make decisions in that respect, we conducted a research for the purpose of which we defined criteria for selecting the most appropriate tool and examined them on the representative sample of four tools. Details on employed research framework and discussion of findings are presented in following sections.

III. ANALYTIC HIERARCHY PROCESS

The analytic hierarchy process (AHP) designed by dr. Thomas Saaty in the 1970's is a very practical and efficient method which is used for solving a great number of multi-criterial problems in decision making [28]. The method is based on the pair-wise comparison of alternatives where the decision maker expresses the intensity of the preference of one alternative versus other ones with respect to relevant set of criteria. The intensity of preferences in the context of criteria is determined in the same fashion. Drawing on the expressed preferences, the AHP method outputs the optimal choice. The added value of the method is that one can easily perceive the intermediate stages of using the method as well as the extent to which particular element in the AHP model contributes to the decision making objective.

The application of the AHP method consists of following steps:

- Design of a hierarchical decision making model that includes objective as a root, criteria at the first level of the model, and alternatives at the second level of the model.
- Pair-wise comparison of criteria with respect to the objective followed by pair-wise comparison of alternatives regarding each criterion in the model. The intensity of preference is expressed by means of a nine-point scale (presented in Table 1) where five of them clearly indicate preference one alternative over another while remaining four represent intermediate preferences.

TABLE 1. SCALE FOR PAIR-WISE COMPARISONS [29]

Intensity of importance	Definition	Explanation
1	Equal importance	Two alternatives contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one alternative over another
5	Strong importance	Experience and judgment strongly favor one alternative over another
7	Very strong or demonstrated importance	An alternative is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one alternative over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	

- Based on the results of pair-wise comparisons conducted by a set of field experts, the AHP algorithm estimates weights for each criterion and alternative.
- The outcomes are interpreted in the context of the decision making objective.

IV. RESEARCH METHODOLOGY

The sample of the research participants was composed of field experts working as programmers or employed in related positions. Since the tools described in section 2 are intended for programming novices, four criteria for selecting the most appropriate one have been defined:

A. **Documentation availability**. This criterion examines the degree to which potential user of the tool finds important that documentation of particular tool is of high quality and available on the Internet through different sources such as the official site of the tools, the Web search engine (e.g. Google), YouTube channel, etc.

B. **Free use.** This criterion determines whether the given tool is 1) completely free of charge 2) free to use for a limited period of time (a test version) 3) free to use but some functionalities are disabled and in order to use them one need to buy a license 4) completely commercial meaning that there is no free version of the same for the users to test its functionalities.

C. **Minimal workload.** This criterion refers to minimal physical and mental activity of the users while interacting with the tool. More specifically, this criterion explores to what extent: (a) is easy to learn to use functionalities of the tool, (b) is easy to use the tool, (c) the tool is intuitive, and (d) the tool is similar to previously used applications in terms of the layout, and all this in order to increase efficiency, effectiveness, and productivity in learning the programming concepts.

D. **Additional features.** This criterion evaluates to what degree the tool provides added value to its users in terms of support for a variety of programming languages, functionalities that enable personalization of the development environment, modules that enhance the process of learning programming concepts and acquiring the programming skills.

As a follow up, tools that are going to be compared with respect to these criteria had to be identified. For that purpose, we have set two criteria: the presence of a particular tool in the literature and the frequency of its application in practice. Considering all tools described in section 2, and taking into account that studies related to Web IDEs and game-based learning environments have been recently carried out [5][10], the mentioned two criteria were mostly met by Guido von Robot, RAPTOR, Flowgorithm, and Verificator. The hierarchical decision making model composed of alternatives, criteria, and objective is shown in Figure 1.

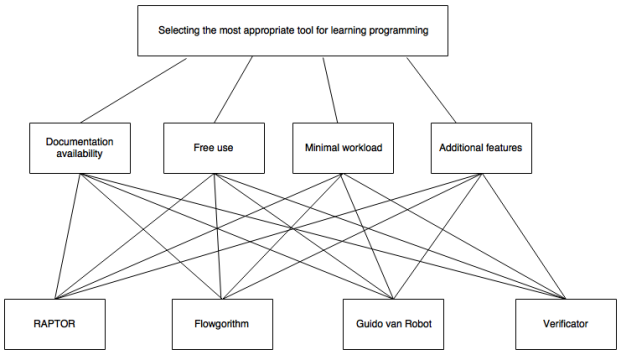

Figure 1. Hierarchical decision making model

Instructions were made for the study participants to familiarize them with the topic and purpose of the research as well as with the relevance of data gathered from them. In order to get as much as objective data, the study was carried out in two middle size IT companies. Each of the participants took part in the study twice – first for the purpose of determining the relevance of the criteria, and then for comparing the tools with respect to these criteria. Before the study participants conducted pair-wise comparisons, they had to complete all steps of the predefined scenario of interaction with each of the four tools. The analysis of the collected data was conducted in the BPMSG AHP Online System [30].

V. DISCUSSION OF FINDINGS

The sample was composed of 15 participants of which 80% were male and 20% female. At the time study took place, majority of field experts (39.9%) had between 20 and 29 years, 33.33% of them had between 30 and 35 years, while 26.8% had more than 35 years of age.

When the expertize of study participants is considered, majority of them (40%) had between 2 and 5 years of experience in programming, 33.3% of examinees had more than 5 years of experience in programming, while 26.7% of them had up to 2 years of experience in programming.

The outcomes of the group decision making on selecting the most appropriate tool for learning programming are presented in Table 2 while preferences of each study participant in that respect are shown in Table 3. The reported findings indicate that the most important criterion for selecting the tool is minimal workload (0.505) followed by documentation availability (0.288), and the possibility of free use of the tool (0.143) while it turned out that additional functionalities of the tool (0.064) are almost irrelevant criterion for decision making in that respect.

The proportions of consistency (CR) of the matrices formed during pair-wise comparisons were in range from 5.2% to 9.7%. Considering the threshold values for CR in [18], the reported results are deemed adequate.

The total proportion of the consistency for the results of the group was 1.1% while the total consensus of the group was 70.6%.

Concerning the tools that were the subject of evaluation, the field experts rated the tool RAPTOR (presented in Figure 2) as the one that has met their expectations in the context of learning programming to the highest extent when compared to remaining three tools. However, it should be noted that difference between the winner and the runner-up was only 1.1% which makes Verificator (shown in Figure 3) also a great choice for the purpose of learning programming. Flowgorithm appeared to be significantly less preferred for the decision making objective in this study while Guido van Robot was perceived as the least suitable tool for learning programming among four involved in the study.

TABLE 2. HIERARCHY WITH CONSOLIDATED PRIORITIES AND ALTERNATIVES

Level 0	Selecting the most Appropriate Tool for Learning Programming				
Level 1	Documentation availability (0.288)	Free use (0.143)	Minimal workload 0.505)	Additional features (0.064)	
RAPTOR	0.376	0.347	0.350	0.400	36.0%
Flowgorithm	0.164	0.199	0.177	0.174	17.6%
Guido van Robot	0.131	0.103	0.105	0.136	11.4%
Verificator	0.329	0.351	0.368	0.291	34.9%
Global Priorities	28.8%	14.3%	50.5%	6.4%	1

TABLE 3. INDIVIDUAL RESULTS

Participants	RAPTOR	Flowgorithm	Guido van Robot	Verificator
Group result	**36.0%**	**17.6%**	**11.4%**	**34.9%**
Part15	45.6%	12.0%	6.3%	36.2%
Part14	25.8%	20.3%	16.7%	37.1%
Part13	12.1%	49.8%	6.2%	31.9%
Part12	23.8%	18.9%	16.6%	40.7%
Part11	25.6%	12.0%	56.4%	6.0%
Part10	31.5%	16.8%	13.1%	38.6%
Part09	58.0%	10.9%	9.4%	21.6%
Part08	32.6%	16.5%	10.9%	39.9%
Part07	37.4%	11.5%	6.7%	44.4%
Part06	43.1%	12.8%	8.2%	35.9%
Part05	48.1%	12.9%	5.6%	33.4%
Part04	13.3%	43.6%	6.0%	37.0%
Part03	41.5%	10.9%	7.4%	40.2%
Part02	34.9%	8.8%	9.3%	46.9%
Part01	41.0%	16.8%	22.0%	20.2%

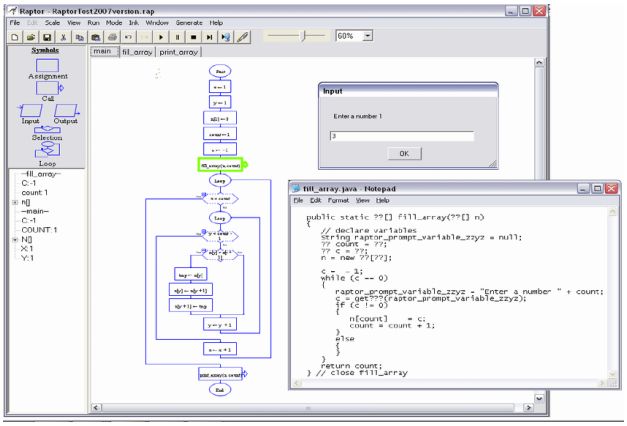

Figure 2. RAPTOR

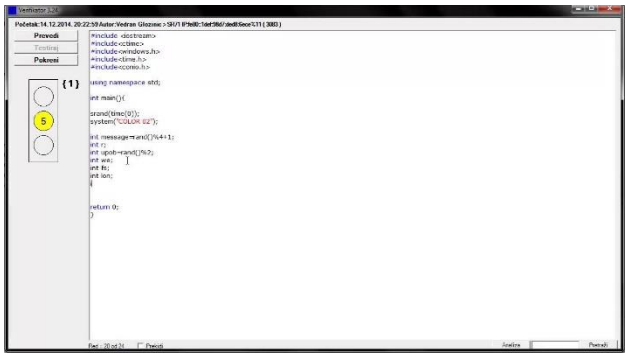

Figure 3. Verificator

VI. CONCLUSION

The aim of this paper was to determine the most appropriate tool that will help programming novices to learn the concepts of programming. For that purpose, a two-phase research was carried out. Firstly, we determined the criteria for evaluating the tools which was then followed by the selection of the tools and their pair-wise comparison by means of indicated criteria. The AHP method was employed for the purpose of conducting both phases of evaluation. Participants in the study were programmers and individuals employed in similar positions in two middle site IT companies. Study findings revealed minimal workload as the most important, and additional features as the least important criterion for the decision making objective of the study. RAPTOR was uncovered as the most suitable tool for learning programming among four alternatives and was closely followed by Verificator that was also perceived as very good solution in that respect. A particular contribution of this paper is a taxonomy of tools designed for learning programming that might encourage educators to implement them into introductory programming courses.

The main limitation of the study is that the sample of the domain experts was composed of employees from only two IT companies. Taking into account that a randomly chosen sample made of both experts from a greater number of companies and programming teachers could result in a different selection of the importance of the criteria and the choice of the most suitable tool, the results presented in this paper should be interpreted with caution. Therefore, in our future work we will expand the research presented in this paper by including representatives of all groups of experts and conduct the selection of the most suitable tool with respect to the age of the targeted group of users.

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Setting up digital forensics laboratory: experience of Zagreb University of Applied Sciences

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Abstract - During the development of a new specialist graduate professional study program at Zagreb University of Applied Science "Information Security and Digital Forensics", a number of challenges was addressed. The key challenges were: a) Defining the curriculum and b) Defining and building computer infrastructure for conducting laboratory exercises. We will address second: defining the necessary equipment for conducting laboratory exercises. New possibilities are given by new technologies, and it would be possible to expand the working environment which, apart from laboratory exercises, will enable independent student work. We will describe and define setting of the environment that can also be used for independent research in the field of information security and digital forensics for expert and scientific community. We will use TVZ private cloud as a place to build digital forensic laboratory, maintained by digital forensic management process tool, where different virtual machines with different digital forensic software will be accessible for students and independent researches.

Keywords - Information Security, Digital Forensics Education, Digital Forensics Computer Laboratory

I. INTRODUCTION

The development of a new study program for higher education institution at Zagreb University of Applied Science includes a series of activities that precede the development of content of teaching and didactic materials for theoretical teaching as well as materials and practices for carrying out exercises, seminars and practical teaching. Research on market needs, employer surveys, projections for qualifications required, analysis of the same or similar study programs, etc. are part of activities that are crucial to the development of a new study program. Specialist graduate study programs of Information Security and Digital Forensics are unique in terms of their content and scope, and for the elaboration of the study it was necessary to carry out all these activities, but also to provide the teaching of laboratory exercises and the preparation of seminars on infrastructure and equipment that is being applied in real conditions. While the theoretical part of the lesson, in addition to the competence and experience of the teacher, can be done by consulting a wide range of available literature, laboratory exercises should, first and foremost, be created to provide laboratory conditions in which students will acquire practical knowledge which, in addition to specific work in a given case, should provide to students' appropriate process knowledge in an appropriate working environment. The development of information security and digital forensics laboratories that provide these prerequisite requires the implementation of equipment and procedures according to the adopted standards [1], [2], [3], [4], adopted models of processes as well as the possibilities of available up to date technology.

II. DIGITAL FORENSIC PROCESS MODELS

Digital forensics is defined differently and according to some authors there are as many definitions as the digital forensic analysts [5]. Here are two definitions that in the author's opinion give the best definition of digital forensics:

- Digital Forensics is considered the application of science to the identification, collection, examination, and analysis of data while preserving the integrity of the information and maintaining a strict chain of custody for the data. [6]
- The application of computer science and investigative procedures for a legal purpose involving the analysis of digital evidence after proper search authority, chain of custody, validation with mathematics, use of validated tools, repeatability, reporting, and possible expert presentation. [7]

Process models of digital forensics change over time due to technology change so, that every new iteration is trying to incorporate new technology. The last example of incorporating technology into digital forensics process models it happens due to the rapidly growing application of large quantities of different digital devices, such as smartphones, tablets, IoT devices, etc. Because of that the application of cloud technology with benefits such as volume of data, remote access to servers with digital forensic tools from anywhere, promptly responding to sudden situations due to the remote availability of various tools, etc., has led to a change in the digital forensic process [8] so Digital Forensics as a Service (DFaaS) becomes ubiquitous.

Although the applied digital forensic process models are not standardized, there are international standard recommendations ISO/IEC 27037:2016 [1], which recommended the Digital Evidence Handling process, through four steps: Identification, Collection, Acquisition and Preservation, along with the limits that the Standard limits only to the "handling process". The second model of the process is often described in literature [9], [8], is an Integrated Digital Forensic Process Model (IDFPM) [10] which is based on six steps: preparation, incident, incident

response, physical investigation, digital forensic investigation and presentation.

According to the latest available works [8], IoT devices bring the need for a extensions and model changes of digital forensic analyzes and have accordingly proposed process models.

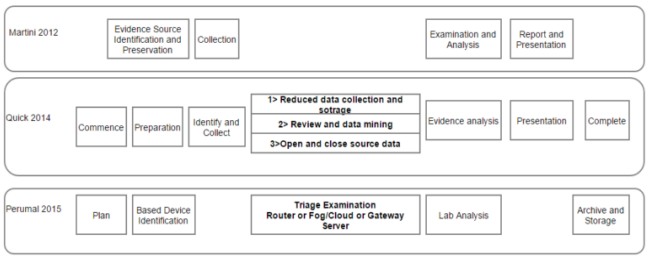

Figure 1. Recent Digital Forensic Models for Handling Modern Digital devices [8]

III. THE OBJECTIVE OF COURSE AND LABORATORY EXERCISES

If we analyze the defined objectives of information security and digital forensics studies, thanks to this designed infrastructure for students to work and gain practical experience, goals should be achieved.

Objectives of the study:

- **Application of information and communication technologies in information security and digital forensics -** students acquire high level of work skills with specialized information security and digital forensics tools, information systems protection, information security management systems and digital forensic analysis
- **Implementing, managing and organizing information protection systems -** Due to the need to implement information security systems in companies and institutions, students create the skills of deploying and organizing security management systems according to defined standards
- **Organization and management of digital forensic analysis -** students develop the ability to conduct digital forensic analysis using project approach and defined best practices
- **The application of the legal bases of information security and digital forensics -** considering the interdisciplinarity of the area of the proposed study, students create the skills of linking different theoretical approaches and different organizational models with the application of legal regulations in realization of specific tasks, learn how to apply legal norms and manage forensic analyzes

In addition to the goals, the competences, knowledge and skills that students will acquire on individual courses through the work and application of resources, tools, procedures and techniques through the Digital Forensic Laboratory are separated.

- Explore new security technology, select tools and equipment for security system application
- Define and implement information security related procedures
- Monitor the production of reports, records, suggestions and programs in the area of information security and digital forensics
- Provide advisory services for digital forensics
- Manage incidents of information security
- Manage information security risks
- Analyze digital devices and detect digital traces
- Document the digital forensic investigation
- Organize procedures in the Digital Forensic Laboratory
- Propose procedures for conducting digital forensic analyzes
- Conduct digital forensic analysis

IV. DIGITAL FORENSIC LABORATORY FOR EDUCATION INSTITUTION

The fundamental task of the new study program for Information Security and Digital Forensics is described in the document Study for Initial Accreditation of Study program Information security and Digital Forensic [11], in which emphasizes that the proposed study program of education is based on the concept of active participation of students in practical teaching, stronger linkage between students and teachers during various teaching and professional activities and the use of various teaching resources and the use of new technology in teaching. During the design of the Plan and Program, special attention is focused on providing students with theoretical contents and practical skills that will be necessary for their future competent work, which is increasingly based on the application of new technologies and the use of new information systems.

Accordingly, it was necessary to select technologies and tools to enable this task to be achieved. In addition to numerous commercial tools there are many open source tools which are applied in digital forensic processes. Although, no single tool can do all the necessary digital forensic analysis, and equally, all the analyzes will not be equally good. [12]. Some of the tools that will be used in teaching are Foreman, EnCase, Amped Five, Autopsy, Encrypted Disk Detector, Magnet RAM Capture, RAM Capturer, USB Write Blocker, Wireshark, NMAP, Browser History, Volatility, InnoD, Paladin etc. Although the application of various digital forensic tools on different courses, allowing students to acquire knowledge and work experience in a specific tool, it was necessary to design a system that would give students practical knowledge regarding the digital forensic process. Also, today's technology provides the ability to use distributed resources through virtualization for the needs of the Digital Forensic Laboratory, so that resources from Cloud can be dynamically utilized in accordance with the DFaaS process.

The Private Cloud Infrastructure of Zagreb University of Applied Science, Figure 2, provides subscription to users on predefined configurations of any server or

forensic computer with predefined content on a Windows or Linux platform.

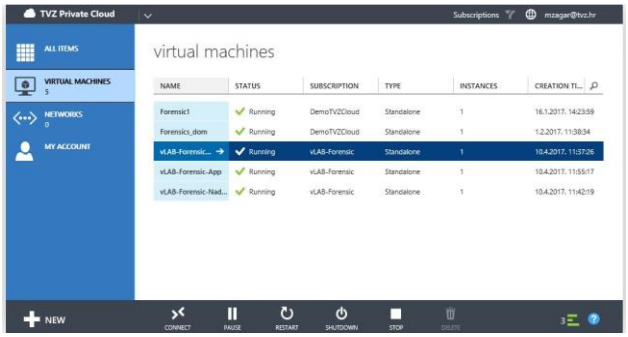

Figure 2. TVZ private cloud

Starting from the defined outcomes[1] of the study, the goal of design and building a digital forensic laboratory is through its use and application through various courses to achieve defined goals and outcomes of studies that are related not only with the application of tools and techniques but also to digital forensic processes. Having in mind this goal, the possibility of applying digital forensic process management tools has been investigated and Foreman digital forensic management tool has been selected and applied, Figure 3. Foreman is open source tool and his advantage is possibility of integration with other open source tools or with tools that have available integration APIs. Through the research we integrated the tool with the Institution's Lightweight Directory Access Protocol to allow all teachers and students access the tool through assigned AAI@EduHr user credentials. Initial integration with Autopsy was also made. Integration with the Digital Forensic Tool Autopsy was performed at the level of user data, all data about open Task: Case description, Investigators, Evidence files and backwards results of digital forensic analysis, Report.

Example of Foreman Tasks.
Foreman case: 20180129001
Evidence file: file.e01
Investigator: Pero Peric
Tasks:

- 20180129001_001
  - Pero Peric,
  - check if file.e01 is unchanged
- 20180129001_002
  - Pero Peric,
  - check if keyword „net" is in evidence file
  .

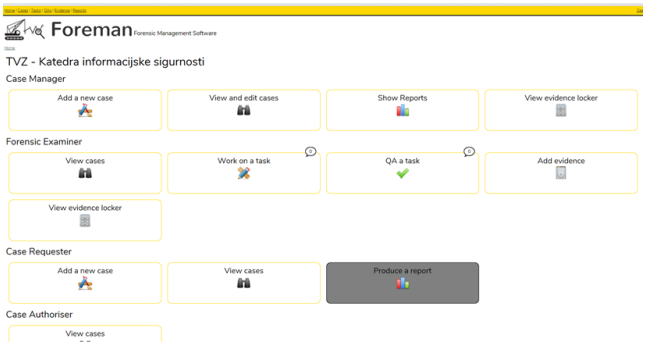

Figure 3. Foreman – Digital Forensic management tool [13]

By applying a management system that supports digital forensic student processes, it will gain practical experience not only in the use of specific tools, but also in processes that take place through the system Figure 4. In addition to the students and teachers, and thanks to the Cloud virtual infrastructure of the institution, remote access to independent forensic researchers was provided. They can subscribe to the appropriate Cloud resource.

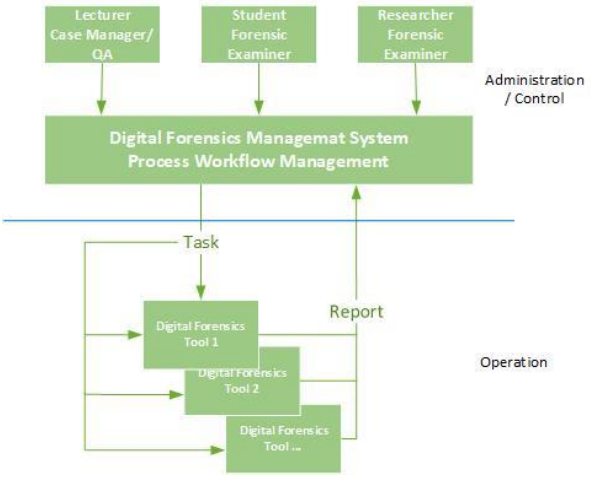

Figure 4. Digital forensic process division

Figure 5 illustrates the workflow of the digital forensic process. All process steps take place in the process management tool Foreman, and appropriate forensic tools are used for specific digital forensic analysis.

[1] Outcomes from „Specijalistički diplomski stručni studij Informacijska sigurnost i digitalna forenzika", p14 : „The candidate can independently use relevant methods in research and development in the area of information security. These methods include studying literature, logical thinking, and conducting scientific experiments together with the interpretation of their results."

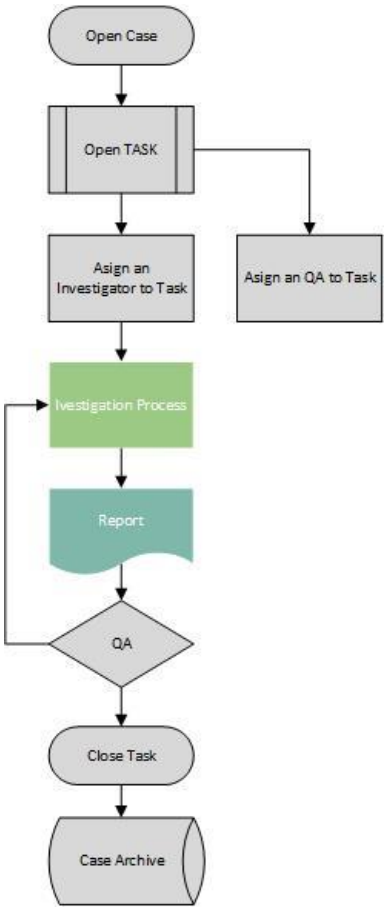

Figure 5. Digital forensic workflow

V. CONCLUSION

The development of a new information security and digital forensic education laboratory will be tested and certified by teaching and performing laboratory exercises. Current research will need to be expanded by verifying integration with multiple digital forensic tools as well as with offensive security tools such as intrusion detection and penetration testing tools. Also, it will be necessary to check the performance and operation of the system at high loads with tens of users and big sets of data.

A great challenge will be, after certain experiences and works, to create a knowledge base that will be used by all students and researchers.

The new specialist degree program for Information Security and Digital Forensics requires the development of computer infrastructure for performing laboratory exercises that will provide students with practical knowledge and work skills with tools for managing digital forensic analysis processes and performing analyzes with special tools. As digital forensics is a relatively young scientific discipline and everyday technological changes bring new models and processes, so the development of teaching infrastructure should take into account the latest achievements in process and technology models. A laboratory for performing exercises, applying virtualization technology and implementing management forensic lab tools has been established, which has enabled the extension of the work environment. In addition to laboratory exercises, it will enable independent student work as well as provide remote access for work to external collaborators or researchers.

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How to upgrade an existing information system

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Abstract - **When designing the development of complex and related information systems, the use of different technologies for different functional parts of the system can be the optimal solution.**

Since the late 1990s, we have witnessed the unstoppable growth of web applications. They provide easy installation and upgrades, use of network resources and the Internet, and the ability to work on any operating system and browser. On the other hand, they are more expensive to develop, have worse user experience than desktop applications and are dependent on availability and network quality. Meanwhile, traditional desktop applications overwhelmed most of the major issues. When we add to this the ability to develop classic service applications, RESTful web services and modern web applications that utilize the processor power of a client, we get a palette with which it is possible to develop a flexible and modular information system that utilizes the optimal technology platform for each user request.

This paper describes some of the technologies for the development of modern applications and how they are used to upgrade the existing information system.

Keywords – development; programming; business system; modularity; services; web; desktop; electronic format, web services

I. INTRODUCTION

In terms of the need for rapid development of business applications, as well as frequent demands for changes and extensions of functionality, the question arises as to which technology to use.

Each of the development platforms and technologies on the market today has its advantages and disadvantages, and key indicators when choosing development technology are:

- speed and simplicity of development
- the ability to create a pleasant user experience
- efficiency in resource usage and response rate
- the ability to quickly and easily change and extend application functionality and ease of distribution of the resulting upgrades
- customization of a business scenario or part of it

The aim of this paper is to show that in the conditions of existing legacy applications with which we need to exchange data, complex business scenarios and large differences in the way the information system is used by different types of users, the best solution can be to use multiple different technologies and application types. This approach enables us to meet customer requirements by using the optimum technology platform for each segment of the information system.

The existing information system is used for personnel, administrative and financial needs. Data in the existing information system is entered manually. The existing information system does not support automatic generation of work tasks and uniform distribution of employees' obligations, nor does it enable monitoring of executed tasks. The existing information system has been upgraded in such a way that every employee can at any time find out their obligations and enable the management to track the progress of task execution. This is especially useful if more than one employee work on a project. This allows timely response if a delay occurs in any of the stages of project realization.

Upgrades described in this paper are implemented as a modular set of applications where the basic transactional application uses Microsoft .NET Framework technology and Microsoft SQL Server. Data transfer between different business systems is solved by using a service application on the Microsoft .NET platform. Microsoft WebAPI application on the server side and web application developed using Angular are used for displaying and review of data and reports. The development environment is Microsoft Visual Studio.

ClickOnce technology (part of the .NET Framework) is used to distribute, install, and upgrade the core transaction application. This technology allows installation from a central location (shared folders, web, FTP). Further upgrades to new versions go automatically (the launcher checks for newer versions).

II. TEHNOLOGIJE

A. Microsoft .NET Framework

The .NET Framework enhances the capabilities of the operating system Windows and offers development engineers ready-made solutions and functionalities to accelerate and simplify application development [3].

It is a technology platform that supports the development and execution of various types of

applications and web services. It is designed to meet the following requirements [3]:

- provide a consistent, object-oriented environment, regardless of whether they are at local or via any type of network,
- enable environment to execute code that minimizes conflicts when installing and managing versions,
- enable code execution environment that ensures code execution security, regardless of whether the code comes from known, unknown or semi-known sources,
- avoid performance problems that exist in scripting and interpreted programming languages,
- enabling a consistent development environment for different types of applications,
- building all communication technologies on standards that allow the .NET Framework code to be integrated with any other code that supports industry standards.

The .NET Framework consists of Common Language Runtime (CLR) and class libraries.

CLR is the basis for .NET Framework. It includes code compilation tools and manages code execution. It allows memory management, multi-threading and remoting. A very important feature of CLR is also the management of memory objects and the automatic deletion of those objects that are no longer used. This reduces the possibility of the most common errors in programming (problems with memory leaks and errors in referencing objects). In this way, development engineers are fully dedication to application functionality and do not need to care about optimum code execution and resource utilization.

Security is also the responsibility of the CLR. Each managed part of the application (or entire application) can have its security settings that determine which permissions it has on the client system. These settings may depend, for example, on the application source (domain, Internet, WAN ...). In this way, it is possible that applications from sources that the client trusts use all the available resources of the client system for increased efficiently.

Class Libraries are comprehensive, object-oriented collection of classes that programmers can use to create different types of applications. Class libraries also contains definitions of the types of data programmers can use.

B. Microsoft Visual Studio

Microsoft Visual Studio is an Integrated Development Environment that enables application development by writing managed and native code. The code can be written in any language for which there is a built-in support or plugin [4].

Visual Studio provides development environments and designers for all kinds of applications that can be developed using .NET Framework.

Visual Studio contains a powerful code editor that includes IntelliSense, code refactoring and code debugging. Program languages that have built-in support are: C, C++, VB.NET, C# and F#. It allows installation of support for other languages (Python, Ruby, Node.js, and M, among others). XML, XSLT, HTML, XHTML, JavaScript, TypeScript and CSS are also supported.

Visual Studio is a commercial product but since 2015 a free version is available. Microsoft Visual Studio Community Edition is very similar to the Professional version and it is intended for stand-alone development engineers and small teams.

C. WinForms

WinForms is a class library that allows programmers to create a desktop application interface. The basic class that is used is Control. This class includes the implementation of basic features of elements (location, size, color, font, ...) and basic events (click, drag & drop, ...). Other classes for graphical user interface inherit this class.

WinForms technology appears in the first version of .NET Framework in 2002. .NET Framework and the new languages enable fast and easy development of powerful business applications using WinForms technology.

.NET Framework 2.0 release introduces a technology that enables desktop applications on the Windows platform to overcome the basic lack of web applications that gain so much popularity:

- easy distribution,
- upgrades via any kind of network without any administrator privileges on the client.

Additionally, the ability to execute .NET applications on other operating systems and the ability to use the SOAP and REST web services to access data over the Internet, programmers get opportunities that almost completely emulate web application capabilities [1].

When creating applications using .NET WinForms and its accompanying technologies, programmers can use the following options [1]:

- use of local resources (hardware and software installed on the client),
- use of network resources (LAN, WAN or Internet),
- supporting occasionally connected users (enabling local data storage for lack of connection to the server),
- simple installation and upgrade (the application automatically checks for a newer version).

Many business processes do not require all these features. When designing any kind of application, it is necessary to consider business requirements and select only the required features. Including features that are not required for a particular business scenario can lead to longer development time, increased costs of development or both [1].

D. Local resources

The well-designed .NET Framework application utilizes to the maximum extent the fact that the software code and configuration data are installed on the client and executed locally. This enables a fast and rich user interface and using processor and memory on the client side. In this way, developers can provide the user with complex search, sorting and visualization of data, while maintaining the speed and efficiency of the user interface. Developers can also allow each user to save their personal settings (personalization) of the application [1].

Modern .NET WinForms applications efficiently utilize client hardware and devices, as well as installed services and applications. For example, it's easy to create integration with Microsoft Office applications to analyze and visualize data from a relational database and take advantage of the known interface and thereby reduce user training costs as well as user interface development costs. Also, it is possible to create an application that will integrate and coordinate the work of other applications and thus create a unified user interface [1].

E. Network resources

.NET WinForms applications can use various services and data sources through various network types. They can be an effective way to combine and analyze data from multiple sources. It is also possible to enable collaboration between multiple employees on multiple locations and with different devices.

Networking of modern desktop applications takes place through standard channels (TCP/IP, SSL, HTTP, ...) and data description languages (XML, JSON). This allows interaction with different data sources available on any platform and through various network technologies.

The basic idea behind the concept of the modern .NET WinForms application is that they should be connected to network resources whenever possible. Also, they should be less isolated applications and instead be part of a larger, modular and distributed solution [1].

F. ClickOnce

ClickOnce is a technology that has been released with .NET Framework 2.0, with support within the Visual Studio 2005. Older .NET Framework applications can't use it before upgrading to the minimum version 2.0. It enables the distribution of Windows applications that can upgrade themselves and require minimal user interaction when installing and upgrading [2]. ClickOnce solves three basic issues related to desktop application distribution [2]:

- Upgrade issues and new application versions. With the traditional installation procedure, each upgrade and new version requires reinstallation of the entire application. ClickOnce allows automatically download and install only modified application parts.
- Impact on the user computer. The traditional desktop application distribution relies on the components reported in the Windows Registry. Their installation has a huge impact on the configuration of the user's computer and there is a great deal of conflict between multiple applications that rely on shared components. With ClickOnce the distribution of each application is stand-alone. Also, ClickOnce applications have little or no impact on the user computer.
- Security Settings. Traditional desktop applications require administrator authority when installing or upgrading, and typically have all the rights on the computer, which can lead to problems and misuse. ClickOnce enables installation and upgrading without administrator authority and limiting the application only to the rights that are required for normal operation and targeted application functionality.

In the past developers had often decided for web application development because of the aforementioned problems, sacrificing the great benefits of desktop applications because of simplicity of distribution of web applications. With ClickOnce technology it is possible to have the best of both for business application development.

Applications using ClickOnce can be distributed in three ways: web pages, network sharing or storage media (CD, DVD, USB, ...).

Such applications can be started even when the computer is offline or can be installed in a way that requires a network connection and leaves no trace on the computer.

Distributed applications using ClickOnce can upgrade and install new versions by checking for newer packages at a defined location. Developer or network administrator defines the way in which checks and installations of upgrades and new versions will be done. This includes the ability to define a certain upgrade as a mandatory or leave the user to decide if he or she wants to upgrade at that time. It is also possible to restore the application to an older version in case of a problem. This can be done by a network administrator or user if it is allowed [2].

Since applications using ClickOnce are isolated, installing or running such applications can not disrupt the normal operation of other applications. They are also fully self-contained, installed with their components within the user profile, each application separately. They take place within an intranet or Internet security zone, but may ask for a higher level of access rights, as needed [2].

G. .NET Framework service applications

.NET Framework service applications (Microsoft Windows Services) allow us to create applications running within Windows session and are intended for long-lasting, continuous work in the background. They can be started when the operating system is booted up, can be stopped and restarted, and have no user interface. These features make them ideal for use on servers and for long-lasting functionality that does not bother other functionality on the same machine. Also, service applications can be run in the security context of a user account that is different from the logged user or the default system account.

Service applications on the .NET platform are developed within the Visual Studio environment.

H. Microsoft SQL Server

Microsoft SQL Server is a relational database management system (RDBMS). In addition to the primary function of storing and receiving data from other applications in OLTP (On-Line Transactional Processing), it can be used for data warehouse, analytics, business intelligence and reporting [5].

It is one of three leading relational database management systems (with Oracle Database and IBM DB2).

Like other relational database management systems, SQL Server is built on the SQL standard. SQL (Structured Query Language) is a standardized programming language used to manage databases and execute different types of queries on the data. Microsoft's implementation is called Transact SQL (T-SQL) and has been upgraded with a set of program extensions that expand standard capabilities [6].

The source code for SQL Server was developed in the 1980s by Sybase (currently owned by SAP). Microsoft has been involved to develop a version for operating system Windows and has taken over development in a few years.

Early versions were primarily intended for smaller applications, but over time, Microsoft has expanded its capabilities by turning SQL Server into a high-performance relational database that can handle other manufacturers. Also, reporting and analytics capabilities as well as support for new technologies have been added.

I. Entity Framework

Entity Framework (EF) is Microsoft's open-source ORM technology for the .NET Framework. Current version is 6.1.3.

Object-relational mapping (ORM) is a mechanism that allows data objects to be managed in memory without worrying about how they are connected to data sources (relational databases) [7].

It is a set of technologies that enable the development of data-oriented applications.

EF provides development engineers with the ability to work with data in the form of domain-specific objects, without worrying about how these data is stored in relational databases. By using EF technology, development engineers can work at a higher level of abstraction and develop and maintain data-oriented applications with less source code than traditional applications [7].

J. TypeScript

TypeScript is a free, open source programming language developed and maintained by Microsoft. It is a programming language that supersets JavaScript by adding features from more powerful, object-oriented programming languages (class, generic programming, ...).

TypeScript has emerged from the need to improve the experience of working with JavaScript in the development of complex business applications [8].

By using TypeScript, advanced, object oriented programming with advanced development tools is enabled (Visual Studio provides full support for TypeScript). Such a code is compiled into plain JavaScript and thus achieves compatibility with all browsers without installing any plugins on the client [8].

K. Angular

In recent years, there has been a rapid development of JavaScript-based platforms, most popular of which is Angular. Angular (currently in version 4) has been developed by Google and enables declarative programming of web application interfaces and auto-linking models and controls to display and edit data.

Angular is written using TypeScript and the applications that use it are most commonly written in this programming language.

Using HTML5 and CSS3 standards, combined with Angular, enables the development of very powerful web applications and enjoyable user experiences. Also, due to abandoning proprietary technologies and turning to open source technologies and standards, complex business web applications finally get the real ability to run on different browsers and operating systems [10].

Angular and similar JavaScript-based development frameworks have their features and popularity due to turning to the traditional desktop paradigm (client – server). By using modern web technologies, web applications switch to executing code on a client computer by executing JavaScript code within the browser. Servers are more used to retrieve, process, and save data through web services (mostly REST) and databases, and less for processing related to the user interface [9].

L. Microsoft ASP.NET WebAPI

WebAPI represents Microsoft's response to a more prominent transition from SOAP-based web services to RESTful Web Services.

This is the type of .NET Framework application that makes it easy and quick to build web services that allow data manipulation through standard HTTP calls (GET, POST, PUT, DELETE). The type of data to be sent / received is defined in the header of the HTTP message (JSON or XML).

III. INFRASTRUCTURE OF THE UPGRADED INFORMATION SYSTEM

The original information system consisted of one server with operating system Linux, PHP application, RESTful web service and MySQL database (Figure 1, Server 2).

Two additional servers were added during the process of upgrading the information system. One server is responsible for suppling the data for the desktop .NET application (Figure 1, Server 1) and other one for suppling

the data for Angular web application and installation of .NET Smart Client application (Figure 1, Server 3).

Server 1 consists of operating system Microsoft Windows Server 2012 R2 with Microsoft .NET Framework 4.5.1, Microsoft SQL Server 2014 R2 and .NET Windows service application. Windows service application is responsible for communicating with RESTful web service on Server 2. RESTful web service on Server 2 is used to retrieve the data from MySQL database and input new data into MySQL database.

Server 3 contains FTP server and Web server. FTP server is used for distribution of installation files for desktop .NET Smart Client application. Web server is used for Angular web application and WebAPI service. WebAPI service is responsible for retrieving the data from Microsoft SQL Server.

.NET Smart Client application is used to display data from Microsoft SQL Server, create reports, enter new data into Microsoft SQL Server. It allows complete access to all the data in Microsoft SQL Server.

.NET Smart Client application works only in the Local Area Network (Figure 1, Client 1, LAN). For a user to use .NET Smart Client application at a remote location, it is necessary to connect to company's private network through Virtual Private Network (Figure 1, Client 2, VPN).

The same limitations were on the original information system, and they were not changed during the upgrade of the information system.

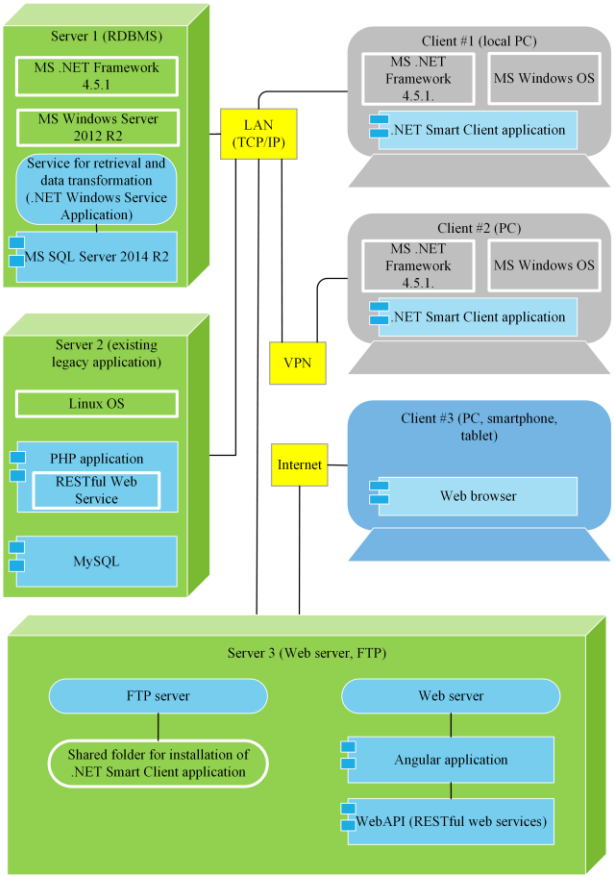

Figure 1. Infrastructure of the upgraded information system

To install .NET Smart Client application, user must access a shared directory on Server 3 (Figure 1, Server 3). Access to a shared directory on Server 3 is only enabled from a Local Area Network (LAN) and a Virtual Private Network (VPN).

Angular web application is used to display only data that is relevant to an employee (Figure 1, Server 3, Web server). To access the data, user must sign in using his or her username and password. Angular web application retrieves data from a Microsoft SQL Server database using WebAPI.

To access Angular web application, user can use any browser on any platform and device (PC, laptop, smartphone, tablet). To use Angular web application, it is not necessary for a user to be connected to company's private network. Access is available from any location in the world via the Internet (Figure 1, Client 3).

IV. Conclusion

Building information systems in complex business environments, with legacy applications, requirements for connection to other systems, different business scenarios and user requirements, has never been more complex.

Many technology platforms that are constantly changing, the speed of changing business requirements and the expectations of users accustomed to commercial applications, make the situation even more difficult.

All this makes the choice of technology platform one of the key steps towards successful implementation of the information system.

The information system was built modularly in the true sense of the word, using separate applications and application technologies for various services and usage scenarios.

As such, it has many advantages - application and service independence in case of error, the possibility of independent upgrading of individual parts of the system, application customization, robustness, less dependence on one technology.

However, the biggest advantage may not be immediately visible. With this approach, it is possible to significantly reduce the risk of application obsolescence and a traumatic, sudden transition to the new technology platform. This danger is especially great for transactional systems that have the deepest interaction with customers.

In the approach that was presented, it was possible to build the most sensitive part of the information system around a proven and efficient technology platform that has the best ratio invested and obtained when it comes to ergonomic user experience (desktop application). Given that this is an old technology where there is a possibility of obsolescence and abandonment by the manufacturer and which does not provide access via various mobile devices and operating systems, the data and reporting subsystem is built with state-of-the-art web technology (WebAPI and Angular). This combination enables a gradual transfer of functionality from desktop to web application and, ultimately, a user's painless and cost-

effective transition to newer technology. In this way, it is also possible to test newer technologies over a longer period of time. Such an approach is at the same time the greatest opportunity to improve the information system.

The weakness of this approach is complexity of development and maintenance. In the case of multiple applications, services and technology platforms, it is necessary to have a much higher level of knowledge and openness to new technologies than in the case of long-term development on one technology or a set of technologies. Also, in maintenance, it is necessary to take care of multiple applications and technology platforms at the same time, which is additional effort.

The described approach provides modularity, optimum work and top-level user experience as well as the ability for further development in the future.

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Internet Use for Online Learning among Youth: Differences across European Countries and Educational Levels

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Abstract - Abundant availability of online courses and materials has greatly expanded the opportunities for gaining new knowledge and skills, especially among younger population. Most of these courses and materials are freeware or could be purchased for a cost substantially lower than compared to those offered by HEIs or publishing companies. Although these new opportunities are available to everyone, researches indicate that their usage is not evenly spread across European countries and educational levels. Goal of the research is to investigate if the usage of online learning materials and courses over Internet is homogenous in Europe among youth (age 16-29) of low, medium, and high level education. Research has been conducted on the data from Eurostat Database on the following aspects of Internet use (i) Looking for information about education, training or course offers; (ii) Doing an online course (of any subject); (iii) Usage of online learning material; (iv) Communicating with instructors or students using educational websites/portals; (v) Usage of any aspect of online learning. Cluster analysis has been conducted in order to create a group of countries according to different level of internet usage for online learning. Relationship of GDP per capita has been compared across identified clusters.

I. INTRODUCTION

Online learning can be defined as innovative form of education which supports traditional teaching methods, and it has substantial positive impact to individuals and companies since it allows facilitated access to relevant knowledge during both university education and long-life learning. Since online learning is based on the usage of information and communication technologies, it could be expected that its usage is influenced by the digital divide, which indicates that there are barriers for the optimal utilization of information and communication technologies among people of different age, education and place of residence. Research goals of this paper are three-fold: (i) to investigate the level of online learning usage in European countries, as measured by Eurostat approach; (ii) to examine the applicability of K-means clustering methodology for the purpose of grouping European countries according to the level of online learning, and (iii) investigate the relationship of GDP per capita with online learning in European countries. We focus to the young residents of European countries (age 16-29) of different levels of education (low, medium, and high), and investigate the relationship between online learning and GDP per capita. Contributions of this paper are two-fold: (i) homogenous groups of European countries are identified that are similar according to the level of online learning usage among youth residents, thus indicating that digital divide is present in that area; (ii) positive relationship has been identified between the level of online learning and GDP per capita, thus indicating that the most likely cause of digital divide in that area is the different level of economic development.

Paper consists on the following parts. After introduction, in the second part of the paper we overview the relevance, advantages and barriers for online learning. Third part of the paper presents the methodology, while descriptive analysis of the data is presented in the fourth part. Cluster analysis is outlined in sixth part of the paper, while part seven investigates the relationship between the online learning and GDP per capita. Conclusion discusses the limitations and future research directions.

II. ON-LINE LEARNING

Ruiz (2006) describe online learning through usage of information and communication technologies. In addition, online learning refers to a virtual learning environment where information and communication technologies facilitate teaching activities (Wan 2008). In order to summarize all mentioned definitions, online learning can be described as internet platform where students can approach to course content, to all relevant information regarding studied program, to different documents and resources important for learning process, with no space or time limit (Raaij and Schepers, 2008).

Online learning presents critical factor in building a culture of lifelong learning. Knowledge economy implicit significant intellectual capital and investments in employees' potential and in job performance of each employee (Rosenberg, 2001). In order to provide more

effective educational process to their employees, companies use different online learning platforms (Rao, 2011). There are several advantages for companies when offer online learning: education with no space and time limit, motivating, cost effective, enhancing lifelong learning, higher productivity [1][2][3].

There are numerous advantages for online learning usage [4][5]. The most important is that users can learn where and when they want, which means that they can better organize their work, family, free time and learning [6]. In addition, online learning provides: many research opportunities, faster and better approach to information, individual instructions, standardize course content, interactivity, confidence, and convenience [7]. Moreover, online learning platforms enhance communication efficiency, provide automation of learners' activities, and permit professors to update the programme easily and enable users to have control over the learning activities [8][9]. Innovations in online learning refer to individual approach and cooperation among students and professors.

Beside many advantages, there are some barriers in online learning usage[10][11][12]. Online learning requires: advanced usage of information and communication technologies, higher investments in technology, user's willingness and motivation to accept online learning activities, more time and effort to organize the course, structured and technically designed course, well-educated and trained professors [13]. However, all these obstacles can be easily overwhelmed if learners and professors are ready to use and apply online learning possibilities.

III. METHODOLOGY

A. Data sources

In order to shed some light on the usage of online learning in European countries, we use Eurostat database, which tracks the following usage of online learning: i) Looking for information about education, training or course offers; (ii) Doing an online course (of any subject); (iii) Usage of online learning material; (iv) Communicating with instructors or students using educational websites/portals; (v) Usage of any aspect of online learning. We focus to youth (age 16 do 29) of different levels of education: low, medium, and high, according to Eurostat definition: 'Low formal education: At most lower secondary education [ISCED 0, 1, or 2]; Medium formal education: Upper secondary and post-secondary non-tertiary education [ISCED 3 or 4]; High formal education: Tertiary education [ISCED 5, 6, 7 or 8]', where ISCED refers to the International Standard Classification of Education.

We take into account the data for year 2015. Table 1 presents the research variables used in the analysis, which refer to the % of individuals using the particular form of online learning, aged 16-29 years. Following countries are included in the analysis: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Finland, France, FYRM, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Turkey, and United Kingdom. Denmark was not included in analysis due to missing data.

Table 1. Research variables, European countries, 2015

Variable name	Statistical units
Looking for information about education, training or course offers	
SEARCH_16_29_ALL	Individ., 16 to 29 years old; %
SEARCH_16_29_HIGH	Individ., 16-29, high education; %
SEARCH_16_29_MEDIUM	Individ. 16-29 medium educ.; %
SEARCH_16_29_LOW	Individ. 16-29 low education; %
Doing an online course (of any subject)	
ONLINE_C_16_29_ALL	Individ., 16 to 29 years old; %
ONLINE_C_16_29_LOW	Individ., 16-29, high education; %
ONLINE_C_16_29_MEDIUM	Individ. 16-29 medium educ.; %
ONLINE_C_16_29_HIGH	Individ. 16-29 low education; %
Usage of online learning material	
ONLINE_M_16_29_ALL	Individ., 16 to 29 years old; %
ONLINE_M_16_29_LOW	Individ., 16-29, high education; %
ONLINE_M_16_29_MEDIUM	Individ. 16-29 medium educ.; %
ONLINE_M_16_29_HIGH	Individ. 16-29 low education; %
Communicating with instructors or students using educational websites/portals	
INSTRUCT_16_29_ALL	Individ., 16 to 29 years old; %
INSTRUCT_16_29_LOW	Individ., 16-29, high education; %
INSTRUCT_16_29_MEDIUM	Individ. 16-29 medium educ.; %
INSTRUCT_16_29_HIGH	Individ. 16-29 low education; %
Usage of any aspect of online learning	
ANY_16_29_ALL	Individ., 16 to 29 years old; %
ANY_16_29_LOW	Individ., 16-29, high education; %
ANY_16_29_MEDIUM	Individ. 16-29 medium educ.; %
ANY_16_29_HIGH	Individ. 16-29 low education; %

Source: Authors, Eurostat

B. Statistical analysis

Statistical analysis is conducted in three steps. First, we calculate descriptive statistics for all the variables at the total sample (including all investigated European countries). Second, we conduct k-means cluster analysis using Statistica software package, with the following parameters: Euclidean distances, Maximize initial distance, with the 10-fold Cross-validation. Finally, we compare GDP per capita across the clusters in order to investigate relationship between economic development and online learning.

However, proposed statistical analysis has some limitations that has to be taken into account. First, online learning is not necessarily related to national boundaries. Second, individual can take online course or use other online resources in different language and other country. Since English is predominant language in education, it is likely that low level of English (but also other languages) will impact the lower level of online learning. Therefore, online learning initiatives in local language would have a strong impact to online learning, besides GDP per capita and availability of high-speed internet. Third, there could be differences in understanding of the notion of e-learning, e.g. online learning can be understood as such only if it is provided by accredited HEI by one respondent, while other

respondent can consider any usage of online sources, e.g. over video search engines as online learning.

IV. Descriptive Analysis

Table 2 presents the results of the descriptive analysis of indicators of online learning in European countries. The highest level of usage is present for the variable "Looking for information about education. training or course offers", while the lowest level is present for the variable "Doing an online course (of any subject)". This result is in line with previous research, which found out that passive usage of online material is more present than active learning over the organized courses [7].

TABLE 2. DESCRIPTIVE STATISTICS OF ONLINE LEARNING, EUROPAN COUNTRIES, 2015

	Min	Max	Mean	Std. Dev.
Looking for information about education. training or course offers				
SEARCH_16_29_ALL	37	79	55.78	12.648
SEARCH_16_29_HIGH	43	86	62.55	12.551
SEARCH_16_29_MEDIUM	34	83	54.45	13.414
SEARCH_16_29_LOW	25	77	51.71	15.321
Doing an online course (of any subject)				
ONLINE_C_16_29_ALL	3	27	8.91	5.006
ONLINE_C_16_29_HIGH	4	34	13.81	6.959
ONLINE_C_16_29_MEDIUM	3	27	8.32	5.088
ONLINE_C_16_29_LOW	0	26	6.00	5.779
Usage of online learning material				
ONLINE_M_16_29_ALL	5	54	25.19	10.584
ONLINE_M_16_29_HIGH	8	57	30.94	12.236
ONLINE_M_16_29_MEDIUM	7	47	24.77	10.375
ONLINE_M_16_29_LOW	2	61	22.97	13.159
Communicating with instructors or students using educational websites/portals				
INSTRUCT_16_29_ALL	4	43	20.28	9.676
INSTRUCTOR_16_29_HIGH	7	35	20.65	8.155
INSTRUCT_16_29_MEDIUM	5	37	20.42	9.468
INSTRUCT_16_29_LOW	1	54	19.06	15.925
Usage of any aspect of online learning				
ANY_16_29_ALL	7	62	35.22	12.546
ANY_16_29_MEDIUM	10	55	34.35	12.637
ANY_16_29_HIGH	15	67	41.32	13.710
ANY_16_29_LOW	4	72	32.68	17.333

Source: Authors

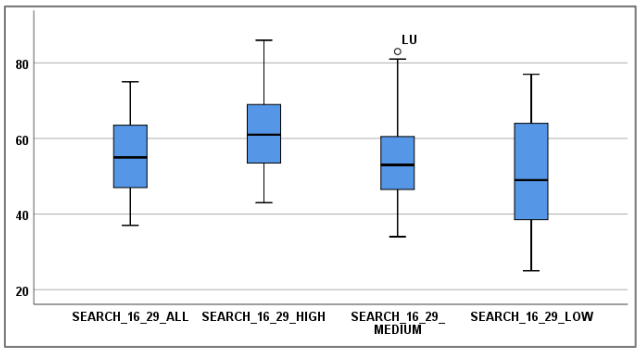

Figure 1. Box plot diagram of variables related to: Looking for information about education, training or course offers (Source: Authors)

Figure 2 presents the box plot diagram of the variable Doing an online course (of any subject). It can be noted that the average usage of online courses is substantially lower than searching for the information presented in Figure 1. Again, the individuals with high education use this type of online learning the most often. However, this indicator has substantially larger number of outliers, such as Finland, Estonia, FYRM, and Lithuania.

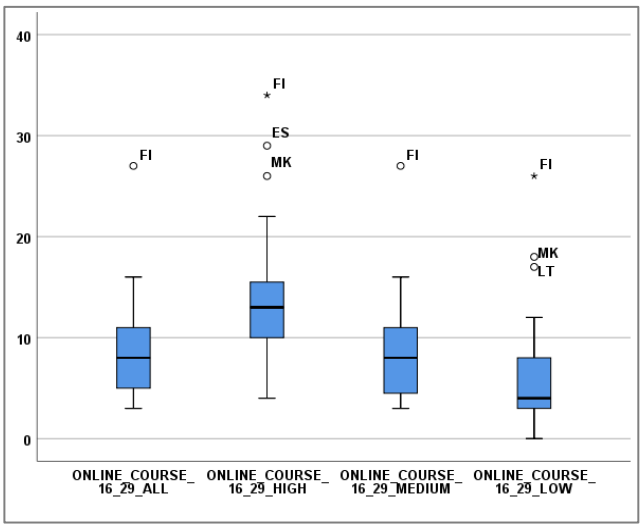

Figure 2. Box plot diagram of variables related to **Doing an online course (of any subject)** (Source: Authors)

Figure 3 presents box plot diagrams of the variable Usage of online learning material. Again, comparing to the Figure 1, the percentage of individuals using this type of online learning activity is lower. Only one country (Finland) is substantially different to others. It is particularly interesting that individuals with low education from Finland is substantially higher than in other countries. Similar trend is present at the Figure 4 presenting the Communicating with instructors or students using educational websites/portals, and Figure 5 presenting the Usage of any aspect of online learning.

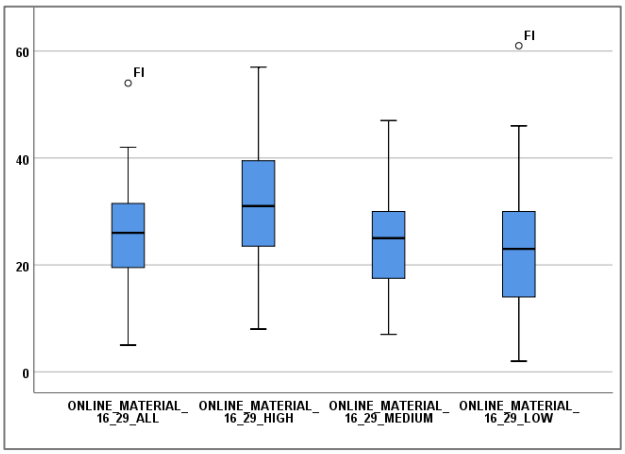

Figure 3. Box plot diagram of variables related to: **Usage of online learning material** (Source: Authors)

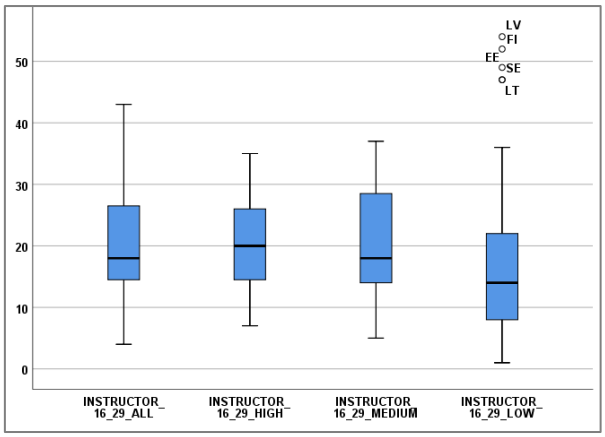

Figure 4. Box plot diagram: **Communicating with instructors or students using educational websites/portals** (Source: Authors)

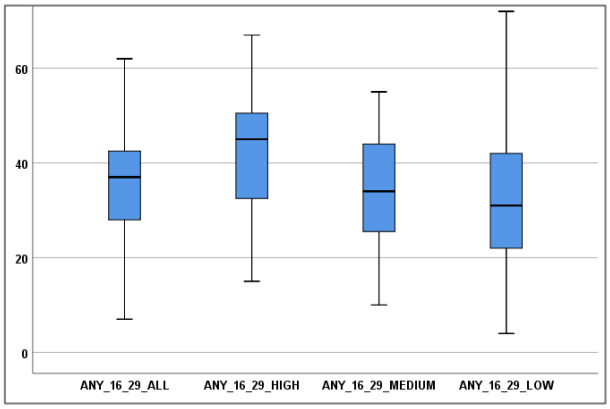

Figure 5. Box plot diagram of variables related to: **Usage of any aspect of online learning** (Source: Authors)

V. CLUSTER ANALYSIS

We apply K-means clustering algorithm to the observed online learning variables in European countries. Maximum average distance approach, using Euclidean distances was used in order to assign countries to clusters [14]. Statistica Data Miner was used for the cluster analysis, and all variables were normalized, using linear transformation. V-fold cross validation with the v=10 was used in order to estimate the optimal number of clusters [15]. In addition, graph of cost sequence presenting the error function for various number of clusters was used (Figure 6) in order to select optimal number of clusters, and it indicates that the optimal number of clusters is five. Cluster analysis was conducted on a sample of 31 European countries.

Table 3 presents the results of ANOVA analysis for the online learning variables of the variables used for developing cluster solution, which indicate that all the variables have statistically significant different values across clusters. In other words, the null hypothesis indicating that average values of variables across clusters are equal, cannot be rejected, which confirms that the decision to use five-cluster solution is justified.

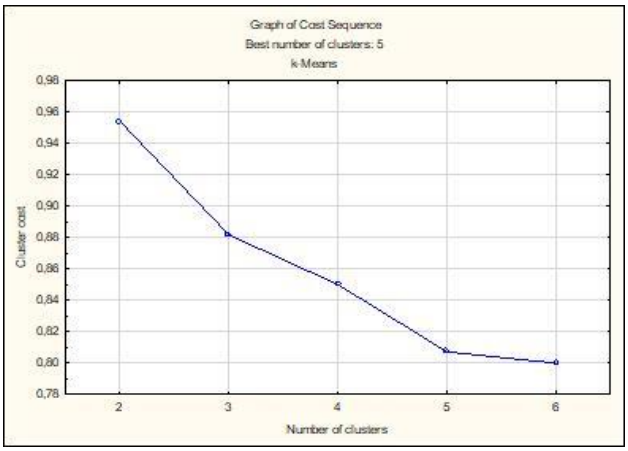

Figure 6. Cost sequence graph (Source: Authors)

TABLE 3. ANOVA ANALYSIS OF VARIABLES USED IN K-MEANS CLUSTER ANALYSIS

	df	F	p value
Looking for information about education. training or course offers			
SEARCH_16_29_ALL	26	7.58	0.00**
SEARCH_16_29_HIGH	26	7.03	0.00**
SEARCH_16_29_MEDIUM	26	9.07	0.00**
SEARCH_16_29_LOW	26	3.79	0.01**
Doing an online course (of any subject)			
ONLINE_C_16_29_ALL	26	13.55	0.00**
ONLINE_C_16_29_LOW	26	9.17	0.00**
ONLINE_C_16_29_MEDIUM	26	11.46	0.00**
ONLINE_C_16_29_HIGH	26	7.17	0.00**
Usage of online learning material			
ONLINE_M_16_29_ALL	26	25.89	0.00**
ONLINE_M_16_29_LOW	26	10.32	0.00**
ONLINE_M_16_29_MEDIUM	26	24.07	0.00**
ONLINE_M_16_29_HIGH	26	19.46	0.00**
Communicating with instructors or students using educational websites/portals			
INSTRUCT_16_29_ALL	26	25.39	0.00**
INSTRUCT_16_29_LOW	26	17.67	0.00**
INSTRUCT_16_29_MEDIUM	26	24.55	0.00**
INSTRUCT_16_29_HIGH	26	5.43	0.00**
Usage of any aspect of online learning			
ANY_16_29_ALL	26	31.48	0.00**
ANY_16_29_LOW	26	15.18	0.00**
ANY_16_29_MEDIUM	26	27.38	0.00**
ANY_16_29_HIGH	26	20.14	0.00**

Source: Authors
Note: Statistically significant at 5%

TABLE 4. COUNTRY MEMBERSHIP ACROSS CLUSTERS

Cluster	Countries
Cluster 1	Belgium, Latvia, Lithuania, Netherlands, Sweden
Cluster 2	Bulgaria, Germany, Croatia, Italy, Malta, Austria, Romania, Slovenia, Slovakia, United Kingdom, FYRM, Serbia
Cluster 3	Czech Republic, Ireland, Greece, France, Cyprus, Hungary, Poland, Turkey
Cluster 4	Estonia, Spain, Luxembourg, Portugal, Norway
Cluster 5	Finland

Source: Authors

Table 4 as well as figure 7 present the countries which are members of each cluster. It can be noted that first cluster contains countries which are geographically and

economically similar (Belgium, Latvia, Lithuania, Netherlands, Sweden). Second cluster is more heterogeneous according to the economic development and geographical position, including countries such as Germany and United Kingdom, but also FYRM and Bulgaria. Members of third and fourth clusters are also diverse according to the economic development and geographic position, while cluster 5 contains only one country (Finland), which was often the outlier according to the highest level of online learning usage.

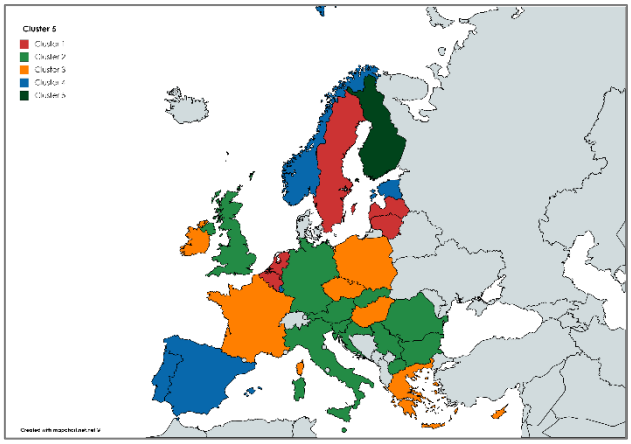

Figure 7. Countries membership across clusters (Source: Authors)

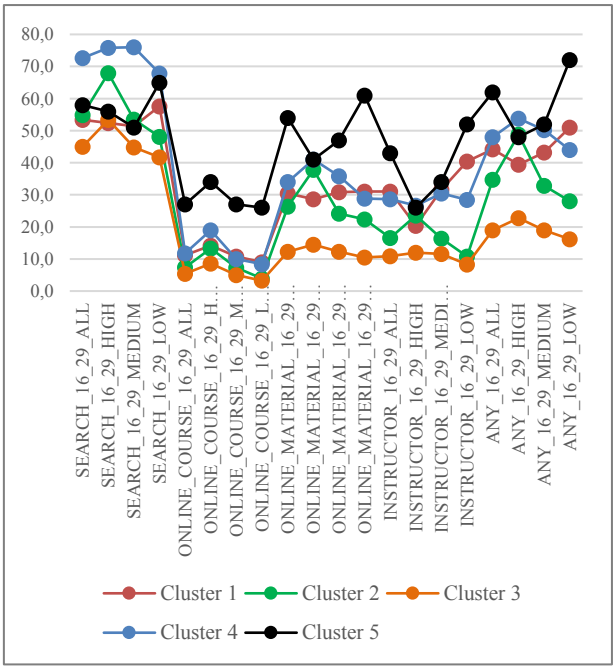

Figure 8. Mean values of research variables across clusters (Source: Authors)

Figure 8 and table 5 presents the mean values of research variables across clusters. It can be noted that countries which are members of cluster 4 (Estonia, Spain, Luxembourg, Portugal, Norway) are leading according to the variable "Looking for information about education. training or course offers", while Finland (as member of cluster 5) is the leading country according to all other indicators of online learning. Members of cluster 3 (Czech Republic, Ireland, Greece, France, Cyprus, Hungary, Poland, Turkey) are lagging behind the most according to all indicators of online learning.

Interesting results were observed according to the group of youth with the highest level of online learning activity. First variable "Looking for information about education. training or course offers" was the most often used online activity among youth with high education, with the exception of Finland in which it was used the most in the youth group with low education, while youth with high education was leading according to "Doing an online course" variable. In other variables, the youth with high education were leaders in clusters 2, 3 and 4, while youth with medium education was leading in cluster1 and youth with low education in cluster 5. It can be concluded that in countries which are leading according to online learning, youth with the low education is not left behind, but is included in lifelong education probably due to the abundant availabilities to reach high-speed internet with the strong computing devices.

Table 5. Mean values of research variables across clusters

Online learning indicator	Cluster value				
	1	2	3	4	5
Looking for information about education. training or course offers					
SEARCH_16_29_ALL	53.4	54.8	45.0	72.6	58.0
SEARCH_16_29_HIGH	**52.4**	**67.9**	**53.4**	**75.8**	56.0
SEARCH_16_29_MEDIUM	51.4	53.5	44.8	76.0	51.0
SEARCH_16_29_LOW	57.6	48.1	41.8	67.8	**65.0**
Doing an online course (of any subject)					
ONLINE_C_16_29_ALL	11.2	7.4	5.4	11.8	27.0
ONLINE_C_16_29_HIGH	**14.2**	**13.3**	**8.6**	**19.0**	**34.0**
ONLINE_C_16_29_MEDIUM	10.8	7.3	5.0	10.0	27.0
ONLINE_C_16_29_LOW	9.0	3.9	3.3	8.4	26.0
Usage of online learning material					
ONLINE_M_16_29_ALL	30.4	26.3	12.3	34.0	54.0
ONLINE_M_16_29_HIGH	28.6	**37.8**	**14.5**	**41.0**	41.0
ONLINE_M_16_29_MEDIUM	**30.8**	24.2	12.3	35.8	47.0
ONLINE_M_16_29_LOW	31.0	22.3	10.5	28.8	**61.0**
Communicating with instructors or students using educational websites/portals					
INSTRUCT_16_29_ALL	31.0	16.6	10.9	28.6	43.0
INSTRUCTOR_16_29_HIGH	20.4	**23.6**	**12.0**	26.6	26.0
INSTRUCT_16_29_MEDIUM	**31.6**	16.3	11.6	**30.4**	34.0
INSTRUCT_16_29_LOW	40.4	10.8	8.3	28.4	**52.0**
Usage of any aspect of online learning					
ANY_16_29_ALL	44.2	34.8	19.0	48.0	62.0
ANY_16_29_HIGH	39.4	**48.8**	**22.8**	**53.8**	48.0
ANY_16_29_MEDIUM	43.2	32.8	19.0	50.2	52.0
ANY_16_29_LOW	**51.0**	28.1	16.1	44.0	**72.0**

Source: Authors

VI. Relationship between GDP per capita and online learning

In order to further investigate if there is a positive relationship between economic development and online learning, we calculate mean values of GDP per capita across clusters. Figure 9 presents the average GDP per capita across clusters. Members of cluster 4 and 5 had the

highest level of online learning usage, and they have also the highest average GDP per capita, which indicates that there is a possible positive relationship between the level of economic development and level of usage of online learning. Other clusters, which were lagging behind according to online learning also lagged behind according to GPD per capita. However, the Kruskal-Wallis test (H=4.180, p-value=0.234) did not confirm that the found differences are statistically significant. Therefore, the hypothesis that there is a positive relationship between the usage of online learning and economic development was not confirmed.

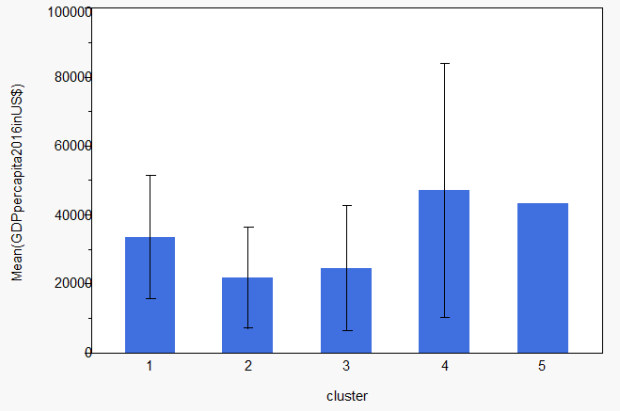

Figure 9. Average GDP per capita across clusters (Source: Authors)

VII. Conclusion

Online learning improves and enhances the quality of learning as well as lifelong educational activities. In this work we focus to the usage of online learning across European countries among youth, measured by the Eurostat indicators. The goal of the paper was to investigate if European countries could be grouped in homogenous groups using K-means analysis in order to investigate which countries are similar according to the usage of online learning. The results indicated that Finland is the most developed according to online learning, following by countries clustered in North Europe (Belgium, Latvia, Lithuania, Netherlands, Sweden). However, clusters that are lagging behind according to usage of online learning are not homogenous according to their economic development. Although cluster members with the highest online learning also have the highest GDP per capita, the relationship was not statistically significant. Preliminarily conclusion is some of the countries which are developing in economic sense, also catch up according to online learning among youth. This conclusion is justified taking into account that digital divide among youth is decreasing, since youth with low education is successful in gaining information literacy skills despite the barriers they face [16] [17].

Our research has several limitations which stem from the data and methodology used, but also indicate the future research directions. First, data sources limitations are described under section B. Statistical analysis. Second, we use only one-year data and we focus to European countries, and we use K-means cluster analysis. Future research should aim at researching wider sample in terms of time coverage, as well as different characteristics, such as gender. In addition, different clustering methods should be applied, such as hierarchical clustering and SOM analysis. This would provide broader conclusions, that could be used as a basis for long-term actions at the level of European Union.

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Teaching Health Care Management with Simulation Games

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Abstract - Usage of simulation games in education is constantly growing, due to their significant benefits, such as interactivity in a risk free environment. Simulation games are a pedagogical tool which allows development and knowledge simultaneously with the development of experience, in controlled environment. Areas of education in which simulation games are used are broad and they range from engineering to business and management. Simulation games are also used in health care management, with range of interesting applications. System dynamics is a simulation method that is often used for the development of simulation games, since it allows an observance of long-term dynamic phenomena. The goal of the paper is to provide an overview of simulation games usage in education, with the focus to health care management. A simulation game, developed with the usage of system dynamics is presented, with the focus to epidemic investigation and management. Graphic user interface of the game, as well as several simulation runs are presented.

I. INTRODUCTION

Simulation models presents a powerful tool that can be used to model and present the real world. Among numerous methods, such as discrete simulation [1] and agent based modelling [2], system dynamics models offer increased understanding of complex social and physical systems over time using feedback loop structures. System dynamics modelling enable users to simulate business processes. In other words, users learn how to develop and understand "What if" scenarios in dynamic world and how to manage complex systems such as company, competition and market [3]. Simulations enable users to improve decision making skills, make experiments and play.

Simulation games provide experiential learning and allow users to conduct experiments in predefined time period without any risk [4]. Simulation games present an effective tool which allows users to make decisions in safe environment and to analyze all steps they have made. Consequences of given actions are visible during simulation period compared with consequences in the real world which can be seen after longer time period. In other words, during simulation game, users practice their knowledge while solving real problems. Therefore, simulation games can be defined as pedagogical tool which enable users to practice their knowledge and gain business experience in controlled and risk free environment.

There is wide range of areas where simulation games can be used, from engineering, transport, and supply to health care management and business. However, in order to have good feedback and results from using simulation games and to acquire knowledge that can be applied in real business situation, several assumptions should be satisfied: cleared learning objectives, prepared learning materials, applied other teaching methods, adequate technology support, detailed analysis of results, well trained teachers, enough time preparation and financial resources [5]. Homer et al. [6] list the number areas of the application of system dynamics in health care, and here we shall mention those related to this research: (i) disease epidemiology (e.g. Homer et al. [7]), HIV/AIDS (Roberts et al, [8]), chlamydia infection (Royston et al., [9]), dengue fever (Ritchie-Dunham et al, [10]) and drug-resistant pneumococcal infections (Homer et al., [11]). The goal of the paper is to provide an overview of yellow fever system dynamics simulation model, that is used for the development of the simulation games used for the teaching of health care management at Faculty for Dental Medicine & Health, University of Osijek.

II. MODEL DESCRIPTION

A. Model structure

Simulation game is developed based on the model of the epidemic spreading of yellow fever among humans over the mosquito bite, which is based on the description of yellow-fever in Study Notes in System Dynamics by Michael Goodman [12]. Model focuses to the situation in the hypothetical city, in which yellow fever is spreading. At first there is small # of contagious humans in the city that have been bitten and have the yellow fever virus incubating inside them. When there are many contagious humans, there are many incubating mosquitoes that become infectious and bites more vulnerable humans that become contagious and generate even more infectious mosquitoes, and so on. After humans are sick they either die or become immune. When person survives yellow fever it cannot get sick any more. In other words, human population that can get sick of yellow fever is limited.

Model is based on the presumption that number of mosquitoes is constant, because yellow fever does not influence mortality and fertility patterns of mosquitoes. In addition, model presumes that mosquitoes hatch rate is constant. Every day equal number of mosquitoes are born. Mosquitoes are potentially dangerous only for three days. Therefore, if mosquito does not bite contagious human during the first three days, it is considered safe and is removed from Potentially dangerous population. If mosquito bites contagious human during the first three days of its life it becomes incubating and is also removed from the Potentially dangerous population.

Figure 1 presents the model of spreading yellow fever. Model is developed using Vensim, the specialized software for system dynamics modelling, that can be also used for game development. Model consists of stocks, flows, and constants.

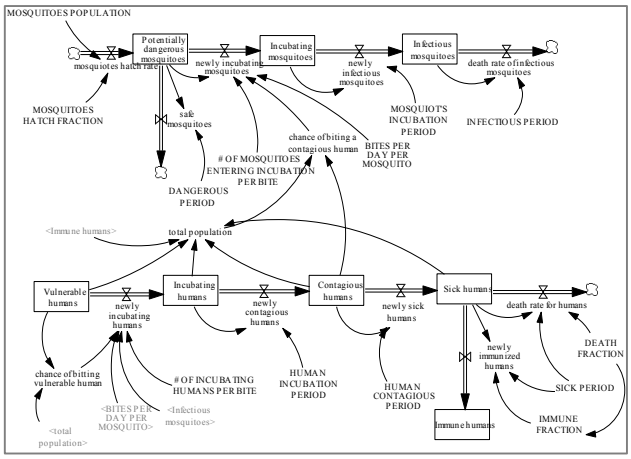

Figure 1 System dynamics model of yellow fever (Source: Authors, based on [12])

B. Feedback loops in the model

There are two feedback loops in the model, that will be briefly elaborated. At first there is small number of contagious humans in the city that have been bitten and have the yellow fever virus incubating inside them. Positive feedback loop is driving the number of newly incubating mosquitoes up during the first 120 days. When there are many contagious humans, there are many incubating mosquitoes that become infectious and bites more vulnerable humans that become contagious and generate even more infectious mosquitoes, and so on.

Model focuses only on the situation in the city. Also, after humans are sick they either die or become immune. When person survives yellow fever it cannot get sick any more. In other words, human population that can get sick of yellow fever is limited, which is the result of the negative feedback loop.

C. Model equations

Vensim notations for the model elements are used. The stocks are written with the first capital letter, flows and auxiliary variables in small caps, and constants in all caps. The stocks in the system dynamics model are the following: potentially dangerous mosquitoes, incubating mosquitoes, infectious mosquitoes, vulnerable humans, incubating humans, contagious humans, sick humans, and, immune humans. Stocks are indicated with the first capital letter.

The flows in the system dynamics model are as following: mosquitoes hatch rate, newly incubated mosquitoes, newly infectious mosquitoes, death rate of infectious mosquitoes, safe mosquitoes, newly incubating humans, newly contagious humans, newly sick humans, newly immunized humans, death rate of humans. Flows are indicated with small caps.

The constants in the system are as following: mosquitoes' population, mosquitoes hatch fraction, dangerous period, # of mosquitoes entering incubation per bite, bites per day per mosquitoes, mosquitoes incubating period, infectious period, # of incubating humans per bite, human incubation period, human contagious period, death fraction, sick period, and immune fraction. Constants are indicated by all caps. The model equations are as following:

"# OF INCUBATING HUMANS PER BITE"=1
Units: humans/bites; # of incubating people resulting from an infectious mosquito's biting one vulnerable person. (1)

"# OF MOSQUITOES ENTERING INCUBATION PER BITE"=1
Units: mosquitoes/bites; # of mosquitos that enter incubation. (2)

BITES PER DAY PER MOSQUITO=0.22222
Units: bites/day/mosquitoes; # of times a day each mosquito bites. (3)

chance of biting a contagious human=Contagious humans/total population
Units: dmnl; Chance that potentially dangerous mosquito will bite a contagious human is ratio of # of contagious humans to the total population in the city. (4)

chance of biting vulnerable human=Vulnerable humans/total population
Units: dmnl; Ratio of # of vulnerable humans to the total city's population. (5)

Contagious humans= INTEG (newly contagious humans-newly sick humans,100)
Units: humans; Current # of contagious humans. (6)

DANGEROUS PERIOD=3
Units: day; If mosquito bites a contagious person in the first three days it will become incubating&infectious. (7)

DEATH FRACTION=0.2
Units: dmnl; # of humans that die per 1 sick human. (8)
death rate for humans=Sick humans*DEATH

FRACTION/SICK PERIOD
Units: humans/day; # of sick humans die per day. (9)

death rate of infectious mosquitoes=Infectious mosquitoes/INFECTIOUS PERIOD
Units: mosquitoes/day; # of mosq. die per day. (10)

HUMAN CONTAGIOUS PERIOD=4.5
Units: day; Time needed for humans to become sick. (11)

HUMAN INCUBATION PERIOD=4.5
Units: day; Time needed for humans to become contagious. (12)

IMMUNE FRACTION=1-DEATH FRACTION
Units: dmnl; # of humans that become immune per sick human. (13)

Immune humans= INTEG (newly immunized humans,0)
Units: humans; Current # of immune hum. in city. (14)

Incubating humans= INTEG (+newly incubating humans-newly contagious humans, 0)
Units: humans; Current # of incubating hum. in city. (15)

Incubating mosquitoes= INTEG (newly incubating mosquitoes-newly infectious mosquitoes,0)
Units: mosquitoes; Current # of incub. mosq. (16)

Infectious mosquitoes= INTEG (+newly infectious mosquitoes-death rate of infectious mosquitoes,0)
Units: mosquitoes; Current # of infect. mosq. (17)

INFECTIOUS PERIOD=3
Units: day; # of days remaining for an inf. mosq. until it dies. (18)

MOSQUIOT'S INCUBATION PERIOD=12
Units: day; Time needed for mosquitoes to become infectious. (19)

mosquiotes hatch rate=MOSQUITOES POPULATION*MOSQUITOES HATCH FRACTION
Units: mosquitoes/day; # of mosq. hatched per day. (20)

MOSQUITOES HATCH FRACTION=0.05555
Units: 1/day; # of mosquitoes hatched per one mosquito per day. (21)

MOSQUITOES POPULATION=500000
Units: mosquitoes;
Total mosquito population is constant and remains in equilibrium throughout the simulation. (22)

newly contagious humans=Incubating humans/HUMAN INCUBATION PERIOD
Units: humans/day
# of humans that become contagious per day. (23)

newly immunized humans=
Sick humans*IMMUNE FRACTION/SICK PERIOD
Units: humans/day
# of humans that are immunized per day. (24)

SICK PERIOD=2.5
Units: day;
Time for sick person to either die or to recover. (25)

newly incubating humans=chance of bitting vulnerable human*BITES PER DAY PER MOSQUITO*Infectious mosquitoes*"# OF INCUBATING HUMANS PER BITE"
Units: humans/day;
# of humans entering incubation per day. (26)

newly incubating mosquitoes=Potentially dangerous mosquitoes*chance of biting a contagious human*BITES PER DAY PER MOSQUITO*"# OF MOSQUITOES ENTERING INCUBATION PER BITE"
Units: mosquitoes/day
# of mosquitoes per day that have bitten contagious person during the first 3 days and enters incubation. (27)

newly infectious mosquitoes=
Incubating mosquitoes/MOSQUIOT'S INCUBATION PERIOD
Units: mosquitoes/day
# of newly infectious mosquitoes per day. (28)

newly sick humans=Contagious humans/HUMAN CONTAGIOUS PERIOD
Units: humans/day
# of humans that become sick per day. (29)

Potentially dangerous mosquitoes= INTEG (mosquitoes hatch rate-newly incubating mosquitoes-safe mosquitoes,0)
Units: mosquitoes
# of potentially dangerous mosquitoes in the area. (30)

safe mosquitoes= Potentially dangerous mosquitoes/DANGEROUS PERIOD
Units: mosquitoes/day
# of mosquitoes that are safe. They have not bitten a contagious person. (31)

Sick humans= INTEG (+newly sick humans-death rate for humans-newly immunized humans,0)
Units: humans
Current # of sick humans in the city. (32)

total population=Contagious humans+Immune humans+Incubating humans+Sick humans+Vulnerable humans
Units: humans
Current total city's population. (33)

Vulnerable humans= INTEG (-newly incubating humans,19910)
Units: humans
# of humans in city that are vulnerable to disease. (34)

III. Model Behaviour

A. Impact of "chance of biting contagious human"

Figure 2 presents a Change of total population of humans, contagious humans, and chance of biting a contagious human.

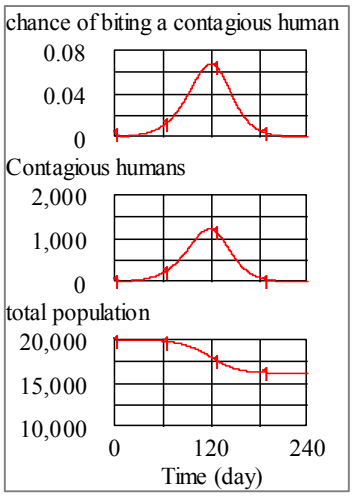

Figure 2 Change of total population of humans, contagious humans, and chance of biting a contagious humans (Source: Authors' work)

Connection between human sector and mosquito sector is "chance of biting contagious human". First there are only 100 sick humans. Compared to 20,000 people that live in the city, 100 sick people is very small number and chance for mosquito to bite sick human is very small. (For few days it even decreases because some of those sick humans died or became immune and the disease is not yet widely spread.) Therefore, yellow fever spreads very slowly for the first 30 days. But, still few mosquitoes succeed to bite sick humans. After 12 days that mosquitoes become Infectious and they succeed to bite healthy humans that becomes contagious and then sick. Positive feedback loop that consists on number of contagious people and infectious mosquitoes increase number of sick people in the city.

The number of sick humans, contagious humans and infectious mosquitoes is rising exponentially. But, not every human that has yellow fever die. Only 20% of humans die and 80% survive and become immune. As many humans get sick, stock of Vulnerable humans decreases. Therefore, after the period of 120 days, the chance for biting vulnerable human (which is ratio of vulnerable humans to total population) decreases. Fewer humans get sick and chance of biting a contagious human also decreases.

B. Changes in human population

Figure 3 presents the change of total population of humans, population of vulnerable humans, death rate for humans, and number of immune humans. In the same time number of immune human increases. The disease theoretically disappears from the city when everyone in the city got sick and either died or became immune. This is what happens at the end of simulation. Chance for sick person to die is 20%, and to get immune is 80%. Therefore, after the epidemic 4,000 people died and 16,000 survived. number of immune people is equal to the total population at the end of epidemic and vulnerable humans do not exist in the city any more (stock approaches to zero).

Number of immune humans, number of vulnerable humans, sick humans and total population exhibit S-shaped growth. Equilibrium value for immune humans is 16,000 because there are at the beginning 20,000 humans in the city that all become sick and the chance to become immune is 80%. Therefore, equilibrium value for total population is also 16,000. Equilibrium value for vulnerable humans is 0 because everybody in the city will eventually get sick and model does not include birth rate in the city because it's purpose is only short term analysis. Equilibrium value for sick humans is 4,000 because chance to become sick is 20%.

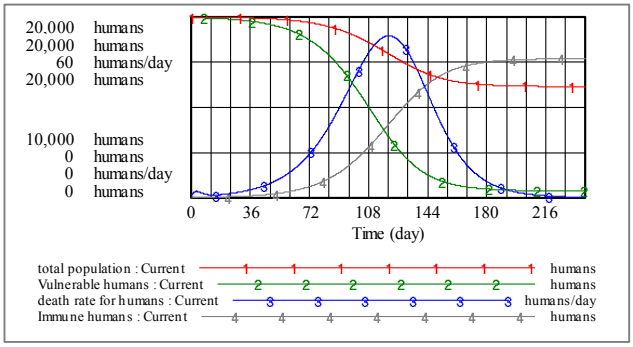

Figure 3 Change of total population of humans, population of vulnerable humans, death rate for humans, and number of immune humans (Source: Authors' work)

For the first 120 days Vulnerable humans and Immune humans exhibit either exponential growth or exponential decay because their net flows are increasing. Inflection point is at the 120th simulation day because net flows reach their maximum values and start to decrease. After that time stocks exhibit either asymptotic growth or asymptotic decay. I shall explain S-shaped decay of stock of vulnerable humans.

Figure 4 presents the change of number of incubating human, infectious mosquitoes, and chance of biting vulnerable human. Stocks and flows in the mosquito sector depend on the spread of the yellow fever in the city.

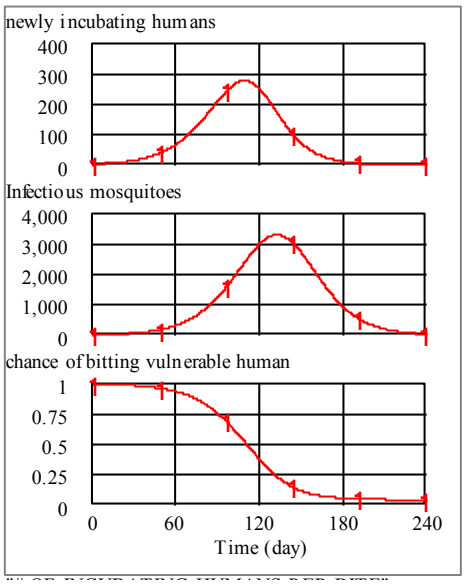

Figure 4 Change of number of incubating human, infectious mosquitoes, and chance of biting vulnerable human (Source: Authors' work)

Net flow into stock of vulnerable humans is equal to number of newly incubating humans. It depends on number of infectious mosquitoes and chance for biting vulnerable humans. As number of infectious mosquito's increase, chance of biting vulnerable human decreases because number of vulnerable human decreases. But, stock of vulnerable humans is limited and soon chance for biting vulnerable human gets smaller than 50%. This is about 120th simulation day which is inflection point for all stocks that exhibit S-shaped growth. As more and more people get sick, number of vulnerable humans decreases and chance for biting vulnerable human also decreases. In the same time number of contagious human decreases because there is less vulnerable humans to become contagious and there are many sick people that was already contagious. Therefore, number of infectious mosquito decreases.

Stock of vulnerable humans exhibits S-shaped growth because there are two feedback loops that drives its behavior. Critical variable is chance of biting contagious human. First, there is positive feedback loop that consists on number of contagious people and infectious mosquitoes. As more mosquitoes are infectious they bite healthier people that become contagious and chance of biting contagious human increases and even more mosquitoes become infectious that bite even more healthy people and so on.

On the other hand, there is negative feedback loop. As number of infectious mosquitoes increases more people get contagious and number of vulnerable humans decreases. Therefore, chance for mosquito to bite a contagious human decreases and number of infectious mosquitoes finally decreases.

C. Changes in mosquito population

Figure 5 presents the change of newly incubating mosquitoes, number of potentially dangerous mosquitoes, and chance of biting vulnerable human (Source: Authors' work).

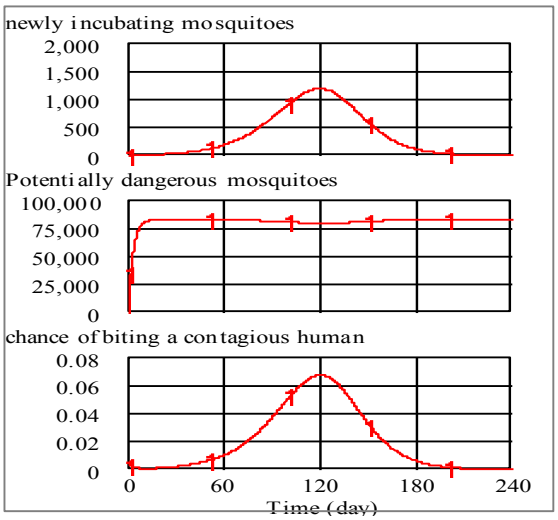

Figure 5 Change of newly incubating mosquitoes, number of potentially dangerous mosquitoes, and chance of biting vulnerable human (Source: Authors' work)

At first number of contagious humans is too small to affect to a great extent population of Potentially vulnerable mosquitoes. Therefore, after ten days population of Potentially vulnerable mosquitoes almost reaches its equilibrium value that would exist if there were no contagious humans in the city. But, because of positive feedback loop (more infectious mosquitoes – more contagious humans – more infectious mosquitoes) number of newly incubating mosquitoes is rising and it reaches maximum value of 1,194 newly incubating mosquitoes per day at 119th day of simulation.

Positive feedback loop also influences potentially vulnerable mosquitoes and safe mosquitoes. From 70th and 150th simulation day number of Potentially vulnerable mosquitoes and number of safe mosquitoes have decreased bellow their equilibrium values. This is the period when yellow fever peaks in the city and chance of biting contagious human is larger than 2%. After 150th simulation day chance of biting contagious human has decreased enough, and number of newly incubating mosquitoes is small enough for Potentially vulnerable mosquitoes and safe mosquitoes to reach their equilibrium values again.

Figure 6 presents the change of Incubating mosquitoes, infectious mosquitoes, and contagious humans. If there are more contagious humans in the city, chance for mosquito to become incubating is larger, and there will be also more infectious mosquitoes. number of contagious human peaks at 119th simulation day. Other stocks lag behind and

number of incubating mosquito peaks at 130th day, and number of infectious mosquitoes peaks few days after.

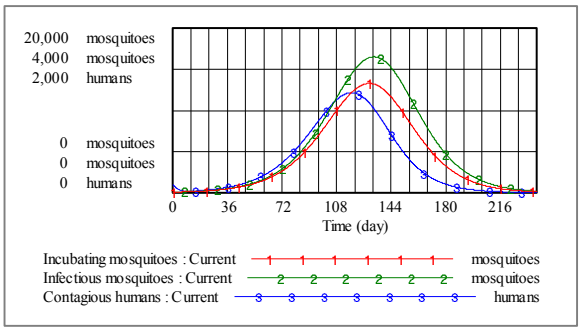

Figure 6 Change of Incubating mosquitoes, infectious mosquitoes, and contagious humans (Source: Authors' work)

IV. USAGE OF THE MODEL FOR TEACHING HEALTH CARE MANAGEMENT

Software Vensim allows conversion of the model to the game with the usage of sliders and output windows. Figure 7 presents the yellow fever game interface. Students can control size of the initial mosquitoes' population, number of bites per day per mosquito, and mosquitoes hatch fraction. The change of these values reflects the decisions related to mosquitoes' population that is significantly influencing yellow fever spreading. Size of the mosquito population is indicating the health care management actions before the disease spreads. On the other hand, sliders that can used for changes of bites per day per mosquito and mosquitoes hatch fraction reflect the actions that are done after the disease has already started to spread.

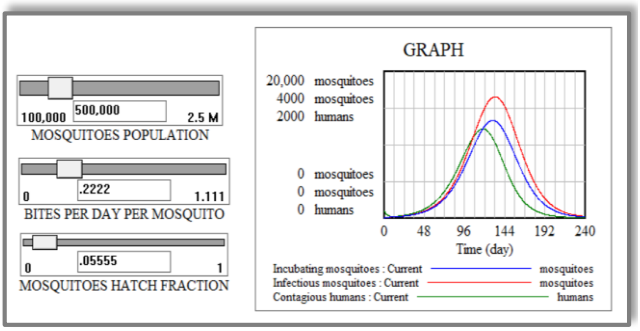

Figure 7 Yellow fever model interface (Source: Authors)

Model is used for teaching health care management at the Faculty for Dental Medicine & Health, University of Osijek. Model structure is presented to students, and game dashboard is discussed, which allows students to make experiments with the model. Before students play the game, the experiments with the model elaborated in this paper are presented to students. Graphic user interface of the game, as well as several simulation runs are presented, and students are encouraged to experiment with different values of sliders (Figure 7). Feedback from the students is positive, indicating that experimenting with the model allows more in-depth understanding of disease spreading. Experiment that is conducted using the model is presented in the following text, with the elaboration that is also discussed with the students. However, feedback from the students is not collected in formalized manner, which represents the limitation of the work.

V. CONCLUSION

Simulation games has become one of most used tools for enhancing teaching effectiveness in different fields of management, one of them being health care management. In this paper, we focus to teaching health care management using the simulation game developed with system dynamics approach. Our work has two contributions. First, we provide in-depth presentation of the yellow fever system dynamics model developed by the authors, based on the Goodman model [12], which consist of three elements: model description, model equations, and model behavior. Second, we propose the usage of the model as a simulation game for the purpose of teaching health care management. Future research directions should be oriented towards the testing of the model usage in comparison with traditional ex-cathedra teaching in order to assess the potential positive impact of simulation game to students' satisfaction and learning outcomes.

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Adoption of BPM Systems for Process Design in a Higher Education Institution

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***Abstract* - The objective of the paper is to present a case study about innovations of business processes related to bachelors' and masters' theses on the Faculty of Electrical Engineering of University Sarajevo by applying concepts of business process management (BPM) on those business processes. Theoretical context of the paper is created by presenting BPM concepts. Then, these concepts where applied on the case study of business processes of Faculty. Those processes are led through first phase of BPM lifecycle. In the phase of process design, current processes are analyzed, problems are recognized, and the new processes are proposed. Innovations of Faculty's information system are proposed and described.**

Keywords - business process management; higher education, BPM life cycle; data model

I. INTRODUCTION

Although a young educational institution, comparing to other similar faculties around Europe, Faculty of Electrical Engineering Sarajevo represents an institution of strategical importance for Bosnia and Herzegovina. For few decades, this faculty has been the center of scientific-research work in the fields of automation and control, electronics, power systems, telecommunication, and computing and information technologies. It has also been the key generator of human resources who represent the best experts in the above-mentioned fields. Besides being a leader in education and scientific-research work in Bosnia and Herzegovina, Faculty of Electrical Engineering is recognizable today by the continuous reform of all business processes that take place within this institution: from the enrolment process and holding admission tests, different methods of teaching, to assessment. Compared to other organizational units of the University of Sarajevo, this faculty has gone the furthest in the automation of business processes with a thorough reengineering and business process management (BPM) in general. However, the cyclicity of BPM guarantees a continuous analysis of business processes and the activities on their improvement as well [1]. Evidently, lots of business processes on the faculty contain small problems, which is a space for improvement.

The aim of this work is to apply the BPM concepts on business processes related to bachelor's and master's theses at the Faculty of Electrical Engineering. Those processes include the topic proposal for bachelor's and master's theses, the selection of topics and advisors by the students, forming a thesis committee, then writing of the thesis and consultations, and finally submission, defending and archiving of theses. The real aim of this work is to analyze the outlined processes, spots the problems and propose the innovations of these processes.

To meet the aim, this work uses the BPM processes with the key words from this field [2] [3]: process, model and process instance, BPM, BPM systems, standards and languages. A special attention is drawn to the first phase of BPM life cycle [5] [6] [7] – the model of current processes is created and problems in current processes are noticed (Figure 1). Then, after analysis, it is created new improved model. Based on the model, some innovations in the information systems of the faculty are proposed, and they are described by functional and non-functional requirements, roles within the system, and the data model.

II. THEORETICAL CONTEXT: BUSINESS PROCESS MANAGEMENT

Business process management systems, as a special type of information systems, becoming more and more present in today organizations all over the world [8] [9] [10]. They are an unavoidable part of all transaction and operative-managerial activities of these organizations. In narrow terms, looking at business management systems, as specialized systems intended only for business management systems life cycle support, then it is possible to quantify the importance of these systems. According to the research by WinterGreen Research Inc., the organizations spent $3.4 billion on BPMs in 2014, and the projection is that the value of BPM systems will reach $10 billion in 2020 [11]. However, if BPM systems are observed in broader sense, as a paradigm of information systems development, like a set of principles, concepts, and standards, then the importance of BPMs is even higher, since almost each information system contains elements of BPM systems to a lesser or greater extent. Having recognized such importance of BPM systems, there is a bit surprisingly limited set of scientific literature

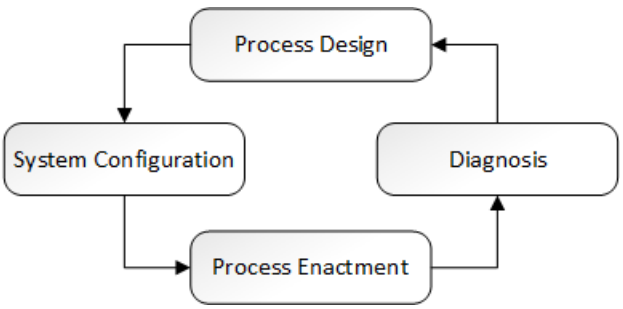

Figure 1. BPM Life Cycle [7]

related to these systems. Their presence is superficial in IT studies curricula and generally neglected within global academic community. Very rare are cases of adapting BPM methodologies to manage business processes for higher educational institutions. Solution should be BPM knowledge transfer with best practices from the enterprises and managing business processes like enterprises do. BPM life cycle has been formulated for the first time by professor Van Der Aalst [1], and such BPM life cycle refers to a management of a single business process and describes the four phases that each business process should go through [12].

A. Process Design

In the phase of the design, an analysis of current process is being performed and model of the existing process is presented on Fig. 2. using UML notation [13]. A series of research is performed such as document analysis, polls and interviews with the active participants of the process, and the process instances monitoring. The results of research are recapitulated in the description of existing process model, and that is formalized by UML notation. Such process model is a basis for the discussion with the active participants, trying to notice problems and domains for optimization and improvement. The modified business process model eliminates the extra resources or adds the new ones, removes or adds the activities, changes the order of activity performance etc. Such model needs to be validated, i.e. to confirm that it will really contribute a better business goals achievement, with the increased efficiency. Some of the approaches include the discussion of active participants about the new model, the development of solution prototype, and the simulation of process through the development of few instances of the process. It is possible that a new model is changed for a few times during this phase since the intention is to improve it incrementally [8].

B. System Configuration

When manual processes or processes with human interaction are implemented, it includes operational rules modification, development of new procedures and creation of new regulations that describe how a business process should be performed [2] [3]. It is necessary to propose the alternatives for the choice of the platform where the process will be implemented, to evaluate each alternative, and choose the best solution. Then it is necessary to perform the implementation itself, according to one of the software development methods, which includes the defining of software architecture, interface, program code writing, and database configuration. After the process is implemented, developed solution should be tested. Different techniques of validation and verification with a special focus on acceptability tests are used for the purposes of quality insurance. The integration and performance tests are important as well, since the newly created solution integrates into the existing technological and organizational environment [5].

C. Process Enactment

In this phase, BPM monitors the instance implementation, in a way that it creates records about each instance implementation. The records contain important data about the implementation – the events which initiated the activities, entering and leaving activities, etc. Those records are analyzed within BPM, and according to the data from the records, the information about the efficacy of the implementation of process instances is measured in relation to the expectations that have been set and in relation to the model [1] [3] [5]. The aim of BPM in this phase is to ensure as small deviation from the process instance compared to process model as possible.

D. Diagnosis

In this phase BPM assesses the processing model in relation to a business goal [1]. The main input parameters of this phase are the records on process implementation collected in the previous phase of BPM life cycle. These records undergo the mining process techniques which use the data mining algorithms to collect the appropriate and useful information on processing model. Process mining field is relatively young field related to BPM, and it is expected to take on a lot more significance, both in business organizations practice and within the academic community. After the diagnosis phase, the business process enters the design process phase again [2]. The conclusions obtained with process mining are used, together with the evaluated and modified attitudes and demands of an active participant, to create a new model of such process [9]. This is the best example of observing the cyclicity of BPM and its continuous incremental business processes improvement which differs it from Business Process Reengineering (BPR), and continuous observation of processing model and process instances, which makes it different from Workflow Management (WFM).

E. BPM Standards and Languages

BPM standards and languages are created to support the phases of a BPM life cycle [1] [2]. Although some theoreticians make a difference between BPM standards and BPM languages, in most of the academic literature these terms are used alternately, and both terms refer to a set of symbols and/or words (from natural languages) that are used in a precisely defined way to facilitate the communication among people, between a man and the technology or between different information technologies.

III. CASE STUDY

In the case study representing the basis of this work, most of elements from the first two phases are presented: process design and system configuration. The information about analyzed business process are collected through interviews and documents analysis, then the model of process is developed with an appropriate notation, and finally, the improvements are proposed together with the development of a new model for the analyzed process. The model draws a special attention on demands and expectations from technological solution. The alternatives in platform selection are concerned within the system configuration, and user interfaces are described with the system architecture. Finally, the prototype which follows the activities and the events of processing model are implemented. It serves as the basis for discussion and further model improvement.

To create a current business processes model, it is necessary to analyze legal acts and to interview the key active participants. However, when all activities at the Faculty are concerned, related to the bachelor and master theses, it is hard to talk only about one business process, even on the highest levels of abstraction. The activities are numerous, covering many active participants, happening in different time periods and in context of different events, so it is possible to identify several business processes. The first business process concerns the proposal of topics for the bachelor and master theses by the professor. Another process covers the choice of advisor and topic by the student, verification by the Faculty authorities and forming a committee for assessment of the thesis. Then goes the process of submission of preliminary version of thesis, the review and comments by advisor, corrections on the thesis done by the student, and submission of the final version of thesis. Next process describes verification of thesis, scheduling and defending thesis, and assessment by committee. The last is about legal procedures performed after thesis is defended, like archiving and certain legal acts. Analysis of these six business processes describes the current situation and potential problems.

A. The Description of a current process

After the student chooses topic and advisor, and after all legal procedures are completed, a new process starts, student writes the thesis, doing consultations with advisor. The Act on Higher Education and the Statue of the University guarantee the students their right to have help and consultations during making of the thesis. Rules of studying stipulate that student makes the thesis individually, and that advisor observing the students work, and help the student with advice and literature recommendations.

The key problem of this process is that students do not continuously work on the making of their thesis and they do not start on time. Besides that, the mentor neither can thoroughly observe the student's work nor to perform a quality review on the work due to the lack of time in September when most of the students decide to submit and defend their thesis. One of the main reasons of this problem is the fact that not even the advisor has precise instructions on how and how often to observe the student's work. And since there is no stimulation system for the advisor, the advisor neither initiates the consultations nor continuously observes the student's work. All these factors significantly change the process instances in relation to what was supposed to be performed in this process mode.

B. The Proposal of Modified Processes

To increase the student's motivation so they can start writing their theses on time and work on them continuously, and to increase motivation of advisors to regularly observe student's work and hold their consultations regularly, this business process should be innovated in the following way:

- Student should send progress report periodically.
- Generate deadlines at the beginning and use them strictly. Send alerts.

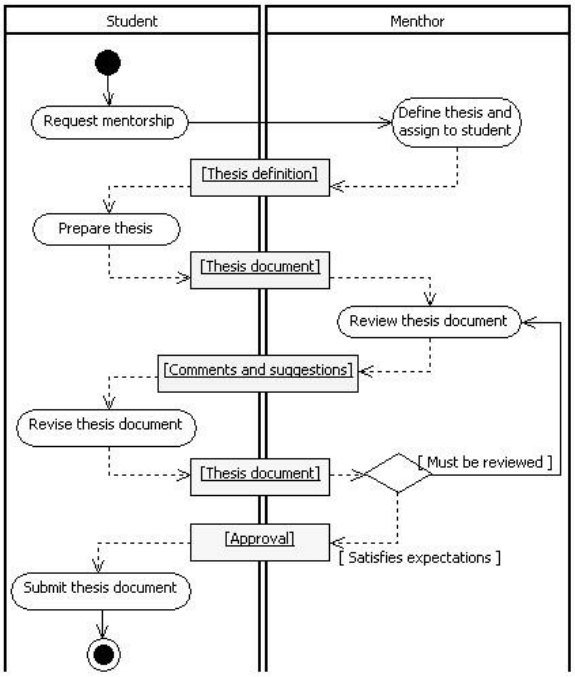

Figure 2. The diagram of the existing process activities on bachelor and master thesis and consultations

- If deadline for the activity is passed, then break it. If necessary, sanction persons responsible for not performing activity within the given time.
- Formalize interaction between the student and his mentor. Document work plan, questions, answers, comments, and reports produced during this interaction.

The implementation of these modifications will force students to continuously work on thesis, but also protect them from negligence of his mentor or other participants in these processes. Formalized interaction between student and his mentor will considerably affect the increase of the quality of theses. Through the analysis of the current processes it is possible to determine the following main actors in the system: Student (candidate), Mentor (advisor) and Faculty. Fig. 3 shows activity diagram of the modified process related to bachelor's and master's degree thesis preparation and defense. In the modified process, actors have some strict obligations and deadlines. There are activities related to sanctioning negligence. In fact, the diagram illustrates rules from formal system. Informally, professors talk with students before suggesting themes. Authors suggest to formally allow students to participate in formulating themes, but the current rules are not such.

Sub-activity related to work on thesis is presented on Fig. 4 and this is the most important change. Interaction between student and his mentor is precisely formalized. Student knows his obligations and mentor also knows his obligations. Each activity has some formal output – document. At start, student must prepare a work plan in coordination with his mentor and works on theoretical bases. All that time student interacts with mentor and this is recorded in the form of questions and answers. When all theoretical aspects are clear student applies it.

During this student also interacts with mentor and this interaction is recorded in the form of questions and answers. After that, student writes the document and interacts with his mentor. When the document structure is completed he sends it to the mentor for a review. Based on mentor's reviews, student makes document revisions until document is prepared for submission. All time, during work on thesis, student has formal obligation to periodically send progress reports to his mentor. Formalization of the interaction between the student and his mentor during work on thesis provides lot of information for evaluation report.

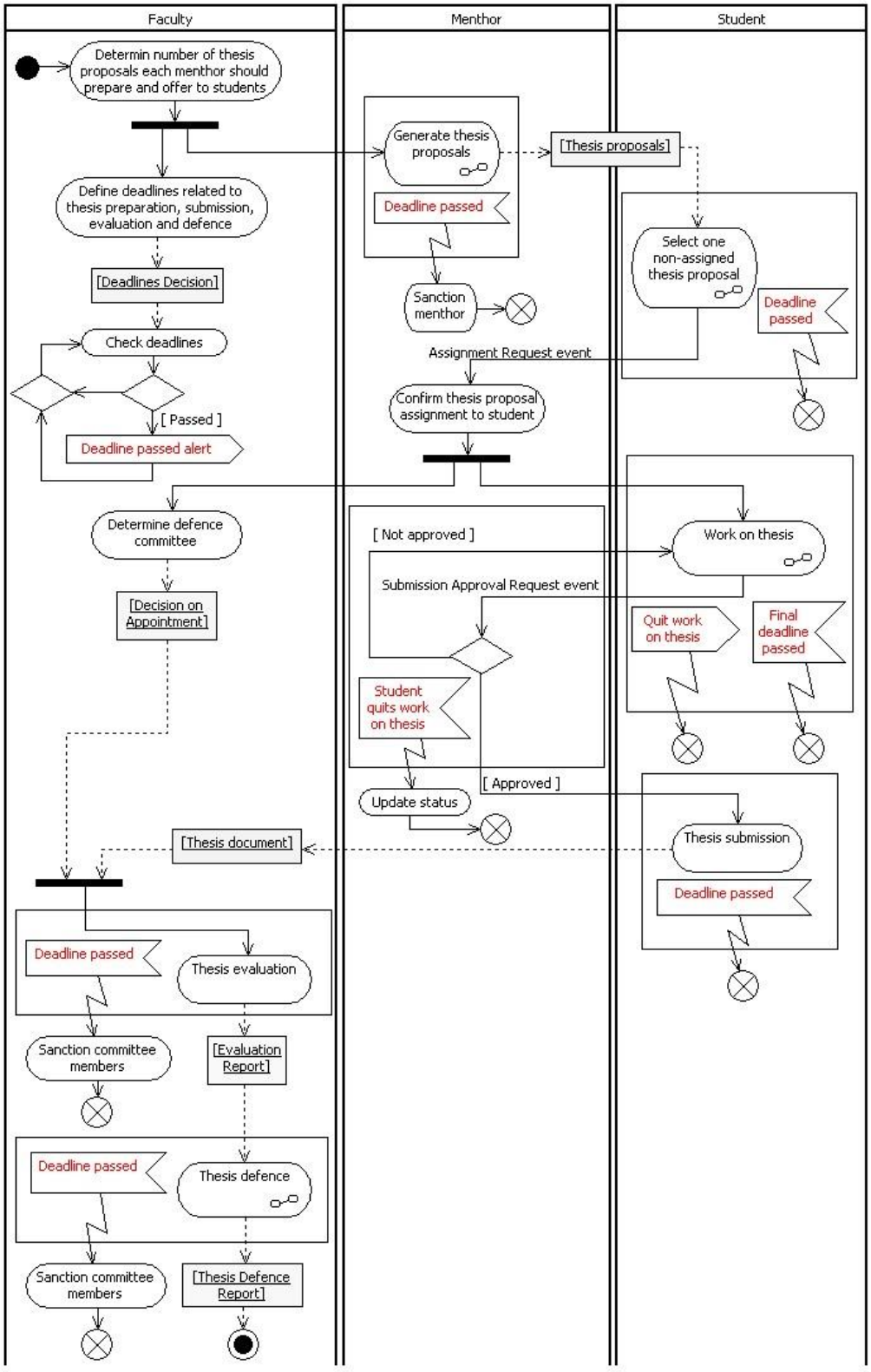

Figure 3. A diagram of the modified process related to bachelor's and master's degree thesis preparation and defense

IV. SYSTEM CONFIGURATION

The next phase in BPM life cycle go through is the system configuration. The basic purpose of this phase is to implement the modified processes described by the appropriate model in the phase of process design. The first step in this path is to define the platform where the innovations will be implemented. Then the software and hardware architecture of the system should be defined. After that, interfaces that a real information system should provide are created. Finally, the prototype of the solution, with the program code writing and database migration, is implemented. The management should analyze the prototype and decide about transition.

So, the first step within the configuration phase is to select the platform where the processes will be implemented. One part of the process implementation includes the establishment of new working procedures and the amendments in legal act regulating these processes. To implement the amendments and meet the functional and non-functional requirements set before the modification of the information system, it is necessary to develop a certain technological solution. The technological solution requires a platform to operate on, and, therefore, it is necessary to select a group of technologies that will enable the implementation of the process in the best way. There are three alternative platforms, and each will be evaluated with the emphasis on advantages and disadvantages.

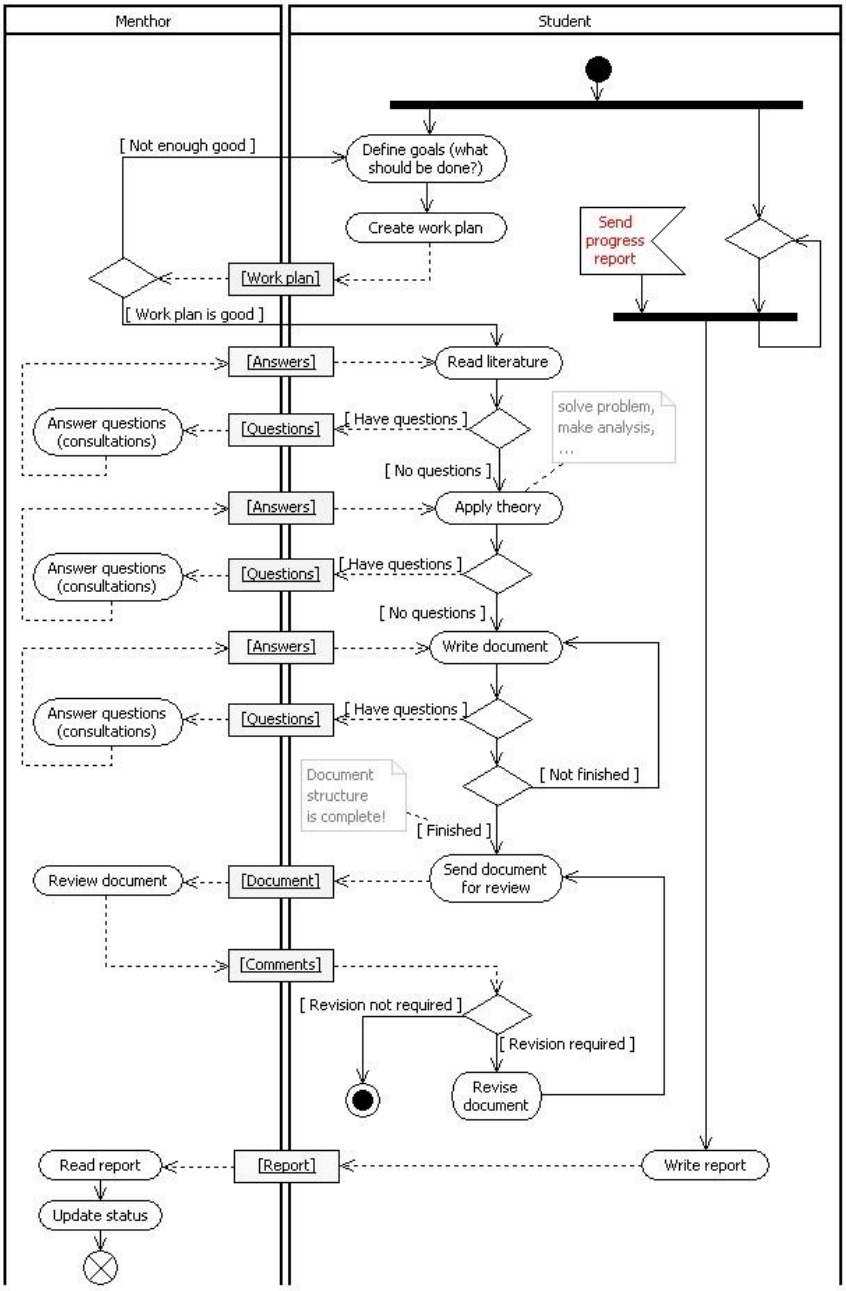

Figure 1. Activity diagram of interaction between mentor and student during work on thesis

A. Generic BPM System

The first alternative is the implementation of the process with commercial generic systems, which means the purchase and installation of the system on central server. The main advantage of such approach is a full sequence of BPM theoretical concepts and bringing recognition of all advantages of business: from an early recognition of process instances deviations from a model, over a process mining, to continuous business process improvement. An additional advantage of such approach is the implementation speed, and the fact that the experts in computing are not necessary, which can represent the key advantage of the choice of generic BPM systems when compared to other alternative platforms. The greatest disadvantage is the price and that is enough by itself to eliminate this alternative. Moreover, BPM systems are not so flexibile in process implementation as development of specific software solutions, and, therefore, some of the requests would only be partially implemented.

B. Individual Application

Faculty is a non-profit organization, and a commercial solution is hardly acceptable. There are debates in academic and business community comparing programming languages and environments, but without answer which is the best programming language and environment. It is chosen that application should be developed using Java programming language in Spring framework and use PostgreSQL as a database. Key advantage of an individual application is the flexibility in implementation of specified requests. There is also scalability and easy maintenance since all noticed problems are repaired in the process enactment phase with minimum interventions on the server. The biggest disadvantage is a very small possibility of integration with the existing system, which does not follow the architectural patterns that can enable an easy access to data and communication with other systems. Also, the implementation of this process is much slower than the generic BPM systems.

C. The Existing System Upgrade

The third way to implement the suggested innovations includes the upgrade of the existing systems. That would mean the modifications on the existing database, the modifications of the existing script files, and adding the new ones. Since the current web application system is written in PHP script language with MySQL database, those will be technologies for implementation of proposed innovations. HTML, CSS and JavaScript without any framework usage are used on client side. The obvious advantage of this approach is the integration of implemented innovations in the information system with an existing system. This approach will also open the possibility of the existing components intensive reuse. That should result in faster implementation. Besides integrability, speed, and the scope of implementation, this alternative inherits all the advantages of an individual web application: flexibility, scalability, simple correction and upgrade, and financial acceptability. The potential disadvantages of this solution are that existing information system has not been developed according to current generally accepted architectural patterns, and, therefore, this system is very complicated for maintenance and that activity is hard to be entrusted to someone who is not system implementer. Upgraded, such system will become even more complex and more complicated to maintain.

D. Platform Selection

When all advantages and disadvantages are taken into consideration, the upgrade of the existing system appears to be the best solution. Besides the disadvantages, the system upgrade is cheaper, more compatible, more efficient and faster solution compared to the other two.

V. CONCLUSION

Presented case study about innovations of business processes related to bachelors' and masters' theses shows power of BPM. This case study shows the advantages of BPM that can help in overall organizational improvements. At the beginning, model of the current business processes is created. Then, places for possible innovations where identified. Innovations proposals where refined through iterations and a new business processes model is proposed. After that, implementation aspects where discussed with the focus on platform selection and, based on the analysis, decision about the platform is proposed. Next step would be a proposal of the architecture and user's interfaces for the innovated system. That would enable creation of a prototype of the innovated information system.

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Teaching the methods of object detection by robot vision

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***Abstract* - This paper presents two methods of object recognition by a robot vision which is being used to educate the students. This includes the basic manipulation of objects using the robotic arm. It describes the procedures needed for setting up the appropriate environment for object recognition and for each method gives the basic examples of practical usage of robot vision. The part of robot vision is accomplished by using a USB camera and software named the Image Inspector for the image analysis, and the ViewFlex is used to interconnect the output data from the Image Inspector and robotic arm. The robotic arm used in the described methods is SCORBOT ER-4U, which is a didactic manipulator. The first presented method uses the blob analysis where the size of the blob conditions object detection and the second uses the pattern matching. The students should be aware of a core problem, which is the relationship between the real three-dimensional space and taken image of an object in the reduced robot working area. The right approach and wide teaching of methods for the robot vision will surely increase a chance for rapid improvement of the existing technology.**

Keywords - robot vision; image analysis; Scorbot; Scorbase; ViewFlex; blob, pattern; Matrox Inspector; teaching; robotic arm; object recognition

I. INTRODUCTION

The modern industry has been based for a long time on robotic arms that have carried out various physical tasks, welding of materials as well as many repetitions of automated movements in the unfavorable human environment. There was a need for developing smart robots, robots with autonomous decision-making, not just in industry, but in everyday life as well. To make the robot smart, it should have information about its environment. As for a man – a sight, as well as for robots – the robot vision gives much more information than a narrowly specialized sensor. There must be a section dedicated to the object recognition that requires certain intelligence, so we can say that the robot vision is closely related to artificial intelligence.

The robot vision significantly increases the range of applications of robots themselves, so the teaching of it should be introduced into the education. Students of technical courses should be familiar with the existing basic methods of robot vision by completing formal education for the further development of ideas and applications [1, 2].

Practical application of the robot vision has been achieved by connecting to the Intelitek system, which includes a robotic arm, the conveyors, and sensors. Students need to know how to calibrate a robotic arm, set the required video camera settings, arrange the workplace layout, including appropriate lighting, orient objects properly, and write optimized programs which use robot vision to manage a robotic arm. Equally important are the guidelines regarding the security of the one who manages the system.

A recommended way to start teaching is the demonstration in order to stimulate further interest and motivation. It should strive that students work more independently on systems because, like that, they learn the most [3]. To prevent accidents and destruction of equipment, students should be prepared to work in a specific environment by combining theoretical teaching and demonstration. The robot vision teaching takes place when students know how to handle the basic robotic system. Two methods of objects recognition by robot vision have been chosen. The first method involves object recognition by using patterns, and the other by using blobs.

II. PREPARATIONS AND ADJUSTMENTS OF THE SYSTEM

For teaching are used: the video camera system with the software for the image analysis (Image Processing Tool) connected with the system of robotic arms manufactured by Intelitek – Scorbot ER-4U with the associated controller, teach pendant, the presence sensors, and peripheral equipment, including a linear conveyor belt and a rotary table. The Intelitek controller can manage up to 8 axes, that is, 6 axes for the robotic arm, one for managing conveyor belt and one for rotary table. From the 6 axes intended for the robotic arm, Scorobot has five rotating axes and a gripper.

Scorbot is mostly used for teaching, but laboratory applications are also possible. It contains speed control mechanisms, self-damage control, axis and wrist control, and allows different options for receiving and manipulating objects in the Cartesian coordinate system, the origin of which is based on the bottom of a base of the robotic arm [4].

A. Connecting the systems

Before starting a robotic arm, it is necessary to wire the equipment. The robotic arm and the conveyor belt are connected to the controller on the RS232 sockets with serial

cables that serve to transmit information and power the servomotors. Two USB cables are also required. The first connects the controller and the computer, and the second connects the video camera and the computer.

When all devices in the system are properly connected, on the voltage is first connected a controller of a robotic arm, and then a computer with a connected video camera. The sequence needs to be respected so that the operating system on the computer can correctly recognize the controller connected to the USB. It is necessary to connect one device at the time to avoid human injuries or damages to the equipment or to reduce the possibility of system failure.

B. Launching applications on the computer

After launching the operating system, it is necessary to run the drivers on the computer. The computer is a central location for managing the robotic system. The robotic arm can be controlled directly by the program named Scorbase which also serves to execute program code and calibrate the robotic arm and peripheral devices. ViewFlex serves as a mediator between Matrox Inspector for image and Scorbase program analysis. Matrox Inspector is the most complex part of the system. It contains various filters to improve the image analysis using the required algorithm.

C. Adjusting the image settings

Adjusting autofocus and image resolution of video camera depends on various conditions such as camera distance from the object that is recorded, the size of the recorded object, the intensity of illumination, the level of details that are being observed, etc. Different models of video cameras have their own drivers which can adjust the image settings including resolution, flickering reduction, exposure control, white balance, picture quality, pixel depth and compression. When dealing with smaller objects, it is necessary to have higher image resolution and best possible illumination of the object to achieve the better results and avoid the graininess of the image. It is especially important to reduce the shadows of objects that occur because of object dimensions and the angle of illumination.

D. Calibration of the robotic arm

Regardless of whether it is a part of robot vision or not, the robotic arm needs to be calibrated before starting to work to reduce the errors. The robotic arm Scorbot independently performs a calibration that can be started using the manual teach pendant or Scorbase. The calibration checks the alignment of the servomotors using encoders and microswitches which signalize the end position of the robot movable part. In addition to the calibration of the robotic arm, it is also necessary to calibrate the peripheral devices connected to the controller in case they are used.

E. Synchronizing the video camera and the working area of the robotic arm

The image taken by video camera represents just a part of the working area of the robotic arm that has the shape of a deformed hemisphere. The synchronization of the image and Cartesian system of the robotic arm should be achieved. When it comes to the recognition of objects in the image at the specified location, the robot arm for that location must have assigned the real coordinates. In the process of synchronizing the 2D image and 3D space, one dimension (most often the height) must be manually determined [5]. When using the stereo video cameras, the height would be automatically adjusted. Synchronization should be done at the height at which the objects will be recognized.

On Figure 1 is a symbolic representation of the active area under the direct control of the robot vision in which the robot arm accepts the coordinates from the ViewFlex. The active area is just a part of the working area of robotic arm photographed by a video camera. Beyond it can be manipulated by a robotic arm only using Scorbase and not using ViewFlex. Figure 1 also shows the working points numbered 1 and 2. It is necessary to bring the top of the gripper of the robotic arm at point 1 and then 2, and store measured coordinates in the Cartesian coordinate system. To complete the calibration, in the image of the active area, using a computer mouse a line should be drawn from point 1 to point 2. The system then determines the rest of the coordinates of the active working area. ViewFlex now aligns the coordinates from the image with the actual coordinates of the Cartesian coordinate system of the Scorbot. The size of the area where the robot vision can be controlled using robotic arm depends also on the distance from which the image of an object is taken off.

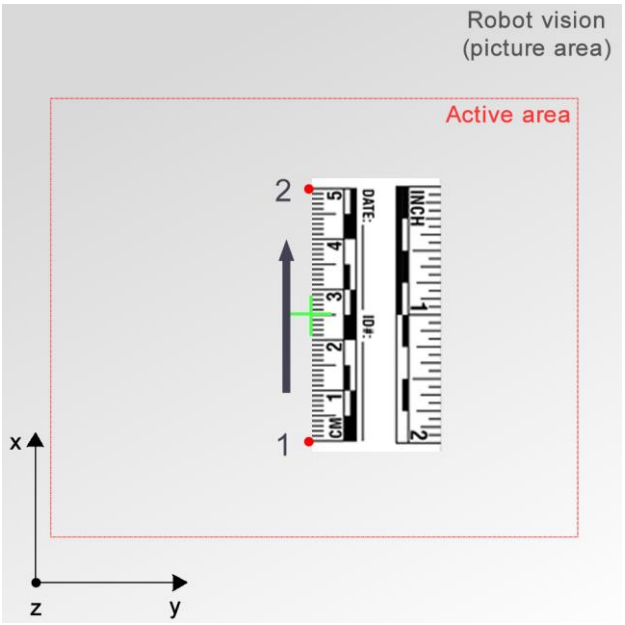

Figure 1. Symbolic representation of the active area

F. Creating models

In order the system could recognize objects by means of a robot vision, it is necessary to define patterns or settings based on which object selection will be made. The

two basic methods of object recognition are based on blobs and patterns recognition.

G. Commands for recognition the objects in Scorbase

The commands for practical application of robot vision by using ViewFlex are Snap, FindObject, FindBlobs, SetPosition, ExternalFunction, GetValue, and ChangeTable.

III. BLOB RECOGNITION

The term BLOB (Binary Large OBject) in this case is associated with the image, although can be associated with the database. The blob can be mathematically represented by the Gaussian distribution function (1). An example of a filter by which the blob in the image can be recognized is LoG (Laplace of Gaussian) (2) [6].

$$G(x,y) = -e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (1)$$

$$\nabla^2 G(x,y) = -[\frac{(x^2+y^2)-\sigma^2}{\sigma^4}]e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (2)$$

When the object in the image must be recognized, it should be removed from the background and detect by its edges. Edge detection is achieved by filtration.
Figure 2a) shows a blob as part of an input image, and figure 2 b) shows detected edges of a blob. Figure 2 c) and 2 d) are Gaussian function and a LoG used for edge detection. LoG increases the probability of blob detection. In practice, the Laplace Gaussian function represents masking of the image [7].

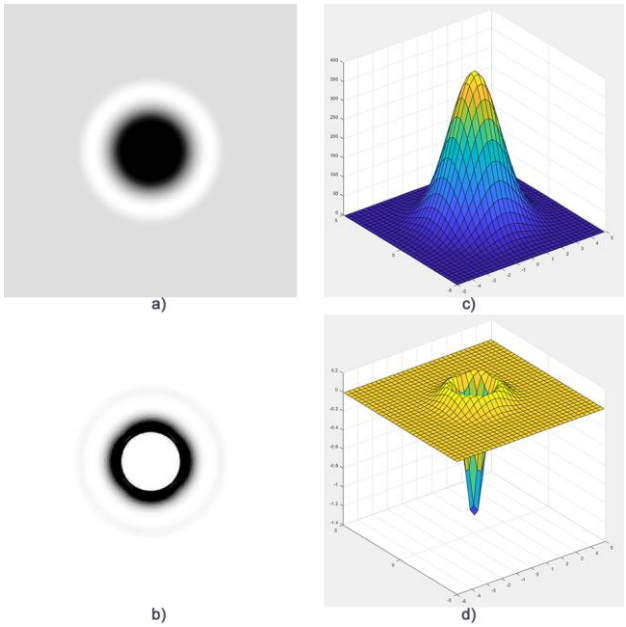

Figure 2. a) The input image, b) Image with detected borders, c) Gaussian function, d) Laplacian of Gaussian

A. Adjustment of blob settings

Blob detection settings are set up in the Maxtor Inspector image analysis program [8]. First, an image of the active area should be taken off and then the blob settings should be defined. The settings that are adjusting are referred to whether the blobs will be black or white, whether they can touch each other, whether an advanced filter is used when recognizing, the surface they are occupying, etc. An example of blob settings adjustment is shown in Figure 3.

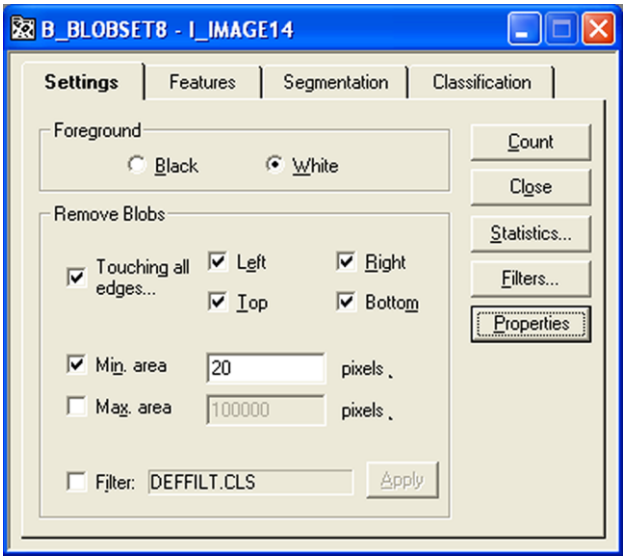

Figure 3. An example of blob settings

B. Example of program code

There should exist a stored blob model to perform a series of commands for object recognition in the active area in front of the video camera. Obtaining the coordinates of the objects in Scorbase is achieved by the following commands:

```
Snap by Camera <cam_number>
Find Blob ('<blob_name>') -> <variable>
Set Position <pos_name> from Results Table (Row=1,
Z=<height>)
```

The first line of code selects the video camera for taking off the image. Since it is possible to connect more video cameras to the system, the image is taken off from a specific video camera by entering the camera number under *<cam_number>*. The second line of code sends the name of the pre-saved model of the blob that should be recognized in the image as well as the name of the variable in which the number of recognized objects will be stored. If zero is saved in the *<variable>*, there is no blob recognized. In case the blob is recognized, ViewFlex stores *x* and *y* coordinates of the blob in a separate table sorted by the lines corresponding to the number of recognized blobs in the image. The next command stores the coordinates *x* and *y* from the first row of the table under the working point named *<pos_name>*. Only the coordinate *z* which represents the height of the working point is entered manually.

A demonstrative example of program code allows a further object manipulation recognized with blob detection. The working point by which the robot arm can reach the object directly or based on a relative shift has been saved in the working area of the robotic arm.

C. Practical examples of blob recognition usage

Blob recognition and blob detection are the cornerstones for pattern recognition. Blob recognition has wide application in image analysis such as:

1. applications in biomedical image analysis such as 2D and 3D nuclei detection, lesion detection, etc.;
2. general image matching etc.

IV. PATTERN RECOGNITION

A pattern is an abstract object representing a group of measurements which describe a physical object. They are classified in the groups by recognition of their common properties. The biggest problem is to extract patterns from their background. Other problems are poor lighting, the position of the observed object, interference in the video camera, etc. Sample recognition implies automatic recognition of shapes, patterns and patterns classifications in the data set, and the image is achieved by filtering.

Pattern recognition procedures:

1. retrieving data (measuring physical variables in defined conditions such as resolution);
2. pre-processing (removal of background noise, separation of possible patterns from the background);
3. advanced processing (identification of patterns based on common properties);
4. grouping (patterns with common properties); and
5. post-processing (reliability assessment of grouping decision).

A. Creating patterns for robot vision

It is necessary to take off the image of working area with an object whose pattern is wanted to be made. The narrow area around that reference object in the image called ROI (Region of Interest) should be marked manually. It is all needed for creating of the model in which settings should be specified by the conditions of recognition among which are: the angle of possible rotation of the pattern, the number of patterns for recognition, recognized image area, etc. [9]. An example of pattern settings is shown in Figure 4.

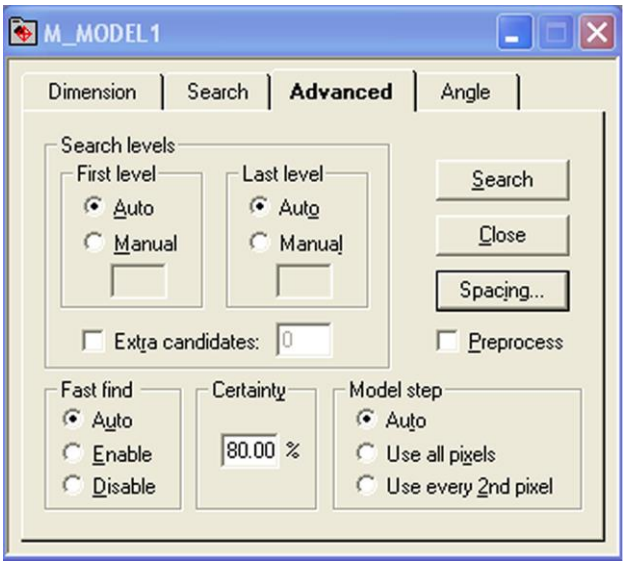

Figure 4. An example of pattern settings

B. Example of program code

Object recognition patterns requests stored model of the pattern. The procedure corresponds to the one in blob recognition. The difference is in the second command invoking the model name saved in the Maxtor Inspector. The commands for retrieving object coordinates by Scorbase are:

```
Snap by Camera <cam_number>
Find Objects ('<model_name>') -> <variable>
Set Position <pos_name> from Results Table (Row=1,
Z=<height>)
```

C. Practical examples of the pattern recognition usage

Recognition of the patterns is used in various fields, from medicine to cosmology. The most common examples of the patterns recognition in the industry are:

1. product quality control (pattern recognition can be used to separate correct and rejected products);
2. classification of rocks in geology (surface material analysis) [10];
3. sorting the letters by ZIP code OCR (Optical Character Recognition);
4. general presence detection and the position of the object; and
5. aligning objects to a reference point or line, etc.

V. ANALYSIS OF RESULTS OF THE ROBOT VISION

Maxtor Inspector conducts an analysis of the images and sends the data to Scorbase. If the required blob or pattern is found, the *x* and *y* coordinates are entered in the special table. They must match to the coordinate system of the robotic arm. In addition to the coordinates, the probability of similar defined pattern or the requested blob and the angle of the recognized object in the relation to the reference are also described. Each value in the table can be retrieved and changed by the Scorbase commands GetValue, or ChangeTable.

The figure 5 a) shows the part of the working area of robotic arm captured by a video camera and 5 b) shows image analysis in the Matrox Inspector using blobs and its histogram on 5 c). There are objects on the conveyor belt that should be recognized. The cube in Figure 5 a) corresponds to the square on Figure 5 b) that matches the higher values in the histogram on the Figure 5 c). Vertical parts of the histogram represent the edges of objects, and horizontal represent a background or object itself. It has been clearly seen that edges are the key component while separating objects from the background [11, 12]. The oblique lines of the histogram represent the gradient change from light to dark and vice versa respectively represent the shadow. A part with smaller spikes represents noise.

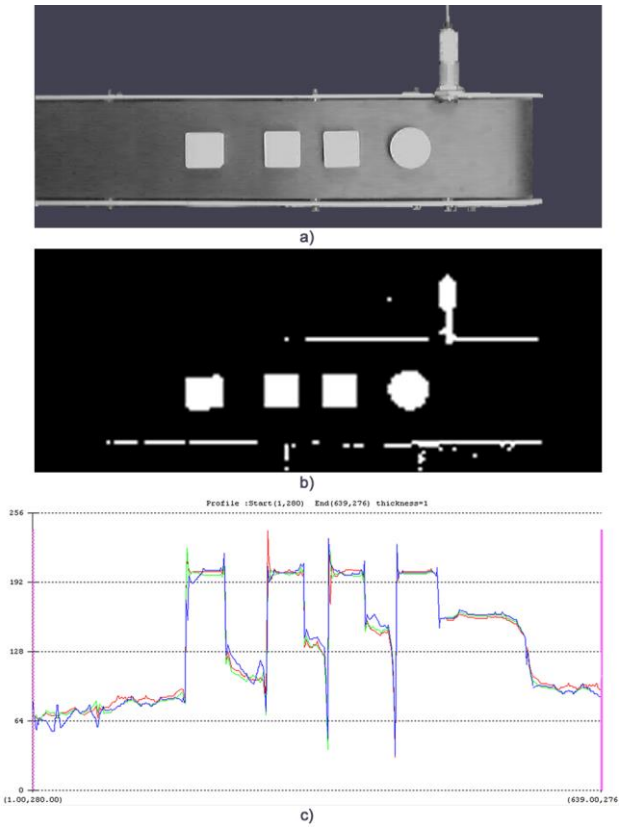

Figure 5. a) Image of working area, b) Blob detection, c) Histogram

The Figure 5 b) which represents the blob analysis, shows that the Matrox Inspector apart from desirable objects has recognized also the unwanted blobs such as the carriers of the conveyor belt and the presence sensor. Similar objects should be considered when defining blob settings. The unwanted recognition should be eliminated by configuring the suitable blob settings. Robot vision can be used to recognize the unwanted and unforeseen changes in the active area which includes a human entry in the robotic workspace where he should not be.

VI. EXAMPLES OF TASKS FOR STUDENTS

After the demonstration of making models for patterns and blobs, and examples of application program code, students with the acquired knowledge should be able to solve variations of the following tasks using robot vision.

A. Recognition of objects by pattern recognition

On the linear conveyor belt 0.12 m of height, there are cubes 0.04 m long and 0.04 m in diameter randomly aligned in the center of the bar. At the end of the bar at a sufficient distance from the edge is placed the presence sensor at the height of the mentioned objects. The sensor gives the output voltage 10 V when it detects an object on coordinates (*x*, *y*, *z*) and is connected to a digital input of 2 controllers. After the detector detects the object, with the robot vision that looks at the area in front of the sensor it should recognize the object. It is necessary to make suitable models and write a program by which the robot arm will sort the cubes in a box A whose center is on the coordinates (*x*, *y*, *z*) and on the spheres in the box B with the center on the coordinates (*x*, *y*, *z*). The boxes are of the equal lengths of 0.15 m.

B. Recognition of objects by blob recognition

In the active area covered with robot vision, a dozen M12 bolts were randomly thrown. It is necessary to write a program that will use the blobs to pick up objects and place them in the center box on the coordinates (*x*, *y*, *z*) and all sites are 0.2 m long.

VII. CONCLUSION

The paper describes a process that involves the preparation of workspace and robotic arm, and settings of robot vision for object recognition in the working area of the Scorbot robotic arm. The blob is defined as the basis for object recognition. There are several problems mentioned during working with the system as well as solutions that minimize or eliminate these problems. Robot vision begins by connecting a two-dimensional image and a three-dimensional Cartesian coordinate system of the robotic arm and ends with data of recognized objects. Examples of tasks are related to the application of robot vision with sorting items. The students are taught in a school example of a complex robotic cell and thus encouraged to multidisciplinarity [13]. Theoretical classes are complemented by demonstrations and, finally, by the practical work of students. The acquired knowledge is applicable to other similar systems since the students were encouraged to develop a logical thinking.

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Using Unity to study properties of a two-dimensional ideal gas

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***Abstract* - Unity is a cross-platform game engine developed by Unity Technologies primarily used to develop 2D and 3D video games. Unity features a powerful physics engine and a GUI-based integrated development environment with support for scripting using C#. This way, game developers can easily create objects either by point-and-click operations or programmatically and assign physical properties (such as mass, initial position and velocity, and friction coefficient) to these objects, while the built-in physics engine takes care of the time evolution of the system. We believe that these features make Unity also suitable for various educational simulations and exercises. In this paper, we will use Unity and its physics engine to study properties of a two-dimensional ideal gas. In the Unity simulation, gas particles will be represented as discs with some physical properties and placed within a container. Unity's physics engine will be used to evolve the system in time, and the state of the system will be observed. Finally, we will provide an analysis of various scenarios and comparisons of observed system properties to the theoretical framework.**

Keywords - Unity game engine, physics engine, physics simulation, two-dimensional ideal gas

I. INTRODUCTION

Today's computer games are incredibly realistic due to powerful computers and sophisticated software used to create these games. The Unity game engine is one such software [1]. Its powerful physics engine is responsible for all calculations in the game regarding physics. Since Unity is a relatively simple, intuitive, user-friendly game engine to start with, we came to the idea of exploring the possibility of using Unity as a virtual physics laboratory in physics education. We expect that this approach might be interesting to some students and educators because it combines programming, virtual data acquisition, and subsequent data analysis.

In this paper, we present how we used Unity to study the following properties of a two-dimensional ideal gas: speed distributions, fluctuations in the number of gas particles, and equipartition of energy. These properties are probably presented in every book that discusses the kinetic theory of gases [2]. Properties like the evolution of the speed distribution are interesting enough to be studied using computer simulations even back in the '70s and '80s [3, 4]. In these computer simulations, particle trajectories are never actually calculated due to the lack of computer power. Two particles collide not because their trajectories cross but because they are randomly chosen from the set of all particles. However, in this work, we use the Unity physics engine, which calculates for us "behind the scene" the trajectories of all particles in the system, detects collisions, and works them out.

II. UNITY AS A VIRTUAL PHYSICS LABORATORY

The two-dimensional ideal gas is a problem that consists of a two-dimensional box and non-interacting gas particles (they do not attract or repel each other except when they collide, and in these collisions, momentum and energy are conserved).

This problem is easy to simulate in Unity because the Unity physics engine handles gas particles movement and collisions. One only needs to:

(a) create the container (a two-dimensional box in our case, though any other shape will do) and gas particles,
(b) set the initial state.

A. *Setting the scene: container and gas particles*

In Unity, objects are represented as images (e.g., png, gif, etc.) called sprites. For sprites to interact with each other, they have to be equipped with at least a collider object. For instance, the gas container can be created by joining four "wall" sprites equipped with the corresponding collider objects in a rectangle. More elegantly, an arbitrary container (e.g., ring) can be drawn in any image editing software (or even MS Word) with transparent areas set and imported in Unity, such as a png image. Unity can create and fit a (multi-polygon) collider to such images with transparent backgrounds.

In our simulation, we need only one container and this container can be manually created as described. However, we also need hundreds of gas particles and obviously, this calls for a programmatic approach. Luckily, Unity features a *Prefab* concept – a way to create an object with many features, and then bundle it as a single template object from which one can create new object instances. In our simulation, we represent gas particles as discs equipped with *Circle Collider 2D* and *RigidBody 2D* with a material friction set to 0 and bounciness set to 1. Hence, all gas particle collisions (either with particles or walls of the container) are elastic ("1 indicates a perfect bounce with no loss of energy" – Unity manual [1]). The single gas particle is created manually and stored as a *Prefab* in order to be

used as a template during runtime when gas particles are instantiated in the container at the beginning of the simulation.

B. Setting the initial state

Unity enables programming (scripting) in C# and Javascript. In this work, C# is used to programmatically instantiate gas particles (from the gas particle *Prefab*) and set their initial velocities and positions. In all simulations, particles are initially uniformly distributed within a container, while each gas particle is assigned the same speed in the direction chosen from the randomized set of uniformly distributed directions. Figure 1 shows an OO style pseudocode of the script used in this work. The script makes use of the *Start()* method to instantiate the objects and set the initial state, and the *LogVelocity()* method to periodically log the velocities of gas particles.

```
public class RunTimeCreator : MonoBehaviour {
  const int numParticles = 1000;
  GameObject[] gasParticles;
  void Start() {
    double scale = calcScale(numParticles);
    ScaleContainer(scale);
    SetCammeraZoom(scale);
    gasParticles = new GameObject[numParticles];
    Vector2[] velocities = RandomDirVectors(numParticles, 4.0f);
    Vector2[] positions = UniformPositions(numParticles, scale);
    for (i = 0; i < numParticles) {
      gasParticles[i] = InstantiateFromPrefab();
      gasParticles[i].setVelocity(velocities[i]);
      gasParticles[i].setPosition(positions[i]);
    }
    InvokeRepeating("LogVelocity", 0.0f, 5.0f);
  }
  private void LogVelocity() {
    static int i = 0;
    DumpVelocitiesToFile(gasParticles, "log" + i++);
  }
  private Vector2[] RandomDirVectors(int n, double vSize){
    Vector2[] vectors = new Vector[n];
    for (i = 0; i < numParticles; ++i) {
      vectors[i] = new Vector2(vSize * cos(2π/n*i),
                               vSize * sin(2π/n*i));
    }
    ShuffleArray(vectors) // Fisher-Yates algorithm
    return vectors;
  }
}
```

Figure 1. Setting the scene and initial state pseudocode

In general, to implement the desired behavior in Unity, a user has to extend the *MonoBehaviour* class – the base class from which every Unity script derives and overrides certain methods. The following methods are interesting in this context:

- *Start()* – called by Unity once on startup,
- *FixedUpdate()* – called by Unity in regular (fixed) time intervals (can run once, zero, or several times per frame).

FixedUpdate() is a part of the "physics cycle" in the execution order in Unity scripting, commonly used when one has to apply forces on rigid bodies [5]. To evolve in time the system with many particles of an ideal gas, it is not necessary to specify or calculate forces that are present in each collision. Hence, we do not use the *FixedUpdate()* method, and Unity progresses to the next part of the "physics cycle" called "*Internal physics update*" [5]. During this stage, the Unity physics engine evolves the system in time for one fixed time step. During this fixed time step, many collisions take place and the Unity physics engine handles all of them for us.

In the running Unity simulation, frame 0 corresponds to the initial state of our physical system. Figure 2 (left) shows the initial state for a container with 20 gas particles. It is apparent that particles are uniformly distributed within the container. The state at frame 100 is shown in Fig. 2 (right) where it is visible that particles have started to move in various directions. The size of the container equals 18.0×22.0 in Unity space units. This raises the following questions: How does Unity space units relate to the real-world units? To what real-world time does frame 100 correspond? In general, how does any Unity unit relate to the real-world unit?

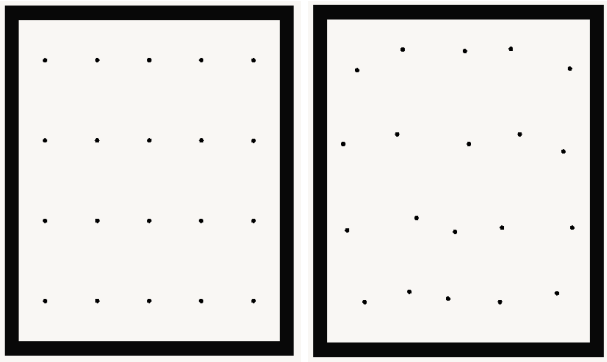

Figure 2. Container with 20 gas particles: initial state at frame 0 (left) and state at frame 100 (right)

C. Unity units vs. real-world units

One Unity space unit is a distance traveled by an object moving with the velocity of 1 Unity velocity unit for a time of 1 Unity time unit. If we choose 1 Unity velocity unit to correspond to 10^2 m/s and 1 Unity time unit to correspond to 10^{-11} s, then 1 Unity space unit corresponds to $10^2\ \mathrm{m/s} \cdot 10^{-11}\ \mathrm{s} = 10^{-9}\mathrm{m}$. Since we will not work with gravity or any other forces present in the analyzed physical system, we can choose for 1 Unity mass unit any real-world mass unit.

D. Some Unity physics engine fine-tuning

Unity exposes to users some of the physics engine parameters so users can optimize the physics engine according to their requirements. We have changed the default values for three parameters.

In our first simulations, we observed that particles with low speeds (less than 1 Unity velocity unit) stick to the walls instead of bouncing off the walls. This is probably a desirable property in games, but it is not in physics simulations. Luckily, Unity allows users to change this *Velocity Threshold* through GUI: *Edit → Project Setting → Physics 2D*. We set this value at 0.0001, which is the minimal value Unity allows for this property.

The physics engine is called at regular time intervals *Fixed Timestep* with the default value 0.02 (Unity time units). One can change this value through GUI: *Edit → Project Settings → Time*. In our simulations, we used a 10 times smaller value.

Physics engine handles collision detection between two objects with a collider. One of the parameters of the *Collider 2D* component is *Collision Detection*. We have changed the value of this parameter from *Discrete* to *Continuous* to prevent objects passing through each other

during an update. The drawback: additional computational demands on the physics engine.

III. RESULTS

To start the simulation, we needed some real-world data. We decided to work with neon gas because neon atoms are spherical and hence have no rotational degrees of freedom. Therefore, in our two-dimensional simulations, neon atoms have only two translational degrees of freedom. Van der Waals radius for a neon atom is 0.154 nm, and this value is used as the radius of the disk representing a neon atom in the Unity simulations. The mass of a neon atom is $3.35 \cdot 10^{-26}$ kg. The mass of an atom is not important in our simulations with only one type of atom. In simulations with several types of atoms, only the ratio of the masses of atoms is important, not the exact values.

In this work, we will perform three different simulations to study three different important properties of an ideal gas. In all three simulations, the state of the system (all particle velocities and positions) is saved into files in regular time intervals, and these data are analyzed using software for data analysis, in our case SageMath [6]. Notice that this procedure resembles real experiments: the experiment is performed, data are collected, and later these data are analyzed using the appropriate software.

A. *Speed distribution for a two-dimensional ideal gas*

One of the results of the kinetic theory of gases is the distribution of speeds in a two-dimensional ideal gas in an equilibrium named the Maxwell-Boltzmann distribution

$$f(v) = \frac{2v}{b^2} e^{-v^2/b^2}; \quad b^2 = \frac{2kT}{m}, \tag{1}$$

where $k = 1.38 \cdot 10^{-23}$ J/K is the Boltzmann constant, m is the mass of the gas particles, v is the speed of the gas particles, and T is the gas temperature. If the initial distribution of speeds is not Maxwell-Boltzmann, the system is not in equilibrium, but as time progresses, the system will reach equilibrium and the distribution of speeds will be Maxwell-Boltzmann.

To demonstrate the process of reaching equilibrium, we started our simulation with 500 gas particles uniformly distributed in the two-dimensional box with the concentration of $0.05\ 1/\text{Unity space units squared}$; each gas particle having the speed of 4 Unity velocity units in a random direction. As time progresses, the initial distribution of speeds widens due to collisions between gas particles. After 15 Unity time units, the peak around 4 Unity velocity units (400 m/s) is still present (Fig. 3), but after 25 Unity time units, the speed distribution is close to the Maxwell-Boltzmann distribution for two-dimensional gas with two translational degrees of freedom at the temperature T obtained using equipartition theorem:

$$2\frac{1}{2}kT = \frac{m\langle v^2 \rangle}{2} \tag{2}$$

B. *Fluctuations around average values for the system in equilibrium*

If we count the number of gas particles in one half of the two-dimensional box from the previous virtual experiment, we expect that number to be about half the number of all particles in the box with some fluctuations in time. Let us denote by N_+ the number of gas particles in one half of the box and by N_- in the other half. The total number of particles in the box N equals $N = N_+ + N_-$. Using the kinetic theory of gases, one can show that these (relative) fluctuations when the system is in equilibrium depend on the number of gas particles in the box [2]:

$$r = \frac{\sqrt{\langle (N_+ - \langle N_+ \rangle)^2 \rangle}}{\langle N_+ \rangle} = \frac{1}{\sqrt{N}} \tag{3}$$

We used Unity to check this result. The size of the two-dimensional box is the same in all simulations. At the beginning of each simulation, particles are uniformly distributed in the two-dimensional box with each gas particle having the speed of 4 Unity velocity units in

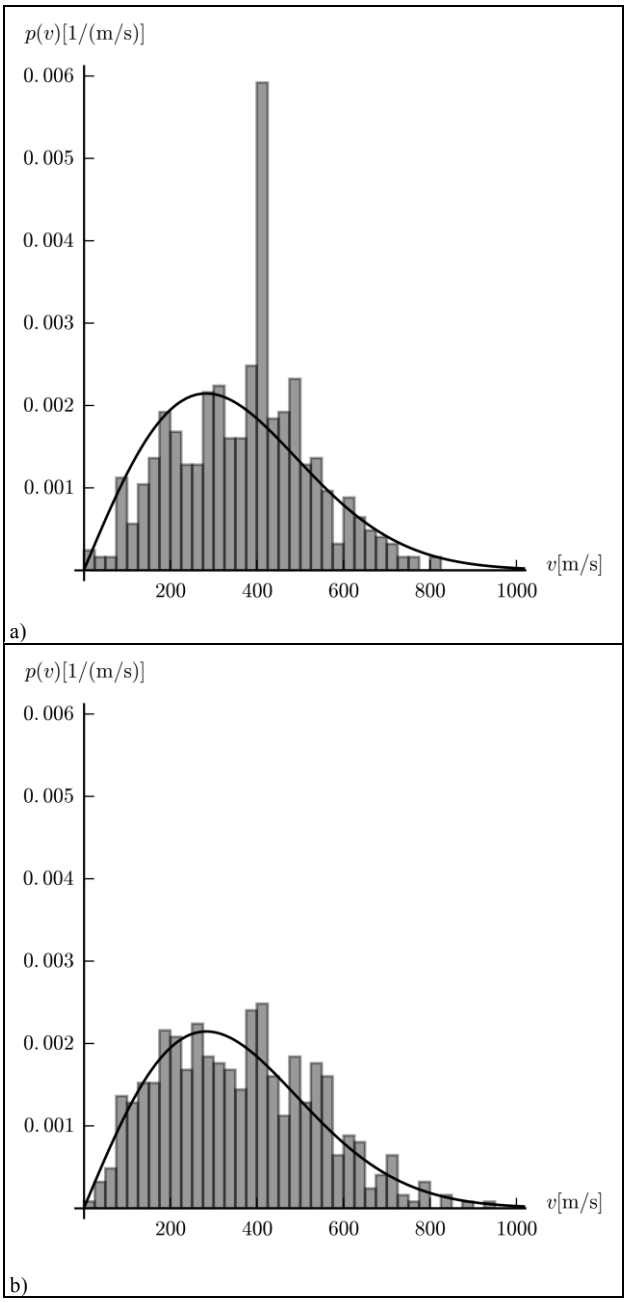

Figure 3. Normalized speed histograms for 500 gas particles at times a) 15 Unity time units, and b) 25 Unity time units. Initially, all gas particles have the speed of 4 Unity speed units (400 m/s). The full line corresponds to the Maxwell-Boltzmann distribution (1) for the two-dimensional ideal gas at the temperature T obtained using equation (2).

random direction. In regular time intervals (5 Unity time units), the positions of all particles are saved into files. Data are analyzed in SageMath, and results of this analysis are shown in Fig. 4.

The results from the Unity simulations are in agreement with the theory (Fig. 4). The nonlinear fit with the model function $a \cdot N^{-b}$ to these results (full line in Fig. 4) yields $b = 0.52 \pm 0.01$, which is close to theoretical $1/2$.

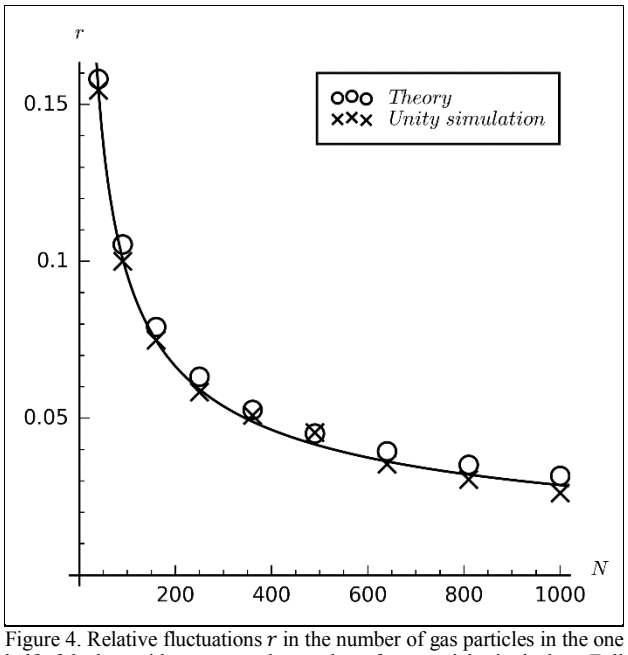

Figure 4. Relative fluctuations r in the number of gas particles in the one half of the box with respect to the number of gas particles in the box. Full line corresponds to the fit of Unity simulations data to the function $a \cdot N^{-b}$.

C. Theorem of equipartition of energy

The theorem of equipartition of energy (or simply equipartition theorem) says that energy in the system in thermal equilibrium is shared equally among all its independent parts (degrees of freedom). Hence, in the two-dimensional ideal gas with no rotational degrees of freedom in equilibrium, energy is shared among two translational degrees of freedom:

$$\langle \tfrac{1}{2} m_A v_{A,x}^2 \rangle = \langle \tfrac{1}{2} m_A v_{A,y}^2 \rangle, \quad (4)$$

where m_A is the mass of gas particles, and $v_{A,x}$ and $v_{A,y}$ x and y components of the velocity vector, respectively. If we add to the system another type of gas particle with mass m_B (we are working now with the two-component two-dimensional ideal gas), the equipartition theorem predicts that in thermal equilibrium, the average kinetic energy of gas components are equal:

$$\langle \tfrac{1}{2} m_A v_A^2 \rangle = \langle \tfrac{1}{2} m_B v_B^2 \rangle. \quad (5)$$

To see the equipartition theorem in action, we simulated in Unity two-component two-dimensional ideal gas with 500 gas particles of mass m_A equals to the mass of a neon atom and 500 gas particles of mass $m_B = 2 \cdot m_A$. Initially, the system is out of equilibrium: all gas particles of mass m_A have a speed of 400 m/s in the random direction while all gas particles of mass m_B are stationary. As time progresses, energy is exchanged between all gas particles, and the system approaches equilibrium where Eq. (5) is satisfied with some fluctuations in time (Fig. 5).

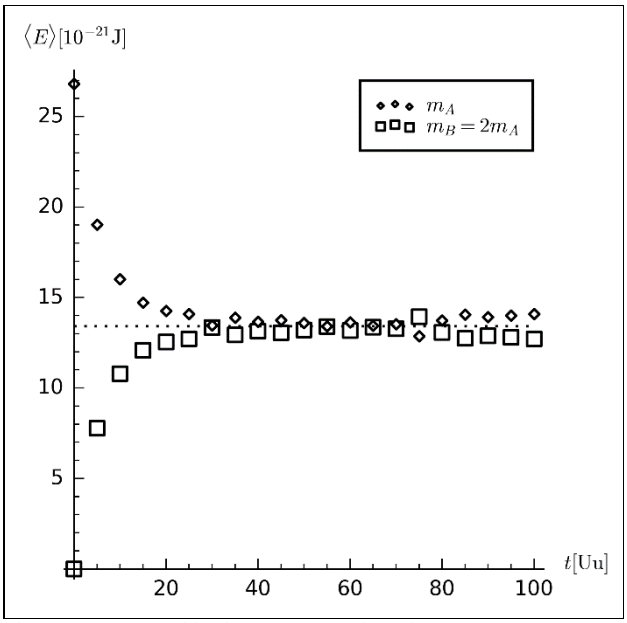

Figure 5. Average kinetic energy vs. time for two-component two-dimensional ideal gas with only translational degrees of freedom. Initially, all 500 gas particles of mass m_A have the same speed of 400 m/s in the random direction, and 500 gas particles of mass $m_B = 2 \cdot m_A$ are stationary. Initially, gas particles are uniformly distributed in the two-dimensional rectangular box. The dotted line shows the average kinetic energy that gas particles of both components should have in equilibrium according to the theorem of equipartition of energy. Uu stands for Unity units.

IV. Conclusion

We have shown that the Unity game engine, with its physics engine, can be used as a virtual physics laboratory in which students perform virtual experiments to study physics and deepen their understanding of physical laws. Unity features a graphical user interface and scripting support, and is easy to use and learn. Also, Unity is free for students. As shown in this work, with an understanding of just a few fundamental concepts (such as prefabs and unit conversion), students can create powerful and realistic simulations. This approach is probably best suited for ICT students. However, since in modern natural sciences, such as physics and biophysics, computer simulations of physical processes are very important, they might also find this approach of some interest.

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Results of the National Photography Competition in Croatian Primary Schools, High Schools and Schools of Applied Arts in 2017

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***Abstract* - From 27 to 28 April 2017, organized by the Croatian Education and Teacher Training Agency, the Ministry of Science and Education and the First Croatian Grammar School in Sušak (Rijeka), the 19th National Competition - LIK, an exhibition of primary schools, high schools and schools of applied arts in the field of visual arts and design, this time focused on photography, was held in Rijeka. In this article the results of this competition, based on photography and computers, in Croatian schools on the three levels mentioned above, will be analyzed and evaluated from the artistic and statistical point of view.**

***Keywords*–photography;computers;teaching;schools;visual arts**

I. INTRODUCTION

Under the auspices of the Ministry of Science and Education (Ministry), the Education and Teacher Training Agency (Agency) and one of the selected secondary or primary schools organize every school year, a competition - exhibition of pupils of primary and secondary schools in the field of visual arts and design called - LIK.

The competition includes three target groups of pupils: 1) pupils from fifth to eighth grade of primary schools in the field of art, 2) pupils from first to fourth grade of high schools, art schools in the field of visual arts, art history and theory of fine arts and 3) pupils from first to fourth grade in secondary schools who are educated in the field of visual and applied art and design in a variety of programs and fields of fine art.

The competition - exhibition LIK has a 19 years tradition and represents the visual range of the pupils in the performance of artworks on a given topic and different art techniques (traditional and modern). Artworks by pupils are selected on the three levels and assessed by various commissions, on the school, county and national levels. [2]

From 27 to 28 April 2017 at the First Croatian Grammar School in Sušak (Rijeka) the 19th competition and exhibition LIK (Contest) was held with focus on photography. There were 39 primary and secondary school pupils in 3 categories participating from all over Croatia.

The photos were evaluated by a State Commission (Commission) appointed by the Croatian Education and Teacher Training Agency (Agency) and the Ministry of Science and Education (Ministry). This Commission was composed of professors from art academies, professors from study of design and architecture, history and fine arts as well as of teachers from primary schools and secondary schools in the field of fine art and photography.

The Commission prepared and created the tasks for all three target groups of primary and secondary schools. From the members of the Commission, 3 committees, each established from 3 teachers, in charge of the selection and evaluation of photos of the three above-mentioned groups of primary and secondary schools were appointed.

The evaluation of photos was carried out according to high-quality standards for fine art photography and was provided by objective criteria for the assessment of individual elements that apply to all three levels of schools. The most successful photos were presented at a public exhibition in the Gallery "Principij" which is run by the Rijeka Photoclub and the best photos have won awards. Three awards for primary schools, three awards for high schools and four generation awards for participants from schools of applied arts and design. [3] [4] [12]

The criteria and evaluation of the best photos, i.e. the results of the Contest as well as their statistical analysis are presented in the next parts of this article. From the technical point of view, for evaluation of photos on all three levels a special computer program called PhotoBox, actually a database in graphic format [1], was developed and programmed in Visual Basic for Windows, what was explained in an earlier article. [9]

In this software all photos of the participants or pupils were stored, viewed and notes made. Similar computer programs were already presented by the authors in previous articles at two earlier MIPRO Conferences. [10] [11]

II. Evaluation of the results - Artistic point of view

Criteria for evaluation of the Photography Contest are presented in three subheadings below.

The main topic and categories of the Contest, i.e. the competition and later on the exhibition is "Sound Image" on all three levels mentioned above.

A. Primary School Level

Artistic techniques:
traditional photography, digital photography
(Photos must be in color [B])

Key concepts:
photo, color, light, rhythm, contrast, composition, framing

Goals:
Pupils will observe, learn about and evaluate the role of color, light, rhythm, contrast, composition and framing to create images on the sub-theme-stimulus rhythm lights, the rhythm of colors. Pupils will explore, express and evaluate different kinds of rhythms in their own work.

Task:
-explore art / visual elements and key concepts for subtopic-stimulus rhythm lights, the rhythm of colors (separating bit of art work pupils): photo, color, light, rhythm, contrast, composition, framing
-express own idea in the medium of photography
-apply photographic procedures in making photographs (classical and digital, the ability of computer processing to the extent that does not distort and does not alter the basic meaning of the recording)
-evaluate role of color, light, rhythm, contrast, composition and framing

Evaluation i.e. the photos were evaluated according to the following components:
-divergent opinion
-art problem / key concepts: photo, color, light, rhythm, contrast, composition, framing
-understanding and creative application of art techniques and resources: the classic photography, digital photography
-connecting / interdisciplinary and correlated approach
Each component could be evaluated with a maximum of 20 points and the total sum amounted to 80 points.

B. High school Level

Artistic techniques:
traditional photography, digital photography
(photos may be color [B], monochrome [M], black&white [CB]), a collage and photo collage.

Key concepts:
photography, composition, rhythm, framing, light, contrast, composition - recomposition, definition - redefinition, recycling, texture, structure.

Goals:
The aim of the competition is to accomplish a picture using photography as a medium, taking into account its historical significance, technological capabilities, functions and aspects of photography. After selecting approach to traditional and contemporary photography, pupils will be able to interpret the artistic manipulation of a photograph through the history of the connotation of the stylistic periods and artistic direction XX century. Research activities will encourage the realization of artistic creations, develop creativity, the ability of divergent and convergent thinking and independence in planning and realizing the artistic task. [5] [8] [7]

Task:
Pupils prepare exclusively a collage of photos that are individually recorded. It can be done in digital or analog (classical) paper collage of printed photos. In the collage, with elements of photography, can use a collage of colored paper, can be used as a newspaper article, but not in terms of content, but in terms of its graphism.

Among other pupils will also:
-apply photographic procedures in making photographs (classical and digital, the ability of computer processing to the extent that does not distort and does not alter the basic meaning of the recording)
-formulate a picture as a matrix for further consideration of the techniques of collage
-devise a collage as a redefinition, recomposition, confrontation and recycling questioning tone, rhythm, composition, structure, texture, schematisation, variation, modularity, multiplication and fragmentation
-realize their own idea as a piece of artwork in the medium of photography and in the technique of collage and photo collage
-evaluate the role of composition, rhythm, framing, light, contrast, texture, structure, chiaroscura
-conclude intermedia, multimedia, interdisciplinary, correlation creating new compositions photography

Evaluation i.e. the photos were evaluated according to the following components:
-visibility and correlation interdisciplinary approach to research and artistic expression and study forms of communication in different areas of art
-creative self-expression and world view and an appreciation of ethical and aesthetic values in the artistic creations
-creativity and expression in artistic expression
Each component was evaluated with a maximum of 20 points and the total sum amounted to 60 points.

C. Schools of applied arts and design Level

Artistic techniques:
Pupils can realize their ideas as: photogram, chemo-gram, collage (analog and digital), photography, photomontage, photo story, photo albums, photo books, photo object, photos in textile design and photo graphic design.

Key concept:
photography, composition, color, light, intermediality, recomposition

Goals:
During the realization of tasks pupils will be introduced to photography as a medium of expression, historical and artistic development of the same, and the role and importance throughout the 20th century. They will investigate the possibilities of photography, the achievements of modern technical / technological capabilities and to traditional or contemporary processes reinterpret obtained record (procedures redefinition /recomposition create new visual facts). [6]

Task:
Pupils need to formulate and define systems within the photographic composition or recomposition on the concept of intermediality, and show the symbolism of cooperation of each element.

Evaluation i.e. the artworks will be evaluated according to the following components:
-interdisciplinary and correlated approach to research and artistic expression
-unifying themes as incentives (research access to forms of communication) and skills development in the material / medium
-the relationship of form and ideas
Each component can be evaluated with a maximum of 20 points and the total sum amounts to 60 points.

D. Awards for best photos on all three levels

According to the propositions of the Contest the best pupils` photos got an award. Three awards for primary schools, three for high schools and four generation awards for participants from schools of applied arts and design.

Category 1A: primary schools, 5th to 8th grade

1st place: 8th grade PS

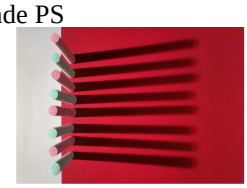

Figure 1. 1st place in category 1A

Color photo made with the composition of objects moved from their natural and customary frame. The rhythmic problem of rhythm is solved by a series of colored cylinders and a shadow thrown at a red background. The high-quality selection of motifs and compositions of the golden cut emphasizes the correlative approach that connects art and music.

2nd place: 8th grade PS

Figure 2. 2nd place in category 1A

The character of the composition is highly contrasted with the warm and cold colors of large and small shapes, sharp and blurry edges, and their own and thrown shadows. Photography is the result of research and understanding of key concepts and reflection of a divergent author's opinion.

3rd place: 7th grade PS

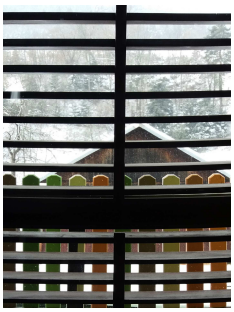

Figure 3. 3rd place in category 1A

The connection of the rhythms of light and color in the symmetrical composition was strengthened by the grid of vertical and horizontal lines. With the contrast of the bright and dark surfaces, a dialogue of the front plan with the background was realized. The atmosphere of the ambient is emphasized with tones of all senses.

Category 2A: high schools, 1st to 4th grade

1st place: 3rd grade HS

Figure 4. 1st place in category 2A

The color photo is elaborated by fragments of squares creating a dynamic surface of clear structure. The art motif is in the function of creating the composition. The message of picture is clear. The application of compositional definitions is thoughtful, systematic and complete.

2nd place: 3rd grade HS

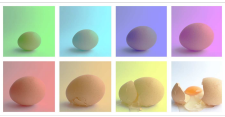

Figure 5. 2nd place in category 2A

The quadratic rhythm expresses the creative application of the visual language. The frames are full and the light is in the function of building the composition. Harmony is achieved by using filters in the shades of warm and cold colors. The contentful art story makes different explanations and a multifaceted interpretation possible.

3rd place: 3rd grade HS

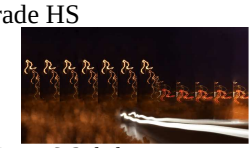

Figure 6. 3rd place in category 2A

Color photography supports the sound and the atmosphere of the accentuated rhythm of the instrument. Only the figurative elements indicate the dynamic surface and are read as elements of the art syntax construction.

Category 3A: schools of applied arts & design, 1st to 4th grade

1st generation award: 1st grade SOAAD

Figure 7. 1st generation award in category 3A

The pronounced rhythm supports the composition of grouped and scattered elements. The clear message of picture in the structure supports contrast, motion, and light dynamics. The clarity of the shapes and colors suggest movement and define the sound track leaving a trace in vanishing.

2nd generation award: 2nd grade SOAAD

Figure 8. 2nd generation award in category 3A

The clear message in the photo recording is endlessly simple with minimal dealing with the motif. The default task does not restrict but it supports multidimensionality of the audio track and confirms that less is actually more.

3rd generation award: 3rd grade SOAAD

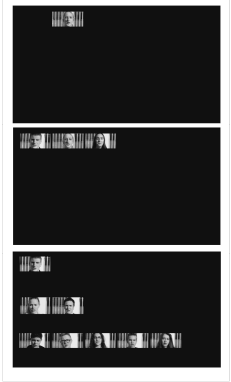

Figure 9. 3rd generation award in category 3A

The recomposition of the given forms dynamizes the new situation so by exploiting the technological possibilities the author opens up the situations for new visual reflections. An extremely developed sense of the given media and historical significance in creating a new composition.

4th generation award: 4th grade SOAAD

Figure 10. 4th generation award in category 3A

Clearly defined frames support the sound of the image in the closed space of the photo. The motion and the composition of the light as a building element create the unity of the form and the message, and the sound record is in traces.

III. EVALUATION OF THE RESULTS - STATISTICAL POINT OF VIEW

In order to evaluate the results from statistical point of view, namely, to perform statistical analysis of relevant numerical data, authors have used Excel spreadsheets that were explicated in one of their earlier articles. [9]

Prior to statistical analysis, in Fig 11. authors have integrated map of Croatia with green dots indicating cities of awarded pupils with the aim of illustrating how widespread, within Croatia, are the last years' (2017) award winners. It clearly shows that National Photography Competition in Croatian Primary Schools, High Schools and Schools of Applied Arts is properly and truly country-wide competition with equal opportunities for all pupils.

Figure 11. Map of Croatia with green dots indicating cities of awarded pupils

Pupils, as explained earlier, were categorized in 3 categories i.e. 1A, 2A, 3A. Each of 3 categories was separately evaluated by carefully selected committees, each established from 3 teachers. Each of 3 categories had its own total sum of amounted points i.e. 80, 60, 60 with maximum overall amounted points, summed from all 3 teachers, being respectively 240, 180, 180. After pupils' points from all 3 teachers were properly summed, pupils' overall amounted points were calculated. Those points were also used for statistical analysis within each category.

Hence, in a total of 18 figures below, each category and its subcategories i.e. grades, were analyzed statistically with the help of statistical functions for calculating maximum values, minimum values, average values and standard deviation of values. These functions are available within Excel and other commercial and free spreadsheet software.

Overview of category 1A is presented in Fig. 12 below, with Points being the most important and relevant column.

No.	School grade	City	County	Points	Place
1	8th grade PS	Našice	Osijek-Baranja	240	1st
2	8th grade PS	Graberje Ivaničko	Zagreb	239	2nd
3	7th grade PS	Skradin	Šibenik-Knin	238	3rd
4	6th grade PS	Varaždin	Varaždin	237	4th
5	8th grade PS	Zadar	Zadar	235	5th
6	6th grade PS	Lipovljani	Sisak-Moslavina	233	6th
7	6th grade PS	Imotski	Split-Dalmatia	231	7th
8	8th grade PS	Varaždin	Varaždin	230	8th
9	7th grade PS	Pakrac	Požega-Slavonia	228	9th
10	5th grade PS	Karlovac	Karlovac	227	10th
11	5th grade PS	Dvor	Sisak-Moslavina	226	11th
12	5th grade PS	Rijeka	Primorje-Gorski Kotar	225	12th
13	7th grade PS	Zagreb	Zagreb	224	13th

Figure 12. Overview of category 1A

Hence, conclusions of this specific category 1A are: 1) older pupils (7th grade PS and 8th grade PS) have taken first 3 places, 2) pupils from smaller cities and counties were (in general) more successful than pupils from larger cities and counties, 3) one middle-sized city (Varaždin) and its county (Varaždin) is the only one that had 2 pupils who won the awards.

In this category, the maximum number of points (240) was reached, average is closer to maximum number of points, difference between the best and the worst pupils is small and standard deviation of points is low.

ALL (5th, 6th, 7th, 8th) grades PS	VALUE
ALL MAX Points	240,00
ALL MIN Points	224,00
ALL AVERAGE Points	231,77
ALL ST. DEV. of Points	5,61

Figure 13. Statistical analysis of category 1A

The most significant research findings for this subcategory were very small differences between pupils that are indicated by very low value of standard deviation.

5th grade PS	VALUE
MAX Points	227,00
MIN Points	225,00
AVERAGE Points	226,00
ST. DEV. of Points	1,00

Figure 14. Statistical analysis of category 1A, subcategory 5th grade PS

The most important research results for this subcategory were, once again, very small differences between pupils that are indicated by a tad higher, but still very low standard deviation.

6th grade PS	VALUE
MAX Points	237,00
MIN Points	231,00
AVERAGE Points	233,67
ST. DEV. of Points	3,06

Figure 15. Statistical analysis of category 1A, subcategory 6th grade PS

The most evident research findings for this subcategory were small differences between pupils that are indicated by low value of standard deviation. This category includes the pupil with minimum points (224).

7th grade PS	VALUE
MAX Points	238,00
MIN Points	224,00
AVERAGE Points	230,00
ST. DEV. of Points	7,21

Figure 16. Statistical analysis of category 1A, subcategory 7th grade PS

The most significant research results for this subcategory were very small to small differences between pupils that are indicated by very low to low value of standard deviation. This category includes the pupil with maximum points (240).

8th grade PS	VALUE
MAX Points	240,00
MIN Points	230,00
AVERAGE Points	236,00
ST. DEV. of Points	4,55

Figure 17. Statistical analysis of category 1A, subcategory 8th grade PS

Summary of category 2A is presented in Fig. 18 below, with Points being the most important and relevant column.

No.	School grade	City	County	Points	Place
1	3rd grade HS	Koprivnica	Koprivnica-Križevci	180	1st
2	3rd grade HS	Virovitica	Virovitica-Podravina	172	2nd
3	3rd grade HS	Varaždin	Varaždin	169	3rd
4	4th grade HS	Krapina	Krapina-Zagorje	162	4th
5	4th grade HS	Krapina	Krapina-Zagorje	153	5th
6	1st grade HS	Varaždin	Varaždin	141	6th
7	2nd grade HS	Vinkovci	Vukovar-Srijem	136	7th
8	3rd grade HS	Delnice	Primorje-Gorski Kotar	135	8th
9	4th grade HS	Varaždin	Varaždin	134	9th
10	2nd grade HS	Karlovac	Karlovac	131	10th
11	4th grade HS	Koprivnica	Koprivnica-Križevci	131	11th
12	2nd grade HS	Zagreb	Zagreb	128	12th
13	2nd grade HS	Dubrovnik	Dubrovnik-Neretva	125	13th

Figure 18. Overview of category 2A

Thus, conclusions of this individual category 2A are: 1) older pupils (3rd grade HS) have taken first 3 places, 2) pupils from smaller cities and counties were, once again, (in general) more successful than pupils from larger cities and counties, 3) one middle-sized city (Varaždin) and its county (Varaždin) had 3 pupils who won the awards and two small-sized cities (Koprivnica and Krapina) and their counties (Koprivnica-Križevci and Krapina-Zagorje) had 2 pupils who won the awards.

In this category, the maximum number of points (180) was reached, average is closer to maximum number of points, difference between the best and the worst pupils is large and standard deviation of points is very high.

ALL (1st, 2nd, 3rd, 4th) grades HS	VALUE
ALL MAX Points	180,00
ALL MIN Points	125,00
ALL AVERAGE Points	145,92
ALL ST. DEV. of Points	18,87

Figure 19. Statistical analysis of category 2A

The most important research finding for this subcategory is only one pupil included in it, whose points (141) match all values.

1st grade HS	VALUE
ALL MAX Points	141,00
ALL MIN Points	141,00
ALL AVERAGE Points	141,00
ALL ST. DEV. of Points	-

Figure 20. Statistical analysis of category 2A, subcategory 1st grade HS

The most evident research results for this subcategory were very small to small differences between pupils that are indicated by very low to low value of standard deviation. This category includes the pupil with minimum points (125).

2nd grade HS	VALUE
ALL MAX Points	136,00
ALL MIN Points	125,00
ALL AVERAGE Points	130,00
ALL ST. DEV. of Points	4,69

Figure 21. Statistical analysis of category 2A, subcategory 2nd grade HS

The most significant research findings for this subcategory were very large differences between pupils that are indicated by very high value of standard deviation. This category includes the pupil with maximum points (180).

3rd grade HS	VALUE
ALL MAX Points	180,00
ALL MIN Points	135,00
ALL AVERAGE Points	164,00
ALL ST. DEV. of Points	19,88

Figure 22. Statistical analysis of category 2A, subcategory 3rd grade HS

The most important research results for this subcategory were large differences between pupils that are indicated by high value of standard deviation.

4th grade HS	VALUE
ALL MAX Points	162,00
ALL MIN Points	131,00
ALL AVERAGE Points	145,00
ALL ST. DEV. of Points	14,94

Figure 23. Statistical analysis of category 2A, subcategory 4th grade HS

Outline of category 3A is presented in Fig. 24 below, with Points being the most important and relevant column.

No.	School grade	City	County	Points	Place
1	4th grade SOAAD	Zagreb	Zagreb	176	4th g. p.
2	3rd grade SOAAD	Split	Split-Dalmatia	173	3rd g. p.
3	4th grade SOAAD	Zadar	Zadar	170	-
4	2nd grade SOAAD	Zagreb	Zagreb	169	2nd g. p.
5	4th grade SOAAD	Osijek	Osijek-Baranja	168	-
6	2nd grade SOAAD	Pula	Istria	167	-
7	4th grade SOAAD	Zabok	Krapina-Zagorje	166	-
8	2nd grade SOAAD	Rijeka	Primorje-Gorski Kotar	162	-
9	4th grade SOAAD	Zagreb	Zagreb	161	-
10	3rd grade SOAAD	Pula	Istria	161	-
11	4th grade SOAAD	Rijeka	Primorje-Gorski Kotar	159	-
12	3rd grade SOAAD	Zabok	Krapina-Zagorje	159	-
13	1st grade SOAAD	Zagreb	Zagreb	133	1st g. p.

Notes about Place(s)
1st g. p. = 1st generation award i.e. 1st in 1st grades SOAAD
2nd g. p. = 2nd generation award i.e. 1st in 2nd grades SOAAD
3rd g. p. = 3rd generation award i.e. 1st in 3rd grades SOAAD
4th g. p. = 4th generation award i.e. 1st in 4h grades SOAAD

Figure 24. Overview of category 3A (with Notes about Place(s))

Accordingly, conclusions of this distinct category 3A are: 1) older pupils (3rd grade SOAAD and 4th grade SOAAD) have taken first 3 places, 2) in this case, pupils from larger cities and counties were, (in general) more successful than pupils from smaller cities and counties, 3) one large-sized city (Zagreb) and its county (Zagreb) had 4 pupils who won the awards, one large-sized city (Rijeka) and its county (Primorje-Gorski Kotar) had 2 pupils who won the awards, one medium-sized city (Pula) and its county (Istria) had 2 pupils who won the awards and one tiny-sized city (Zabok) and its county (Krapina-Zagorje) had 2 pupils who won the awards

In this category, almost maximum number of points (176) was reached, average is closer to maximum number of points, difference between the best and the worst pupils is moderate and standard deviation of points is moderate.

ALL (1st, 2nd, 3rd, 4th) grades SOAAD	VALUE
ALL MAX Points	176,00
ALL MIN Points	133,00
ALL AVERAGE Points	163,38
ALL ST. DEV. of Points	10,58

Figure 25. Statistical analysis of category 3A

The most evident research finding for this subcategory is only one pupil included in it, whose points (133) match all values. Since this was the only pupil from 1st grade SOAAD, he is actually the one who expectedly won 1st generation award. However, this pupil had overall minimum points (133).

1st grade SOAAD	VALUE
ALL MAX Points	133,00
ALL MIN Points	133,00
ALL AVERAGE Points	133,00
ALL ST. DEV. of Points	-

Figure 26. Statistical analysis of category 3A, subcategory 1st grade SOAAD

The most significant research results for this subcategory were very small differences between pupils that are indicated by very low value of standard deviation. Pupil with maximum points (169) from 2nd grades SOAAD won 2nd generation award.

2nd grade SOAAD	VALUE
ALL MAX Points	169,00
ALL MIN Points	162,00
ALL AVERAGE Points	166,00
ALL ST. DEV. of Points	3,61

Figure 27. Statistical analysis of category 3A, subcategory 2nd grade SOAAD

The most important research findings for this subcategory were small differences between pupils that are indicated by low value of standard deviation. Pupil with maximum points (173) from 3rd grades SOAAD won 3rd generation award.

3rd grade SOAAD	VALUE
ALL MAX Points	173,00
ALL MIN Points	159,00
ALL AVERAGE Points	164,33
ALL ST. DEV. of Points	7,57

Figure 28. Statistical analysis of category 3A, subcategory 3rd grade SOAAD

The most evident research results for this subcategory were small differences between pupils that are indicated by low value of standard deviation. Pupil with maximum points (176) from 4th grades SOAAD won 4th generation award. Conclusively, this pupil had overall maximum points (176).

4th grade SOAAD	VALUE
ALL MAX Points	176,00
ALL MIN Points	159,00
ALL AVERAGE Points	166,67
ALL ST. DEV. of Points	6,19

Figure 29. Statistical analysis of category 3A, subcategory 4th grade SOAAD

IV. CONCLUSION

In this article the results of the national competition of photography in Croatian primary schools, high schools and schools of applied arts and design were elaborated and the award winning photos altogether ten (three on primary school level, three on high school level and four generation awards on the level of schools of applied arts and design) were analyzed from the artistic and statistical point of view.

In that sense, artistic analysis was actually the foundation for statistical analysis of pupils' works. With statistical analysis based on pupils' points authors were primarily able to determine the similarities and the differences within 3 categories of pupils that each had its specifics and differences in numerical data and their interpretation.

Valid conclusions of all three categories (1A, 2A, 3A) are: 1) older pupils, i.e. 7th and 8th grade PS plus 3rd grade HS plus 3rd grade SOAAD, have taken first 3 places in all categories, 2) pupils from smaller cities and counties were (in general) more successful in categories 1A and 2A, while pupils from larger cities and counties (in general) were more successful in category 3A and 3) pupils from various-sized cities, i.e. large sized, middle-sized, small-sized and tiny-sized, have won the awards in 2017, but in different portions and in diverse categories.

Real significance and contribution of this particular article and the accompanying research is that they will definitely serve as a framework and as a basis for significant improvements of National Photography Competition in the coming years. Since this competition includes Croatian Primary Schools, High Schools and Schools of Applied Arts, this article will primarily be used as the incentive to bring category 3A closer to categories 1A and 2A, especially when it comes to the essential detail such as the awards and how they are won.

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Students' Preferences Regarding the Transfer of Information and Knowledge through Infographics Tools

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Abstract - Infographics is visual presentation of data, information and knowledge. Infographics is used to simplify complex information and knowledge which can knowledge transfer make much quicker. Nowadays infographics is mostly present in media such as newspapers, marketing of different products but also in education in a little bit smaller extent. This paper gives special emphasize to applications of infographics within educational process in higher education. For that reason, students' preferences toward infographics are explored and the results are presented in the paper.

Key words - infographics; infographics tools; knowledge transfer; educational process

I. INTRODUCTION

Infographics tools are nowadays used for information and knowledge transfer in a visual way. Although, infographics is widely present in different areas, in education is employed in a little bit smaller extent. This paper gives special emphasize to applications of infographics within educational process in higher education. For that reason, students' preferences toward infographics are explored thus the research questions raised in this paper are the following:

(1) What preferences do students have toward students' knowledge transfer through infographics in higher education?
(2) What preferences do students have toward teachers' knowledge transfer through infographics tools in higher education?
(3) What preferences do students have toward transfer of different types of information through infographics in higher education?

II. LITERATURE REVIEW

According to literature review there are several recently conducted case studies in regard to use of infographics within educational process in higher education. The case study [1] conducted in year 2016 among 34 freshman students enrolled at Portland State University in USA had a purpose to explore the extent to which an infographic assignment facilitated students' learning about health science issues. Students were divided into small groups of three or four students and they had to create an infographic focused on a health science issue. The assignment consisted of four steps: brainstorming, developing, designing and finalizing. In the brainstorming step students selected a topic and began drafting their infographics. After that students developed draft in software for infographics namely Piktochart and selected colors and fonts. In the last step students tested their infographics among their friends, family and faculty members. The main results of this case study shown that the infographics assignment was efficient teaching tool for students to acquire the key skills in learning how to communicate science related topics to non-experts. Furthermore, the infographics assignment promoted a deep learning about health issues. The another case study [2] was conducted during the fall semester of the 2015-2016 academic year with main purpose to explore the impact of infographics on education within the anatomy course of the Physical Education and Sports Department (PES) at Near East University. The case study encompassed 140 students and they were examined through a semi-structured interview form on their opinion in regard to application of infographics for anatomy lesson. The results shown that more than half of the participants (52.9%) did not know the exact meaning of the word "infographics" before the case study and (61.4%) of them stated that they had never seen infographics before the case study. There is a high level of satisfaction for the students in general about infographics because 86.4 % students said that infographics helped them to understand the issue better and 75.7% students declared positive view about infographics. However, still 38.6% students were unsure about the advantages of infographics. The majority of students (62.9%) considered use of infographics. According to this case study it can be concluded that students think that infographics provides better visuals, more memorable and understandable learning materials. H. Bicen and M. Beheshti [3] made a research under the name The Psychological Impact of Infographics in Education to examine students' perceptions about using infographics in education. It was a quantitative study conducted with questionnaire with close-ended questions. The number of undergraduate students participated in this research was 163 and they were from four different departments of Education faculty at Near East University, N. Cyprus. The main questions were about students' perceptions towards using infographics for learning, towards the effectiveness of using infographics in education and using visual literacy rather than just text. The majority of students believe that infographics can make learning

process faster. Almost all students underlined that learning with this method is very efficient because of development of creativity, knowledge, motivation, imagination and communication skills. Even 83.7% of students confirmed that using visual literacy in education is more engaging than learning with textual information which means that they prefer to study with infographics materials rather than books or other types of traditional materials. A. L. Saurbier [4] conducted a research in USA named Using Infographics as an Integrative Higher-Order Skill Development Assignment in Undergraduate Leadership Instruction to explore the use of infographics in an undergraduate leadership course as the higher-order skill necessary for workplace success. She proved that infographics can help students to visualize concepts that may otherwise remain too theoretical and can help in synthesizing those concepts. The learning outcomes may be increased with the development of the ability to refine data visualization and presentation skills. The main conclusion was that the integration of this type of assignment may create an open-ended learning environment institution-wide.

III. METHOD

The method used in this research is an online questionnaire in Appendix distributed in February 2018 year toward random sample of students at University of J. J. Strossmayer in Osijek. Total of 100 fulfilled questionnaires were analyzed for the purpose of answering to the research questions.

IV. RESULTS AND DISCUSSION

In regard to gender 70% of female students and 30% of male students fulfilled the online questionnaire. Fig. 1 shows the distribution of students in regard to their age. At Fig. 2 it can be seen the distribution of students according to the year of the study.

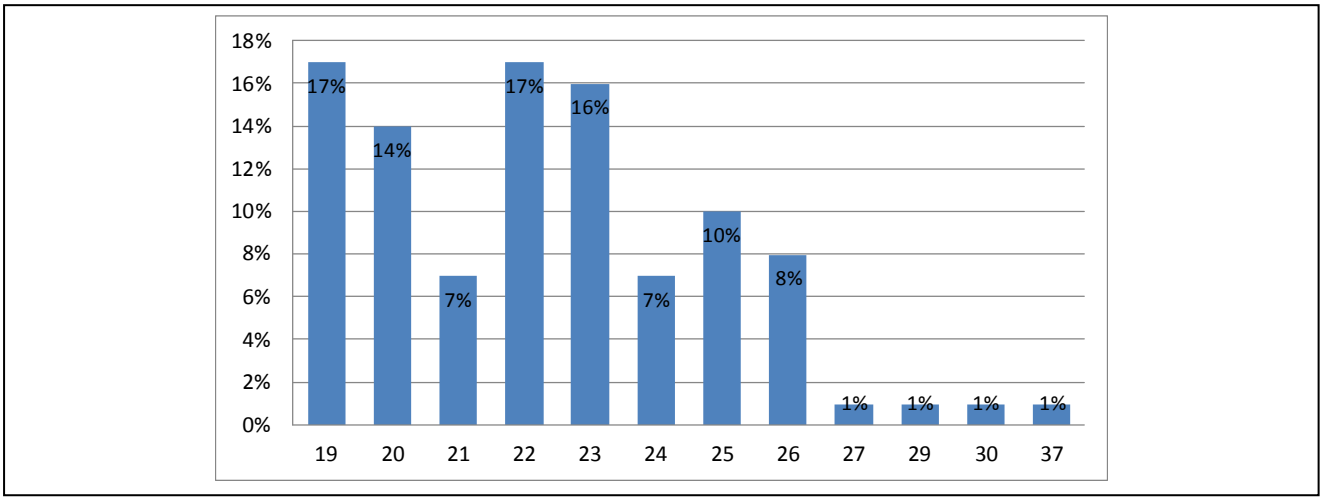

Figure 1. Distribution of students in regard to their age

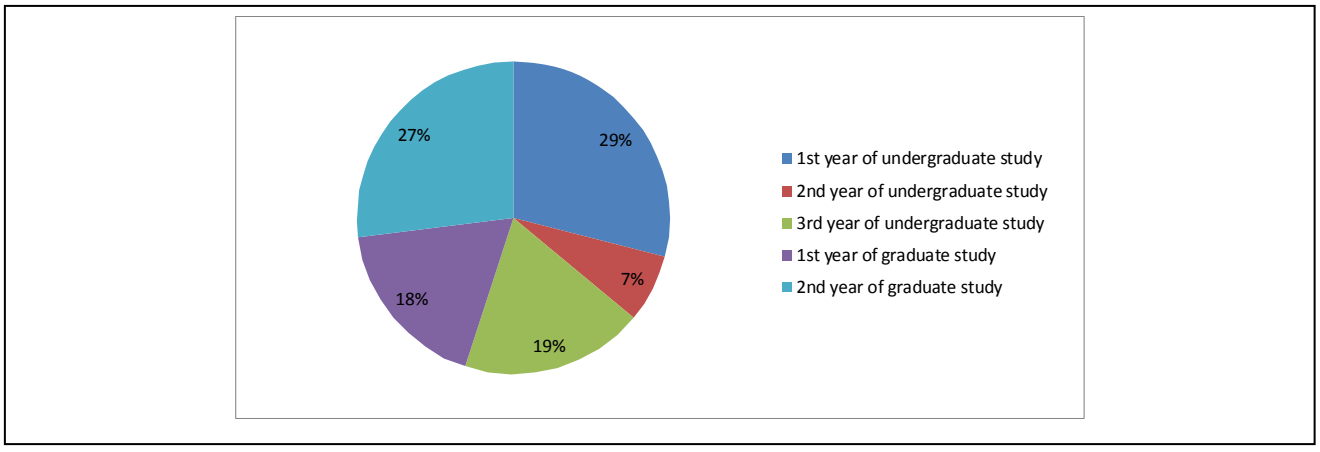

Figure 2. Distribution of students in regard to the year of study

Students were asked do they use some of the following open source tools for creating infographics: Canva [5], Adobe Spark [6], Piktochart [7], Easel.ly [8], Venngage [9], Infogram [10], Visme [11] etc. which can be seen at Fig. 3.

More than one third of students (34%) answered that they used Canva but also even one third of students (33%) answered that they didn't use any of tools for creating infographics. After Canva follow Adobe Spark (20%) and Piktochart (14%) according to popularity among students.

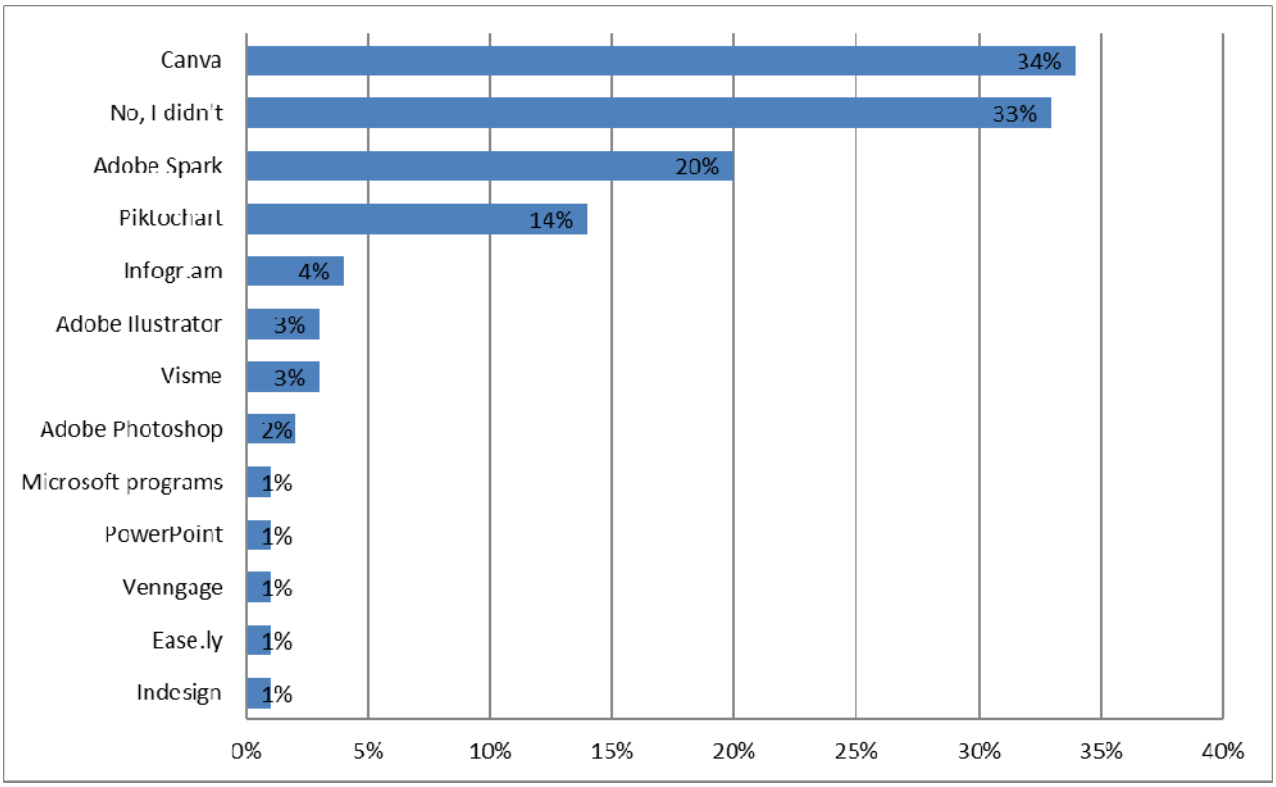

Figure 3. Students' preferences toward different tools for infographics

The students were asked if they think that knowledge transfer through infographics tools within educational process would be more efficient if teachers use infographics tools in creating presentations, tests, textbooks or manuals and tasks. Fig. 4 shows that students would prefer from their teachers to use infographics within their presentations (85%), textbooks or manuals (39%), tasks (30%) and tests (25%).

The students were asked if they think that knowledge transfer through infographics tools within educational process would be more efficient if students use infographics tools in creating presentations, posters, seminars and grade works. Fig. 5 shows that students would prefer to use infographics for their presentations (75%), posters (52%), seminars (47%) and grade works (31%).

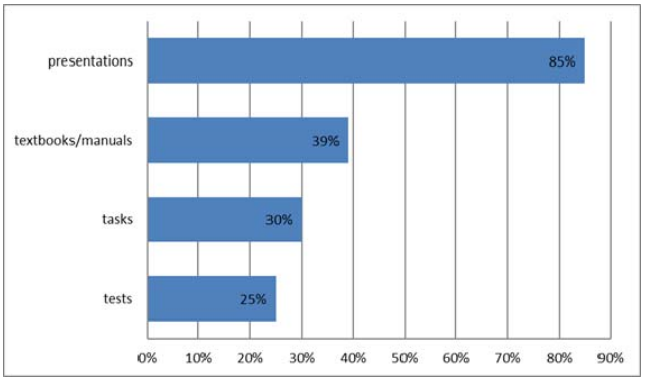

Figure 4. Students' preferences toward teachers' knowledge transfer through infographics

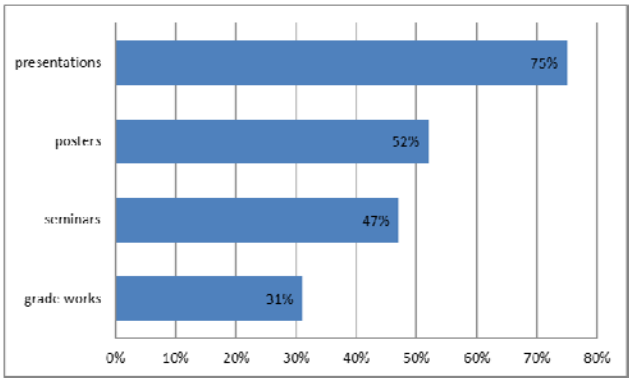

Figure 5. Students' preferences toward students' knowledge transfer through infographics

Students were asked if they think that transfer of quantitative/scientific/professional/historical information within educational process would be more efficient if students and/or teachers use infographics.

Even 90% of students answered positively in regard to the use of infographics in knowledge transfer of quantitative information, even 86% of students answered positively in regard to the use of infographics in knowledge transfer of scientific information, even 80% of students answered positively in regard to the use of infographics in knowledge transfer of professional information and even 85% of students answered positively in regard to the use of infographics in knowledge transfer of historical information which can be seen at Fig. 6.

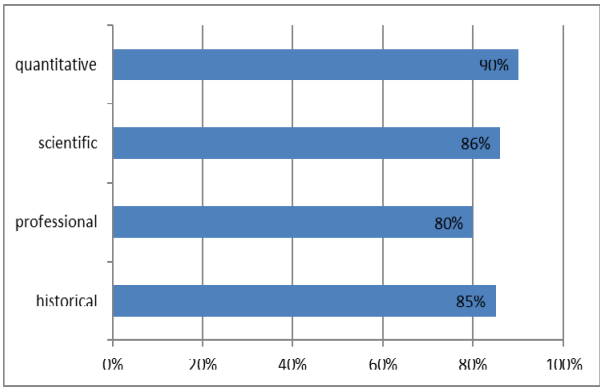

Figure 6. Students' preferences toward knowledge transfer of quantitative/scientific/professional/historical information through infographics

Students were asked if they think that students need some kind of education in regard to infographics creation. Even 84% of students answered positively in regard to introducing some kind of additional education on infographics for students which can be seen at Fig. 7.

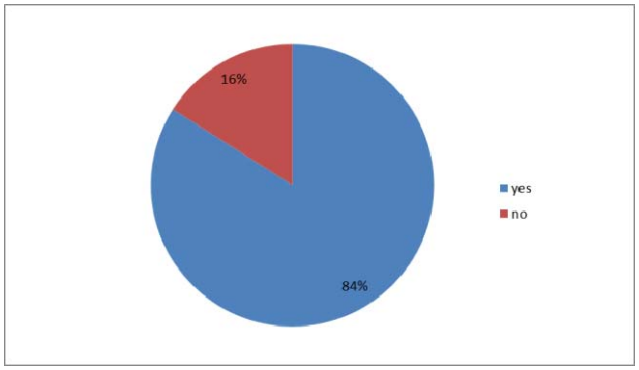

Figure 7. Students' preferences toward introducing of some kind of education on infographics for students

Students were asked if they think that teachers need some kind of education in regard to infographics creation. Also even 84% of students answered positively in regard to introducing some kind of additional education on infographics for teachers which can be seen at Fig. 8.

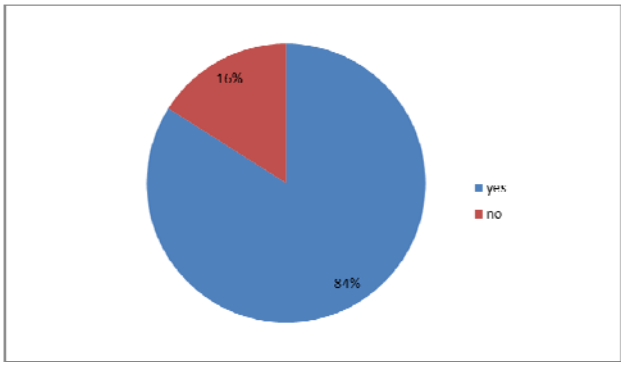

Figure 8. Students' preferences toward introducing of some kind of education on infographics for teachers

The students were asked if they think that knowledge transfer through infographics tools within educational process would be more efficient if students and/or teachers use already available infographics. Even 89% of students answered positively in regard to the use of already available infographics in knowledge transfer.

V. CONCLUSION

This paper gives special emphasize to applications of infographics within educational process in higher education. For that reason, students' preferences toward infographics are explored and the results are presented in the paper. According to the research results it can be concluded that the majority of students had experiences with some of the infographics tools. The most popular infographics tool among students is Canva. Students also use Adobe Spark and Piktochart for creation of infographics. Students would prefer from their teachers to use infographics within their presentations (85%), textbooks or manuals (39%), tasks (30%) and tests (25%). Also students themselves would prefer to use infographics for their presentations (75%), posters (52%), seminars (47%) and grade works (31%). Between 80-90% of students think that knowledge transfer of different types of information such as quantitative, scientific, professional and historical information would be more efficient if supported by infographics. The majority of students welcome introducing some kind of additional education on infographics for teachers as well as for students.

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Appendix. Online questionnaire about students' preferences regarding the transfer of information and knowledge through infographics tools

Gender:

- female
- male

Age:_____

Year of the study:

- 1st year of undergraduate study
- 2nd year of undergraduate study
- 3rd year of undergraduate study
- 1st year of graduate study
- 2nd year of graduate study

1. Do you use some of the following open source tools for creating infographics:
   - Canva
   - Adobe Spark
   - Piktochart
   - Easel.ly
   - Venngage
   - Infogr.am
   - Visme
   - Other _____

2. Do you think that knowledge transfer through infographics tools within educational process would be more efficient if teachers would use infographics tools in creating:
   - presentations
   - tests
   - textbooks/manuals
   - tasks

3. Do you think that knowledge transfer through infographics tools within educational process would be more efficient if students would use infographics tools in creating:
   - presentations
   - posters
   - seminars
   - grade works

4. Do you think that knowledge transfer through infographics tools within educational process would be more efficient if students and/or teachers would use already available infographics?
   - yes
   - no

5. Do you think that transfer of quantitative information within educational process would be more efficient if students and/or teachers would use infographics?
   - yes
   - no

6. Do you think that transfer of scientific information within educational process would be more efficient if students and/or teachers would use infographics?
   - yes
   - no

7. Do you think that transfer of professional information within educational process would be more efficient if students and/or teachers would use infographics?
   - yes
   - no

8. Do you think that transfer of historical information within educational process would be more efficient if students and/or teachers would use infographics?
   - yes
   - no

9. Do you think that students need some kind of education in regard to infographics creation?
   - yes
   - no

10. Do you think that teachers need some kind of education in regard to infographics creation?
    - yes
    - no

Identification of optimal features of the knowledge base in project-based learning engineering education - Qualitative analysis of applications in engineering practicum

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Abstract - Project-based learning (PjBL) is an important segment of today's technology and engineering education. It is essential for the development of students' adaptation and anticipatory competencies, i.e. the acquisition of procedural knowledge, the development of tacit knowledge and metacognitive skills. Accordingly, the relevant knowledge base could be of an invaluable help to students in performing problem-solving tasks, which are one of the key elements of project-based learning. For this very reason, the aim of the research was to identify the basic elements and characteristics that the knowledge base in project-based teaching should exhibit, and that are important from the point of view of their cognitive effect. The paper therefore gives an overview of the qualitative analysis of the achievements in project-based engineering practicum, which is offered to students enrolled on the undergraduate study of Polytechnics, University of Rijeka. The observation analysis indicates the main features of the knowledge base that are important from the cognitive impacts in the project-based engineering education. In summary, main features and characteristics are as follows: simplified visualization, fundamental and / or simulated abstraction, segmented problem situations and tasks, user friendliness, the possibility of basic interactivity and collaboration, and clear students' expectations. Despite the role that knowledge base and knowledge management system can occupy in a project-based engineering education, their importance and use should not obstruct the main PjBL activities.

I. INTRODUCTION

A successful solving of the main problems of modern education, as well as technical (technology) and engineering education, can be explained to the efforts of educational institutions and systems for more effective development of the adaptation and anticipatory students' competencies [1], [2], [3]. Adaptation competencies include verifiable knowledge, skills and personal values that will help an individual to enter the labour market faster and become an integral part of the "real world" after they complete their formal education. The term "anticipatory competencies" is applied to the abilities to jointly analyze, evaluate and create rich "images" of the future that are pertinent to the issues of sustainability and the sustainability of the problem solving framework [1]. In fact, these competencies, which could be regarded as a qualitative upgrade of the adaptation competencies, mostly refer to the development of the individuals' mental mechanisms, i.e. their cognitive and metacognitive skills, which will enable them to faster managing in new and unfamiliar situations and circumstances. Nowadays, the need for the aforementioned competencies is strongly emphasized in different technical and technological branches and engineering. Such state of affairs highlights the necessity to encourage the development of these competencies at educational institutions.

A. Project and problem-based learning

Contemporary teaching and learning strategies, systems and models of technology and engineering education are seeking to respond to the challenges and demands of contemporary world in which current educational systems, which are mostly organized in a traditional manner, recognize an immense importance of project and problem-based learning and teaching. However, the differences in defining the models of problem-based and project-based teaching and learning suggest an overriding and constant need to draw a clear distinction between the aforementioned approaches and traditional teaching. Without going into different theoretical definitions, let us state that the so-colled project-based learning (PjBL) should meet the following criteria: it should take a central place in the curriculum relating to a specific subject area; it should focus on issues or problematic tasks that that "drive" students to encounter and struggle with the central concepts and principles of a discipline; students should conduct applied, multidisciplinary and constructive investigations in which they need to invest a great deal of mental effort in order for project realization to be successful; it should allow students to have a high level of autonomy and a great responsibility for project realization; and it should create a sense of authenticity, which links the education and the "real world", amongst students [4]. Despite the fact that problem-based teaching and learning (PBL) are defined and interpreted differently, PBL activities usually share some common features, which are as follows: an increased focus on students who work independently in small groups and under the guidance of teachers who perform the role of facilitators; the students are faced with authentic problems that represent tools for acquiring the necessary knowledge and skills required to solve the problem in question [5], [6]. The characteristics and

criteria of the project- and problem-based learning and teaching reveal many correlations that emphasize the importance of the learning context, as well as the features of contextual teaching [7]. Although in the field of technology and engineering education, project-based teaching and learning make a more acceptable option, or even a key component [8], it is clear that the some steps of PjBL represent a typical PBL, i.e. micro-steps of project-based teaching and learning. Therefore, in this research, student problem-solving activities, as part of the PBL, represent important micro-steps of PjBL whose purpose is to product development.

B. Knowledge base and knowledge management

Even though the use of a knowledge base (KB) and an appropriate knowledge management system (KMS) could constitute an important part of project-based technical and engineering educational context, their implementation depends on the necessary support in terms of management and organizational culture and structure [9]. The term KB is generally used to refer to as an organized repository of knowledge that comprises concepts, data, aims, requirements, rules and instructions 10]. On the other hand, KMS are conceived of as tools aimed at supporting knowledge management processes (KM), i.e. knowledge creation, storage and retrieval, the transfer of knowledge, the application of knowledge, and the flows between these processes [11], [12]. Taking into account these definitions and the previously mentioned features of PjBL, it is not difficult to conclude that the process pertaining to the dynamic development of an appropriate KB and the implementation of the KM system in engineering and technology education is extremely complex. This complexity also calls for a high level of explicit knowledge, tacit knowledge which is rooted in action, experience and participation in the specific context [11, 13], as well as a high amount of embedded knowledge, which resides in a number of norms, rules, processes, products, specific ethics, etc. [13].

In the light of this review, it seems fair to conclude that any application of the KB and KMS in project-based teaching should take into account all of the above, as well as the systematic assessment of the direct impact of KB and KMS on the student's overall achievements and competencies.

II. PROBLEM, AIMS AND RESEARCH CONTEXT

This research is concerned with the issues concerning the basic characteristics of the KB, but also the processes and KMS, important from the standpoint of cognitive impact and specificity with regard to the particularities of technology and engineering education. In the light of these issues, the present study poses the following research question: *Which essential features knowledge base and an appropriate knowledge management system should have in order to achieve the optimal cognitive effect in project-based technical (technology) and engineering education?* In other words, the aim of this research is to identify the basic elements and characteristics of the KB in project-based teaching, which are important from the point of view of their cognitive effect, namely to achieve the optimal level of student achievement.

In this respect, it is important to explain the context in which the research was conducted. The contexts of learning and teaching are particularly vital and they differ in terms of conditions, dispositional and experiential students' knowledge, but also in terms of the level of education. The research reported in this paper was carried out during the implementation of a project-based approach to the teaching of the course in *Practicum of the material processing*, which in fact represents an introductory engineering practicum. The aim of this practicum was to enable students, future engineers, to apply theoretical engineering knowledge to the development of products, as well as to perform different activities and standardized manual material handling (*Hands-on* activities). For a long time, this practicum has been taught in a traditional way. This means that students were not encouraged to developing products. Rather, they were given practical exercises that stimulated them to implement standardized manual material handling procedures. By observing that the competencies developed in such a manner do not satisfy the needs of the contemporary society, four years ago the traditional approach was replaced which project-based teaching and learning aimed at stimulating students to come up with product ideas, create products, adapt to conditions, make decisions about materials and resources, make the product, document and present their own project and product. The preliminary research into this approach has shown that some of the effects of project-based learning are better then the impacts exerted by traditional exercises [14]:

- Students find project-based learning and teaching more interesting than traditional approaches;
- Students believe that the quality of their technical knowledge and competencies is higher and that the knowledge and skills that they have acquired are more useful;
- The analysis of the results of students' activities shows a significantly higher level of product quality in their work;
- The analysis of the results shows a higher level of motivation, self-confidence, responsibility, and readiness for team work, especially in the final stages of project realization.

Despite the above-mentioned findings, the average level of students' achievements in project-based teaching context is not strikingly different from the level of achievements in the environment which adopts traditional teaching approach [14]. In this reseach, standard tools for measuring were used in order to measure workpiece precision and the quality of the documentation produced, as well as to assess the practical skills of applying standardized material processing. However, the achievements of those students who were provided with the opportunity for self-realization were significantly higher than students' achievements in those contexts which adopt traditional teaching approaches. Therefore, it ought to be emphasized that the value of PjBL lies in the possibilities of students' self-realization and the development of anticipatory, communicative, collaborative and socialization competencies, which are

nowadays regarded as the key competencies of an individual.

By analyzing the previous students' experience with technology as some kind of assumptions for successful PjBL, preliminary research [14] revealed a relatively low level of such experience. That can significantly influence the student's final competencies, but also determine all the stages and end result of project-based learning. Based on a short overview of students' previous experience (Table I), we can conclude that despite the fact that they have been attending various engineering courses for many years, most classes have a low level of real-world experience with technology. What remains an exception is a somewhat higher level of experience in the following areas: technical design and drawing, ICT experience, and experience in the e-learning environment. Such state of affairs seems to be the result of the educational system in the Republic of Croatia, where technical competencies are developed at a minimum level or are not developed at all in primary and secondary education. In such a context, which is still demanding and intensive, it is necessary to conform to students' expectations. Moreover, facilitating, moderating and encouraging should be more intensive.

TABLE I. AN OVERVIEW OF STUDENTS' PREVIOUS EXPERIENCE IN TECHNOLOGY AND RELATED AREAS

Areas of student experience	Approximate level
Experience with technology and technological equipment	**LOW**
Mechanical engineering experience	**LOW**
Technology design and drawing experinece	**MEDIUM**
Experience in the field of applied sciences and mathematics	**LOW**
Electrical engineering experience	**LOW**
Programming and program languages experience	**LOW**
ICT and e-learning environments experience	**MEDIUM**

Apart from the above, it should be emphasized that the research was conducted within a typical Croatian educational context whose characteristics are as follows: relatively limited resources and technical support, no qualified staff, fairly limited opportunities to find external partners for project cooperation and the difficulty of harmonizing such learning with the traditional teaching approaches. Taking into account the fact that there is no systematic strategic and organizational support for the integration of the relevant knowledge bases into a complete KMS, it is not difficult to conclude that teachers carry the burden of incorporating project-based teaching in the curriculum, and they have the obligation to cover necessary expenses.

Despite such circumstances, it is possible to organize and implement project-based teaching, whose results, guidelines and developed systems and mechanisms could be a good roadmap for the future implementation and the wider use of appropriate KB, KM and KMS in technology and engineering education.

III. RESEARCH METHODOLOGY AND SAMPLE

A. *Procedure-KMS developement*

For the purposes of the research, different and already available LMS and CMS systems and tools for the storage and dissemination of materials, as well as the ones for cooperation, communication and content exchange were used. The system was developed as a series of handheld mechanisms that provided content, problem tasks, and performed activities in various ways and with different dynamics. Therefore, no separate or specific software has been developed, but a dynamic mechanism that simulates KB and KMS, without elements of corporative strategy and policy. Due to the peculiarities of project-based technology and engineering education, which are characterized by the fact that in these areas of study the explicit and tacit knowledge is demonstrated and assessed through application and practice [17], the KM mechanism was based on a general theoretical framework. In this framework, which is considered to be a certain hybrid between the matrix of knowledge types and approaches proposed by Gamble and Blackwell [13] and the process model of knowledge management quoted by Botha et al. [15], individual activities have priority over technology. Technically, it is a platform of related and integrated data that is based on a model of the connected data architecture [16], and consists of the core of basic knowledge component, knowledge acquisition component, a set of meaningful links, a problem-solving component, and a component relating to communication and information exchange. More specifically, general knowledge consists of information on the structure of technical creations, products, materials, tools and machinery, processing methods, standards and technical equipment. The problem-solving component comprises: technical requirements for the realization and design of the mechanical construction, the selection of materials, procedures and equipment for the realization of the products, the selection and realization of the electrical and electronic circuits, and the realization of the program support and the circuit management codes. The knowledge acquisition component includes the contents and materials produced by the students, as well as students' segmented problem solutions. The validity of these contents and materials was verified by students during project implementation, with intensive use of the communication and information exchange component. Everything mentioned so far was related to a set of meaningful links, i.e. a separate component which was a link between the components, but also the links with external sources.

KB and KMS that were structured according to the above-mentioned procedure were used to facilitate students' project activities, research, decision-making, communication, content sharing, and problem-solving at the key stages of PjBL (Figure 1). Using KB and KMS, students designed the product, solved segmented problem tasks, produced documents, and valorised their own solutions during product realization. In practice, they

implemented their solutions, refined them, or revised them.

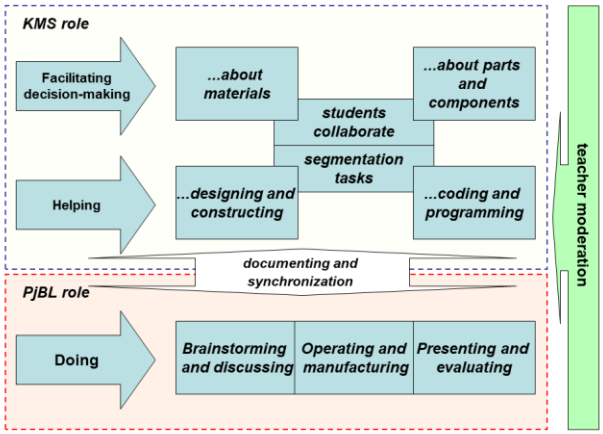

Figure 1. Logical scheme of the main KMS roles in PjBL

Consequently, they expanded their knowledge, developed new skills, and a knowledge acquisition component. In the end, they presented the acquired knowledge, the developed product, project documentation, experience and contributions to their colleagues.

B. Sample

The sample *(N = 56)* comprised undergraduate students of Polytechnics, University of Rijeka and the research was conducted during three academic years. The participants were the students enrolled in the 5th semester, who already had some background theoretical knowledge of sciences and the field of technical design, mechanical engineering, electrical engineering, computing and energy. Participants were not randomly selected. As a matter of fact, all students enrolled in a particular academic year participated in the study. During each academic year, students were engaged in designing, constructing and building prototypes, i.e. functional CNC milling machines and robotic arms. Project topics were chosen by students themselves, while the limitations were imposed by the teacher or the community. Limitations were related to the use of products, as well as the use of discarded materials, assemblies and parts (recycling), and the use of widely available and inexpensive microcontrollers and other development platforms. Activities were conducted in teams consisting of 7 to 10 students, and the teams were formed by the students themselves.

C. Instrument

In order to monitor the cognitive effect of the described mechanism and the progression of students, participative observation was applied, as a method of observing student behavior / response during the teaching activities. For this purpose, a semi-structured instrument was developed. In this instrument, students' achievements, which are relevant in terms the KB and KM, were thoroughly commented upon. The instrument consisted of predefined categories with descriptive observations / performance indicators. Performance indicators, which were carefully monitored and evaluated during the research by using the above instrument, were as follows:

- Students' engagement, orientation, as well as the level and intensity of teacher's intervention in the solving of partial problem tasks;
- Using sources, contents and other materials to sort out problems and providing feedback on partial problem solutions;
- The quality of produced documents and materials, as well as the overall impact on the achievements;
- The quality of communication, collaboration, and student materials shared by KMS;
- The quality of solution implementation, and the individual and collective presentation of their own activities.

According to this structure, predominantly collective observations were conducted, but also individual if they differed significantly from the group. With this structure of the instrument, the aim was to keep as much observations as possible within the ones that should primarily be the product of using the KB and KMS.

D. Data collection

The previously described instrument was used to note down observations from direct teaching during the 12 weeks of PjBL implementation. Even though the course in question is a one-semester course lasting 15 weeks, the first three weeks were dedicated to the performance of pre-tasks aimed at familiarizing and adjusting students with the conditions, means and the rules regarding the safe use of the equipment. Observations were written by the teacher, who is also the author of this article, after each week of classes, but also during the communication with students, by examining solutions that are shared through KMS and the evaluation of students' presentations. Observations were made continuously and especially after each modification of the KB. Through the modifications of the KB, we directly manipulated different levels and ways of adjusting content, events and segments of problem tasks, as well as ways of content dissemination during project realization. The modifications of the manipulated KB components are shown in Table II.

The research was carried out during the period of the three academic years and it included different student groups. The modifications were introduced in the same manner in all three groups. The default level of KB was used during the first 4 weeks, the first modification during the other 4 weeks, and the second modification during the last 4 weeks of PjBL. Since it was not possible to equalize the groups of students, only those observations that were common to all groups were taken into account. As the research was concerned with the characteristics of the knowledge base, it sought to keep the focus on those observations that were assumed to be the result of the KB and KMS used. All the observations were categorized according to the indicators and their percentage share in overall observations pertaining to each individual component and modification was determined.

TABLE II. MANIPULATED COMPONENTS AND THEIR MODIFICATIONS

Manipulated componet	Default level	First modification	Second modification
The core of basic knowledge	Digitized parts of high-tech resources - compulsory literature, technical manuals, scripts, presentations, existing databases.	Simplified and, schematic views, static images, simulations, separate explanations + technical manuals, existing databases.	Video presentations, schematic descriptions, separate explanations + technical manuals, existing databases.
The problem solving	Clear problem tasks (individual and group) + sources with which they can be solved.	Clear problem tasks (individual and group) + troubleshooting tips, accompanying sources.	Clear problem tasks (individual and group) + students 'expectations + segmented examples leading to the solution.
The meaningful links	Links between the components + links to additional sources and links to extremely similar project solutions.	Links between components + links to additional sources, links to selected project solutions and resources to solve partial problem tasks.	Links between components + links to additional sources, links to almost identical project solutions, and solutions to similar partial problem tasks.
Communication and cooperation	Communication via the official email + the associated LMS system for cooperation and the exchange of information and documents.	Communication, the exchange of information and documents via student e-mail and faculty network services.	Communication, the exchange of information and documents left to the students' free choice (mail, network services, social networks ...).

Only observations with a high percentage share in the overall observations relating to each modification (> 50%) were retained and descriptively modified in order to be comprehensible. The most significant findings, emerging from all the observations, were then grouped into complex categories and an appropriate interpretation of the observations was given. Based on the results, the main characteristics of the knowledge base and the knowledge management mechanism were identified. These characteristics could produce an optimal cognitive effect in the project-based teaching and learning which takes place in the context of technology and engeneering education.

IV. RESULTS

Upon carrying out the research, a total of 963 observations have been extracted from extensive records, produced materials, documents, project work results, and student presentations. In reference to the default, first and second modification, there were 248, 392 and 323 observations respectively. By creating logical links between observation categories and manipulated components, the most common observations pertaining to each manipulated component were identified (Table III). On the basis of such a linkage, the effect of these modifications on the project activities of students was determined.

In regard to the default (initial) level relative to "The core of basic knowledge" component, a high degree of disorientation of students (95%), a low level of understanding and the use of the proposed sources (64%) was observed. Furthermore, it should be pointed out that the impact of such sources on the achievements in project-based teaching was not entirely clear (55%). Although the understanding of the problem tasks (75%) was observed in reference to the "problem-solving" component, there was also a high intensity of teacher interventions (92%) and a low percentage of appropriate partial problem-solving (78%). As far as the "meaningful links" component is concerned, it ought to be emphasized that students were well-oriented (63%), but there was a low level of comprehension of the content they were studying (73%) and inappropriate adjustments to problem solving solutions emerging from the proposed sources (92%). In relation to the default level of the "Communication and cooperation" component, it was noticed that students communicated with the teacher only in order to fulfill their formal requirements (75%). Furthermore, a low level of the use of system for student communication and content exchange (62%) was identified, as well as a low level of production and a poor quality of materials exchanged by students through the system (54%).

The introduction of the first modification to "The core of basic knowledge" component resulted in a higher level of student orientation (69%), and stimulated further research and project activities (57%). Furthermore, it contributed to a high level of comprehension of the contents in the majority of students (75%), a faster development dynamics (73%) and the use of examples and materials to solve problems (89%). In relation to "The problem solving" component, an acceptable level of comprehension of problem tasks (82%), an acceptable level of student engagement (64%), and an acceptable level of satisfactory solutions to partial problem tasks (58%) were observed. Nonetheless, the findings relating to this component indicate a high degree of teacher's engagement in problem solving (56%) and student disorientation in using resources (51%). When it comes to the fist modification of "The meaningful links" component, an acceptable level of student orientation (78%) and a low degree of student engagement (67%) were detected. At the same time, there was a low level of understanding of the content needed to solve the problem (53%). Furthermore, students did not use resources which would help them solve partial problem tasks (57%). Students intensively tried to use the links for inappropriate adaptation of solutions to complete their own problem tasks (81%). In regard to the first modification of the "Communication and cooperation" component, a low level of communication with the teacher (52%) and an increased use of communication and content exchange system tools (71%) were noted. Moreover, it was observed that the level of production of the materials that students shared through the system was low, but of acceptable quality (52%).

The second modification relative to the "Core of basic knowledge" component resulted in good student orientation (89%) and their high motivation for project activities (78%). Regardless of that, there was a low level of content understanding (91%), a low level of use of sources which would facilitate problem solving (83%) and a basic level of achievement (76%). At the same time, this component did not have a clear impact on the dynamics of student development in project-based learning (89%). In relation to the second modification of the "Problem solving" component, an acceptable level of understanding of problem tasks (76%) and student engagement (65%) was observed. There was also a noticeably lower degree of teacher intervention in problem solving (84%), an acceptable use of prepared resources and materials (88%)

and a high quality of partial problem solving (73%). The "Meaningful links" component showed the acceptable orientation (79%) and engagement of students (93%) and an acceptable level of understanding of the content needed to solve partial problem tasks (87%).

TABLE III. MOST FREQUENT OBSERVATIONS FOR EACH MODIFICATION AND MANIPULATED COMPONENT

Manipula-ted compo-nent	**Observations and percentages**		
	Default level (n=248)	*First modification (n=392)*	*Second modification (n=323)*
The core of basic knowled-ge	- A low level of student orientation (95%); - Low student engagement (72%); - Only excellent and experienced students understand the content (64%); - Sources for solving problems are not used (92%); - Without a clear impact on achievement in project-based learning (55%).	- A high level of orientation (69%); - Stimulates further research and project activities (57%); - A high level of understanding of content in most students (75%); - Examples are used to solve the problem (89%); - Noticeably higher level of achievement, better performance and development dynamics (73%).	- A high level of orientation (89%); - Stimulates project activities (78%); - A low level of content understanding (91%); - Sources are not used to solve the problem (83%); - Basic level of achievement (76%); - Without a clear impact on the performance and dynamics of student development (89%).
The problem solving	- An acceptable level of understanding of problem tasks (75%); - A low level of student engagement (63%); - A high degree of teacher intervention in solving partial problems (92%); - High disorientation in using available resources (84%); - A low level of performance and appropriate solutions to partial problem tasks (78%).	- An acceptable level of understanding of problem tasks (82%); - An acceptable level of student engagement (64%); - A high degree of teacher engagement in problem-solving (56%); - Disorientation in using resources (51%); - An acceptable level of appropriate performance and solutions to partial problem tasks (58%).	- An acceptable level of understanding of problem tasks (76%); - An acceptable level of student engagement (65%); - Considerably less intervention of a teacher in problem solving (84%); - Acceptable orientation in resource-using (88%); - High quality solutions to partial problem tasks (73%); - High quality of performance and the presentation of the project (68%).
The meaning-ful links	- An acceptable level of student orientation (63%); - A low level of student engagement (87%); - A low level of the understanding of the content needed to solve the problem (73%); - Intensive attempts at inappropriate adjustment of completed solutions (92%); - Without a clear impact on achievements in project-based learning (67%).	- An acceptable level of student orientation (78%); - A low level of student engagement (67%); - A low level of understanding of the content needed to solve the problem (53%); - Intensive attempts at inappropriate adjustment of completed solutions (81%); - Low level of resource use in problem-solving (57%).	- An acceptable level of student orientation (79%); - Acceptable student engagement (93%); - An acceptable level of understanding of the content needed to solve the problem (73%); - Noticeably less attempts at inappropriate adjustment of completed solutions (59%); - An acceptable level of the use of custom sources and materials (80%).
Commu-nication and coopera-tion	- Communicating with the teacher only for the purpose of meeting formal requirements (75%); - A low level of the use of the communication and content exchange system (62%); - Low production and quality of contents being shared and exchanged (54%).	- Low level and the intensity of communication with the teacher (52%); - Intensive use of tools and systems for student communication and content exchange (71%); - Low production, but acceptable contents being shared and exchanged (52%).	- Intensive mutual communication and use of tools and content exchange systems (82%); - High production of content being exchanged (68%); - Significantly higher quality of solutions and materials being exchanged (67%); - Acceptable communication with the teacher (64%); - Procedure and way of creating content is mostly hidden from the teacher (87%).

Observation revealed noticeably less attempts at inappropriate adjustment of completed solutions (59%) and an acceptable level and way of using custom sources and materials (80%). By providing students with the freedom of choice of communication tools and systems, were observed more intensive use of communication tools and content exchange systems (82%), high production and content exchange of students' own materials (68%), and a significantly higher quality of their solutions and materials (67%) was observed in reference to "Communication and cooperation" component. However, communication with the teacher was only at an acceptable level (64%), while the procedures and ways of creating shared content were mostly hidden from the teacher (87%).

V. DISCUSSION

Based on the observations pertinent to each modification of the KB, which indicate an acceptable or very acceptable effect on performance indicators, and by making a comparison between the features of each modification, it is possible to identify the main features each component needs to meet. For the component "The core of basic knowledge", the most optimal effect on the observed indicators was observed in the first modification. This indicator points out that the core of basic knowledge, which is appropriate for engineering PjBL, should be characterized by appropriate and simplified visualization, schematic representations, static images, simple interactive simulations and various explanations. These explanations should also refer to highly specialized sources and databases. As far as the "problem solving" component is concerned, the optimal effect on students' achievements was observed in reference to the second modification. This indicator shows that the problem-solving component should contain clear problem-based tasks, individual and group, as well as clear student expectations, accompanied by incentive problem-solving sources. The sources in this component are segmented examples of solutions to the problem tasks, which logicaly guide students to more effectively find solutions for solving their own partial problem tasks. In doing so, students adopt and apply the underlying logic, which is clear from the above examples and which leads them to the solution of the problem. It is extremely important not to give the students solutions to their problems, but only segmented solutions to similar problems. Namely, completed solutions will trigger the action in PjBL, but will not stimulate the student's mental effort that is essential for a successful learning process. With regard to the "The meaningful links" component, the best effect is expressed also in the second modification. Given the differences in modifications, it is obvious that linking to similar examples to problem-solving makes the main difference in comparison to other changes. It is therefore clear that the links should include those that will show the student partial solutions to similar problems and thus lead to success. When it comes to the "Communication and cooperation" component, the optimum effect is observed in the second modification. This means that the knowledge base and knowledge management system should allow students a free choice of tools and ways of communications, collaboration and sharing their own contents. Such a way of communication and cooperation, though largely beyond the control of teachers, probably provides the students most effective work environment.

Among the findings outside the context of the processed results, one should also consider some more important observations. When it comes to expert sources (manuals, standards, literature, material bases, tool specifications, etc.) without which it is not possible to develop a product or technology, it should be observed that students are intensively using them only during the preparation of the final documentation and project presentation. Until then, they mostly make use of various types of scripts, internet sources (often unreliable) and prepared (simplified) materials that are part of the core of basic knowledge. Therefore, sources relating to this component are used only if their level of adjustment is in the "cognitive range" of the student. For this reason, it is extremely important to form the core of basic knowledge that it is tailored to the cognitive level of students and comprises only available and highly specialized resources that will gradually become understandable and applicable in the final stage of project-based learning. When it comes to single project-based teaching phases, the research has shown that most of students' time is spent on developing and realizing mechanical prototype design, despite the fact that they have mastered most of the engineering subjects. Thus, the seemingly trivial problems of mechanical construction, in actual realization, become a major obstacle for students. Another major problem arises when connecting the knowledge from programming with the knowledge of electronic and computer hardware, in spite of high level of knowledge in programming, as well as the knowledge of computers, electrical assemblies, interfaces, actuators, sensors, etc. However, linking these knowledges into the meaningful logical concepts for the computer managing of developed prototype is a bigger problem for students. Resolving these two issues, unfortunately, does not facilitated by many examples of the ready-made solutions, but only with segmentation of each problem into smaller, logically related and cognitively appropriate examples.

Although the features of KM and apropriate KMS are apparent from the observations of the effects of each modification, the possible limitations of the research results should be highlighted. Namely, here are not controlled variables of possible external influences on the observed indicators. At the same time, the observed groups were groups of students whose characteristics were not uniform before the research was conducted. Also, it was not possible to distinguish the possible impact of maturation of students during classes, which is not a negligible factor. All this points to the necessity of further research in which these limitations will be controlled, but in which the actual impact of KB and KM on the students' achievements will be determined more precisely.

VI. CONCLUSION

The essential features of the KB and KMS, which are important from the point of view of the optimal cognitive effect they exert in project-based technology and engineering education, were identified based on the results emerging from participant observation. In this way, an answer to the research question was provided, even though this answer will surely require additional scientific confirmation. On the basis of the above-mentioned features, the following conclusions were drawn: a) the core of basic knowledge should be characterized by simplified visual representations, schematic views, static images, simple interactive simulations (appropriate abstractions) and distinct clarifications; b) the problem solving component should include clear individual and collective tasks, clear student expectations, and segmented and logically related examples of similar problem solving, rather than complete solutions; c) meaningful links should necessarily contain more (but not too much) links to the solutions of similar partial problems, which will logically lead students to their own solutions; and d) communication, collaboration and content exchange should be tailored for students, i.e. the system should enable free choice of the use of known and available communication systems and tools (i.e. teachers do not exert full control). In order for project-based learning to exert optimum cognitive effect, what is extremely important is students' practical valorisation of their own solutions directly in the teaching process. Another aspect that should not be neglected is the importance of the students' presentation of the project's final result (product), in which the preparation of appropriate KB and KMS can play an important role. During practical valorisation and the preparation for the results' presentation, students improve their own knowledge, but also the component of knowledge acquisition without which KB and KMS are incomplete.

Finally, computer knowledge base and KMS in project-based technology and engineering education should facilitate project work for students in terms of decision making, problem solving, cooperating and content exchange, rather than becoming self-sufficient. It should not be forgotten that the development of tacit knowledge, which can be gained and valorised only through practice, is the main goal of the project-based teaching which takes place in technology and engineering education. However, tacit knowledge is not the focus of this research.

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In Search of a Syllabus: Comparing Computer Science Courses

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***Abstract* - With the trend of globalization, there is an increasing need for an international computer science syllabi repository, using which students and teaching staff could explore and compare courses on various higher education institutions. Such a system would be vastly beneficial for exchange students as it could provide them a metric when choosing their destination. Driven by that need, a web application named CSyllabus was developed. After acquiring initial course data, currently from 11 universities, minimal attributes found throughout the dataset were defined. Course comparison algorithm was implemented using Latent Semantic Indexing from Gensim library based on comparing aforementioned attributes. To provide institutions the means to manage their syllabi data, keeping it precise and up-to-date, REST API was built with a supporting administration panel. Following the release, a poll was taken among users to evaluate the influence and usefulness of the CSyllabus web application.**

Keywords* - *syllabus; courses; computer science; university; faculty; student exchange; text comparison; text mining; latent semantic analysis; latent semantic indexing; web application

I. INTRODUCTION

Being a good academic citizen in today's world means that you are constantly broadening your perspective through learning new things. In recent years, a new type of learning has risen up - learning by traveling to foreign universities. More and more students and teaching staff use the possibility of going to an academic exchange. Signing up for an exchange requires submitting documents about courses that interested students want to enrol in. Courses have to be similar to the courses they would have at their home university. As there is no systematic reliable way to compare courses taught at different universities, it usually comes down to manually comparing all course descriptions from foreign university syllabuses with the courses from their home university.

This paper introduces a possible solution for comparing syllabi data using web application named CSyllabus which provides that functionality using Latent Semantic Indexing algorithm, described in [1] and [2]. Besides Comparator, application has the Explorer part which offers the possibility to search for courses by keywords. Furthermore, CSyllabus administration panel was implemented for university administrators to create, edit or delete courses (course data) or to control data pushed through the API so the application has precise and up-to-date syllabi data.

The problem was approached by studying different syllabus formats from various universities after which defining the problem statement and requirements was performed in several ways:

- through the online questionnaire, friends and acquaintances
- through faculty Erasmus coordinator and with help of currently enrolled Erasmus students
- through IT department of Faculty of Electrical Engineering and Computing

The main problem found was that syllabi come in different formats and forms so the database had to be designed to handle them all.

The rest of the paper is organized as follows: Section 2 discusses related work and similar applications, Section 3 presents the system architecture and application design, Section 4 describes implementation with an emphasis on implementation of the course comparison and data collection. In Section 5 the resulting application is presented, in Section 6 product evaluation taken among students is described. The paper ends with the conclusion and future work in Section 7.

II. RELATED WORK

There are several papers and platforms regarding syllabus repository at one centralized location. This section goes through three most popular solutions and analyzes the biggest differences between them.

Mastersportal[1] explores over sixty thousand courses on Master's level of studying all over the world. With great awareness of usability, the portal provides information about the course that user has explored. The portal also includes financial information on the costs of a semester at a particular faculty.

Universities and Colleges Admissions Service (UCAS) [2] is a platform used for connecting people who study on higher educational institutions. As Masterportal, this page contains the possibility of finding courses, but

[1] Masters Portal [Online]. Available: https://www.mastersportal.eu/

[2] UCAS [Online]. Available: https://www.ucas.com/

unlike Masterportal this page focuses on UK area only. UCAS offers user registration and enrollments to a certain course over their platform. With registration feature, UCAS is able to engage the user throughout the whole process from finding to enrolling a course.

The Open Syllabus Project (OSP)[3] was one of the first efforts to create a large-scale online database of university course syllabuses. OSP has three main strategies for collecting syllabi:

1. Scraping publicly-available (e.g., university) websites.
2. Securing agreements with universities for access to syllabus archives.
3. Receiving 'donated' syllabi from individuals.

With these strategies, they have managed to successfully map more than one million syllabuses to their database. The platform provides syllabus explorer part, where a user has the possibility of filtering syllabuses by field, institution, state and country. Their future work is about making visualization of explorer part, releasing an API endpoint for syllabus metadata access and tripling the size of syllabus database.

In all such systems, the basis for comparing and analyzing courses is a kind of text search comparison algorithm. Here, the related work on LSA algorithm is presented, as it is one of the most often used text comparison methods.

In [3], authors focused on visualizing document similarity using N-Grams and Latent Semantic Analysis method. They were able to show strong capabilities in discovering literal similarity. That result shows a step towards intelligent similarity detection between documents and in future could be used to compare whole syllabus documents.

In [4], authors offer practical recommendations whilst working with Latent Semantic analysis (LSA) algorithm. They involve text pre-processing and term-filtering with the removal of names, numbers, abbreviations, slang, acronyms, punctuation and low frequent words.

Experiments in [5] show the comparison of both LSA and Latent Dirichlet allocation (LDA) document classification algorithms with that of human classification capabilities. Human classification outperformed both algorithms with up to 94% success rate with classifying at a higher level of abstraction, whilst at the same abstraction level both LSA and LDA had a success rate of 84%.

In [6], authors compared LSA and LDA algorithms in finding movie similarities based on IMDB database using topic modeling from movie plots. Authors had better results using LSA algorithm, coming very close to similarity results from IMDB data extracted from user preferences.

In [7], authors used LSA to identify the emerging research trends in OpenStreetMap (OSM). Study identified five core research areas and fifty research trends within the corpus of 485 academic abstracts of papers published during the period 2007–2016.

Having in mind what papers and platforms already exist, this paper introduces web application which compares courses using LSA algorithm.

III. System Architecture And Design

The system architecture is comprised of five main modules each with completely distinct functionalities, organized into a three-tier architecture (Figure 1). Apart from the scalability, deployability, and testability of this architecture, it is also designed to facilitate our distributed development process wherein distributed teams assume the responsibility of developing and maintaining separate modules.

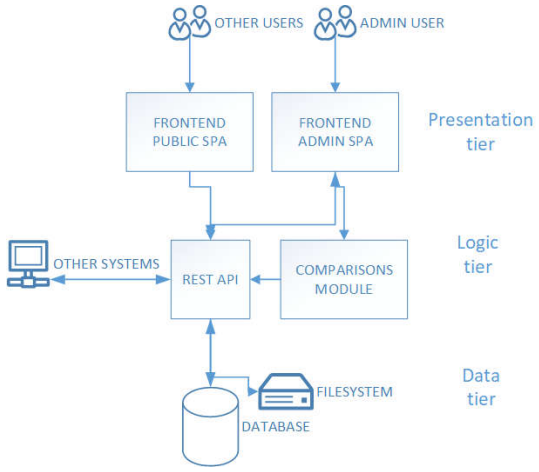

Figure 1. High-level architecture diagram of CSyllabus application

A. Data tier

The data tier consists of an SQL database and a server file system. The database stores universities, course, and user data as well as cached output of the course comparison model.

In designing the data model, special care was taken to ensure the robust handling of logging changes in the entities and creating a synchronization logic to coordinate with the systems that are the originators of each piece of data.

The database is implemented using PostgreSQL. One of the primary benefits of working with PostgreSQL is its ability to provide full text search. This feature is used to provide a course-search-by-keyword functionality.

B. Logic tier

The logic tier is separated into two modules. The first module serves as a REST interface to the data layer. The second module is event-triggered; it runs the course comparison model and caches the results in the database. The REST interface enables interoperability and scalability when connecting to other systems.

[3] The Open Syllabus Project [Online]. Available: https://opensyllabusproject.org/

We used the Python Django framework for development. In addition to being fast, secure, scalable, and versatile, it provided us the option to use Gensim[4], which is an open source topic modeling library. Its LSA implementation is used for text comparison, which is a core part of the system's course comparison functionality.

C. Presentation tier

Driven by a fat client architecture, the presentation tier is separated into two single-page applications. One application is for general public users and the other serves administrative purposes. This allows for self-deployable and self-testable modules.

This tier is developed using the Angular 4[5] framework with Material components. This enables us to build a responsive and fluid web application which adheres to the Material design guidelines.

IV. Implementing The Web Application

As we started implementing previously described design, a great importance was quickly acquiring course data of at least a few different universities so that we could import into our system some initial data. The requirement here was that our application data presented to end user had to be correct and up-to-date. Additionally, the results of our course comparison functionality had to be as precise as possible. Subsections IV.A. and IV.B. describe how we tackled each of these challenges.

A. Data collection

In the data collection phase, we contacted approximately thirty universities, of which eleven provided us with course data from their databases. In fact, many of the universities we contacted answered and supported the CSyllabus project, and granted us permission to use data scraped from official university pages. A common explanation was that it was too difficult to extract information from their systems. Unfortunately, receiving a one-time data dump does not allow us to update our data if and when it changes in the university's systems. After closely investigating approaches to scrape the university webpages, which we deemed unreliable and tedious to perform, we decided on using data that was provided to us by the original eleven universities.

Taking our experience trying to acquire data into consideration, a choice was made to design a REST API through which university web administrators could push the data into our system. We used Google API[6] and JSON style[7] guides to define its resources, since these are viewed as the standard guides. The API is accompanied with an administration panel through which one can edit the data as well.

After we had accumulated sufficient course data, we began to analyze and determine a minimal set of necessary attributes from each of the entities. These attributes, which are course name and course description, are required for pushing data through the API. Thus, all university data in our system have at least these fields populated.

B. Implementation of the course comparison

The documents in our implementation of the comparison algorithm are simply pairs of course names and descriptions. These are the minimal attributes of each course in our dataset. Vector combinations of the most influential keywords are then extracted out of corpus of those documents; these are also referred to as topics. Each document can then be assigned a vector representation of topics. Their mutual similarity can be calculated by their cosine similarity.

In the work of [5,6], similar datasets to ours were considered and LSA was found to perform better than LDA. We therefore chose to utilize LSA (precisely that which Gensim implements). Note that LSA is also commonly referred to as Latent Semantic Indexing (LSI).

Two common pitfalls with vector space representations in classical natural language problems are synonymy and polysemy. The former is agnostic to the fact that different words can have the same meaning. The latter refers to two identical words having different meanings. LSA uses co-occurrence of terms in these documents to alleviate this problem and capture the latent semantic association between them.

It is common [4], to remove stop words (provided by the nltk library) and low-frequency words. After applying these filters, the feature space still consisted of 4600 distinct keywords.

LSA will lower this dimensionality to a value k using Singular value decomposition (SVD), in that process compressing co-occurring words together. The value k is free to choose, the only restriction is that is less than the original rank.

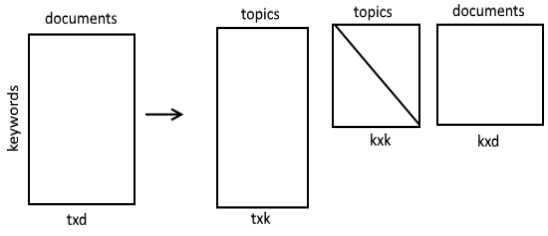

Figure 2. Illustration of SVD in LSA

Experimental results in [1] and [8] have shown that using a value in the low hundreds yields best results. We specifically used value 125, as it gave best results for our heuristic method of finding maximum comparison value for the courses we identified manually as being the best matches.

[4] Radim Řehůřek and Petr Sojka, Software Framework for Topic Modelling with Large Corpora [Online]. Available: https://radimrehurek.com/gensim/

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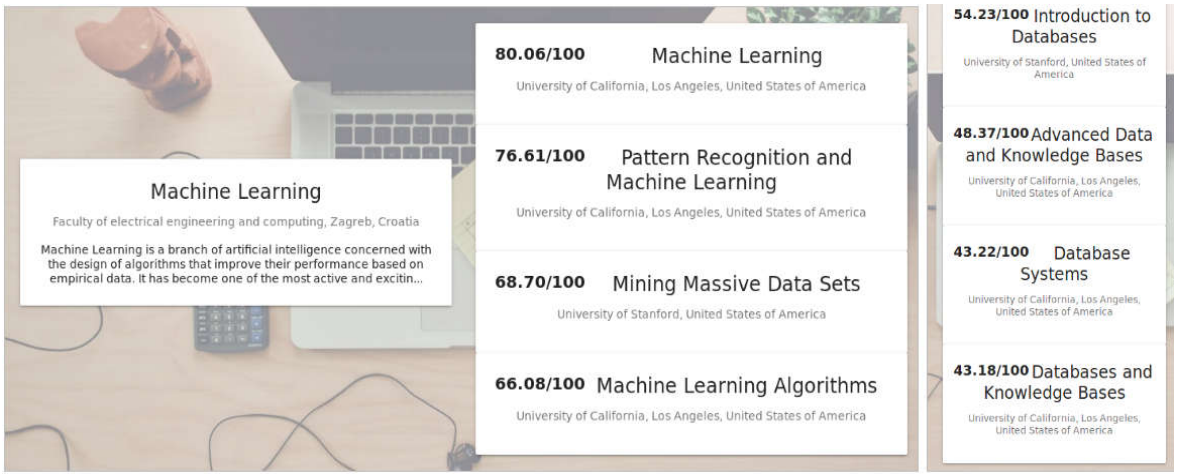

Figure 3. Desktop and mobile view of Comoparator results

Since running the algorithm is time consuming, it is set to run at predefined intervals (timed intervals or changes in course data) and the results are saved to a cache table in the database. Queries that are performed actually return cached results from the database.

C. *Resulting application*

After consulting with Faculty IT department, Erasmus coordinator, students and friends, application's user interface was designed following their inputs. They all agreed it should be simple to use. One of the comments gotten in the anonymous poll created after initial application launch confirms the acceptance of their advice: *'Very intuitive and nice looking application which can make life a little bit easier for transfer students from all over the world'*.

Regarding its functionality, the application can be separated into two parts: Explorer and Comparator. Explorer part can be used to search by keywords the syllabuses of universities currently available in database. Comparator was implemented using LSI algorithm which is described in Section IV.B. and it is the part of the application that distinguishes it among others because, as written in Section II., not many of them have the possibility to calculate the score of comparison between two syllabuses.

The results of Comparator for *Machine Learning* course *(Databases* for mobile view) from Faculty of Electrical Engineering and Computing compared to all universities from United States of America are shown in Figure 3. The results are sorted by LSA similarity score.

University administrators can keep the course data in our system up-to-date with their databases through our REST API. Authentication is done using JSON Web Tokens (JWT) and the credentials users get once they are registered in our system. In addition to the API, Administration panel was implemented in which only authenticated users can login and modify syllabuses. The idea was to create one user for each university that will keep data from his university precise. When the administrator logs in, he obtains the list of courses from his university which can be edited or deleted and he can create a new course.

V. EVALUATION

An evaluation of our system was carried out by 17 students from FER using an online questionnaire. They were guided through the CSyllabus web application and asked to rate their satisfaction with the results obtained through Explorer and Comparator on a scale of 1 to 10. A score of 1 corresponds to "*the results do not match my search"* and a score of 10 corresponds to "the *results match my search completely*".

In the Explorer portion of the questionnaire, students often searched for the keywords 'machine learning' and 'algorithms'. The average satisfaction here was 9.35. In the Comparator section, they were asked to choose three courses and compare them with courses at another university or country. Most survey-takers chose FER for their home institution and the USA as a foreign destination. For 60 courses students compared, the average score for the most similar results given was 8.32. The perceived usefulness of this application received an average score of 8.9.

Figure 4 highlights the relationship between user satisfaction with the course comparison result and the course similarity score obtained through LSA. It is evident

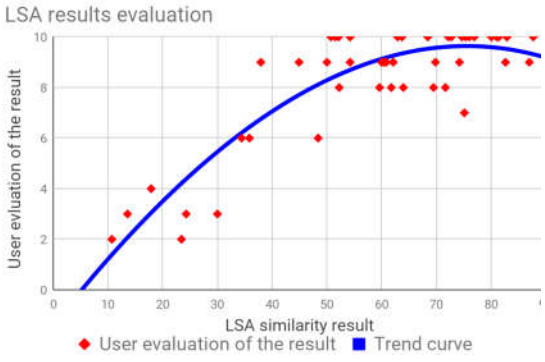

Figure 4. LSA results evaluation

that the higher the LSA similarity score, the more likely a user is to be satisfied with the result. For similarity rates higher than 40%, user satisfaction is mostly confined in the interval between 8-10. The takeaway is that results with higher similarity rates felt correct to them.

VI. Conclusion And Future Work

The idea of CSyllabus is to have one big repository of Computer Science courses which can be explored or compared. Having the repository of courses and the possibility to search them by keyword can be found in some web applications as mentioned in Section II. However, CSyllabus is one of the first web applications to face the problem of comparing courses based on syllabi description using LSA.

The use of this application enables professors to compare their courses with similar ones on other universities and students to search or compare courses before their exchange. Having these options just a few clicks away could be encouraging for users, but for a broader usage it is vitally important to involve more universities and to keep their data precise. For this reason, the administration panel was implemented. By using it, the university administrator can modify the syllabus data of their institution.

Evaluation of the application carried out among students using the questionnaire has shown positive responses for every part of the application and its usefulness.

This project has a bright future only if it gets adopted by the community. In order to do so, universities have to understand the advantages of this application. Our plan is to collect relevant data through logging user behaviour. It will include statistics which keywords, courses and universities were searched the most in a certain time frame. Some of the data will be shown on the public web site while more in-depth university specific analysis will be available in the administration panel.

The next step in the project plan is integration with faculty web systems. If Explorer and Comparator are available in faculty web systems, the project will have more visibility, reputation and credibility. To do so, SDK collection of custom code libraries will be provided to faculty admins. With proper community adoption, we believe that CSyllabus would become the first step for comparing and exploring foreign faculty courses.

The current version of the application is live and available at https://csyllabus.com/.

Acknowledgment

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We would like to thank all the contributors to the final product.

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Discovering e-Learning Process Models from Counterexamples

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***Abstract* - In our paper we are examining the application of process mining techniques in the development of adaptive e-learning systems such as Intelligent Tutoring Systems. Process mining techniques can discover business process models from event log data. Here, we will use process mining to discover and add new useful tutoring sessions (learning paths) to our adaptive e-learning system. E-learning knowledge base is an ontology (union of taxonomies) of a chosen domain. Using data in the ontology we build a directed acyclic graph with nodes (states) and labeled transitions (questions), or more formally, as a deterministic finite automaton (DFA). Each tutoring session is a run of the DFA, or in process mining terminology: one learning process model. We will apply well-known Angluin's L* algorithm on the data from e-learning system log files to discover new useful tutoring sessions which can be added to the e-learning system DFA. We will present use case examples based on our e-learning system used on our course *Fundamentals of Electrical Engineering*.**

Keywords - adaptive e-learning systems; process mining; Angluin's L* algorithm

I. INTRODUCTION

Modern online educational systems are constantly evolving to attract new users and keep current ones. Adaptive e-learning systems, online courseware systems, Intelligent tutoring systems (ITS) and Massive open online courses (MOOC) are developing new functionalities primarily focused on adaptivity, personalization and interactivity. Besides formal education and training, e-learning systems are increasingly used in life-long education, informal and collaborative learning, which can also further expand their user base. Usually, in an advanced e-learning system user activity is recorded in great detail and stored in the system's database and event logs. This can result in a great amount of valuable educational data and other useful user data, which could be challenging to effectively track and analyze.

We can look on each recorded session of user's activity on an e-learning system as a short (educational or learning) process, e.g. a student logs in, downloads lecture notes, solves a practice test and then logs out. This leads us to the process mining techniques, which were primarily developed to analyze business processes through discovering process models from stored data in server event logs. Event logs contain users' activity data as sequences of timestamped event records.

In this paper we will be examining the potential for using process mining techniques in e-learning systems. We will focus on analyzing tutoring sessions (learning paths) in which a student gets a list of practice questions. Each learning path is a sequence of questions based on the domain ontology, which we build using Formal concept analysis. We will discover underlying e-learning process model, which corresponds to a recorded learning path. To achieve this we will use Angluin's L* algorithm, which learns unknown deterministic finite-state automatons using queries and counterexamples. Also, we will try to fix learning paths or generate new useful learning paths. Furthermore, we plan to add this method to our e-learning system *WebOE*[1] which is regularly used on our course *Fundamentals of Electrical Engineering* at Faculty of Electrical Engineering and Computing.

The rest of the paper is structured as follows: in the second section we give an overview of related research, in the third section we provide background details necessary for our research. In the fourth section we propose a method for e-learning process model discovery from counterexamples, and in the fifth section we present and discuss preliminary results from our e-learning system. Finally, we conclude the paper in the sixth section.

II. RELATED RESEARCH

As we have stated previously, process mining is mostly used for business process analysis, and it is especially valuable when dealing with a large amount of data (*Big data*) [1,2]. But, there are already some interesting applications of process mining in the educational domain.

In [3] authors used process mining to study different issues related to authoring and personalization of online assessment procedures within the series of the multiple choice question tests of different styles (strict order of questions and feedback information or flexible order of questions but no feedback information).

In [4,5,6] authors analyzed students' performance on online courses using process mining techniques. As expected, students who failed the course spent less time watching online lectures before the midterm and final exams. In [6] authors have also found positive correlation between online lectures viewing behaviour and final grades. From our experience (and data) we can confirm

[1] http://osnove.tel.fer.hr

that the students who failed our course also spent substantially less time actively using our e-learning system.

III. PRELIMINARIES

In this chapter we will give a brief overview of the basic theoretical background, and also describe the methods and techniques used in our research.

A. Ontology

Domain knowledge is defined by building an ontology. In this research we will use broad definition of an ontology from [7]: „Ontology defines the kind of things that exist in the application domain“. Another notion related to an ontology is a taxonomy (meaning *an arrangement*) which is also used as a basic classification system. In computer science the terms ontology and taxonomy are sometimes used interchangeably, but we can view a taxonomy as a *tree* structure, and an ontology as a *forest* (a union of taxonomies).

In this research we deal with concepts and their objects and attributes, thus our ontologies will define a hierarchy of such concepts. To build our domain ontology we will use the method of Formal concept analysis.

B. Formal concept analysis

Formal concept analysis (FCA) is a machine learning method for knowledge representation, data analysis and information management. FCA can identify and visualize in a concept lattice all the formal concepts and their mutual relationships from prepared tabular data. This method was developed in the 1980s by Rudolf Wille on the mathematical foundations of the lattice theory and set theory [8,9]. The method of FCA is used in various fields, such as data mining and information retrieval, and also for building taxonomies and ontologies [10,11,12].

Input data for the FCA method must be prepared as a matrix (data table). Each row of the matrix represents one object, and each column represents one attribute. To fill this matrix we must select a set of objects from the domain of our interest, and define a set of attributes that can sufficiently describe those objects. Matrix elements can only contain Boolean values. This means that every object either has or does not have one of the defined attributes. If an object has an attribute we put a marking „X“ in the input matrix on the corresponding element, and otherwise it will stay blank [8,9]. In our research objects will be questions from the e-learning system database, and a defined list of attributes will semantically describe the questions. Prepared input matrix is called a *formal context*. A formal context is a triple $<X, Y, I>$, that contains non-empty sets of objects X and attributes Y, and a binary relation between X and Y. The method of FCA identifies all the *formal concepts* from the prepared formal context [8,9].

A formal concept is a pair $<A, B>$, where $A \subseteq X$ and $B \subseteq Y$, where every object $a \in A$ has every attribute from set B, and each attribute $b \in B$ is shared among all the objects from A. All the formal concepts are ordered hierarchically, with a superconcept–subconcept relation in a structure called a *concept lattice*. Superconcept–subconcept relationship is defined with a partial order relation (symbol $\leq$). A superconcept is more general (contains fewer attributes and more objects) than the subconcept (contains more attributes and fewer objects). Therefore, the top formal concept contains all the objects and the set of their shared attributes. Also, the bottom formal concept contains all the attributes and a set of their shared object [8,9].

Concept lattice of a formal context $<X, Y, I>$ is a structure defined as $\{\boldsymbol{B}(X, Y, I), \leq\}$, where $\boldsymbol{B}(X, Y, I)$ is a collection of all formal concepts and $\leq$ is a partial order relation. Concept lattice is a partially ordered set, which can be drawn as a directed acyclic graph (DAG). The nodes are formal concepts and all the directed arcs are oriented from the superconcepts (top) to the subconcepts (bottom) [8,9]. In this research a concept lattice (also called a *Hasse diagram*) will be our domain ontology.

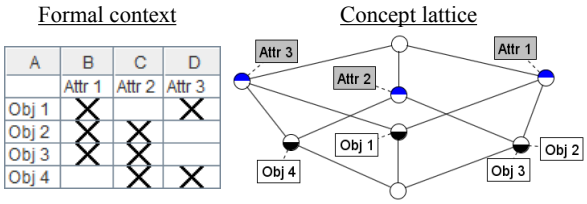

Figure 1. FCA example – a formal context and its concept lattice

In the Fig. 1 we show a simple formal context that contains 4 objects and 3 attributes, and its resulting concept lattice, which consists of 8 formal concepts. For this example we used *Concept Explorer* program [13]. Note that here it is implied that the concept lattice arcs are directed from superconcepts to subconcepts (top to bottom). By convention each attribute is displayed only in its highest formal concept (all of its subconcepts also contain that attribute), and each object is displayed only in its lowest formal concept (all of its superconcepts also contain that object).

C. Topological sorting

There are various sorting algorithms from the field of graph theory that can topologically sort DAGs. The input for a topological sorting algorithm is a partially ordered set (DAG), and the output is the corresponding totally ordered set (*chain*). For each edge uv in the DAG G, node u is placed before node v in the topologically sorted list. The solution is not always unique, there can be multiple valid topological sorts of the same DAG [14,15]. A simple example of topological sorting in shown in Fig. 2.

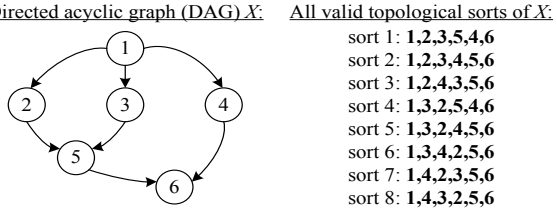

Figure 2. An example DAG and its topological sorts

Topological sort of a concept lattice is a linear sorted list of formal concept nodes that preserves all the

superconcept–subconcept relationships. From this list we will extract possible sequences of questions that will be used to identify the underlying e-learning process model (deterministic finite automaton).

D. Deterministic finite automaton

A deterministic finite automaton (DFA) A is a 5-tuple $A = (Q, \Sigma, \delta, q_0, F)$, that consists of a finite set of states (Q), a finite set of input symbols called the alphabet (Σ), a transition function ($\delta : Q \times \Sigma \rightarrow Q$), a start state ($q_0 \in Q$) and a set of final (accepting) states ($F \subseteq Q$) [16].

When we draw a graph of an automaton, transition function δ is represented by a labeled directed arc (input symbol a) between two nodes (states). The set of all strings (sequences) of input symbols that will lead the DFA from the start state (q_0) to one of the accepting states is the *regular language* of the DFA [16].

E. Angluin's L* algorithm

L* algorithm (also called *Lstar algorithm*) is an established algorithm for learning DFAs. It was published in 1987 by Dana Angluin in [17]. This algorithm defines an exact learning method for discovering a regular language and its DFA from examples of its members and nonmembers. The L* algorithm formally describes a *Learner* that interacts with the *Teacher*. The Learner must know the alphabet Σ of the unknown regular language. Through a query–answer interaction with the Teacher, Learner gradually discovers the unknown DFA and its regular language. Learner submits two types of queries to the Teacher – *membership queries* and *equivalence queries*. Also, it is assumed that the Teacher knows the correct regular language that the Learner tries to identify and that the Teacher will provide correct answers to Learner's queries. Therefore, the Teacher must give a yes/no answer to Learner's membership queries, which ask if a given word is in the correct regular language (is it accepted by the unknown DFA or not). Furthermore, the Teacher must answer to Learner's equivalence queries. With an equivalence query a Learner wants to know if its hypothesis DFA corresponds to the correct DFA. If the Learner's hypothesis DFA is not correct, the Teacher will give the Learner *a counterexample*, which is a word from the correct regular language that is not yet accepted by the Learner's hypothesis automaton [17]. The Learner incorporates this counterexample into its knowledge base and proceeds with another round of membership and/or equivalence queries until it successfully identifies the unknown regular language. In this research we will use an interactive run of the Angluin's L* algorithm through the *libalf* framework [18], where the user can assume the role of the Teacher.

F. Process mining

Process mining is a novel method that enables process analysis, based on the event logs. This method can extract useful information from a large quantity of data (*Big data*). Process mining uses event logs data to identify business process models, which can be further analyzed, fixed or improved. Event log is a textual file that contains records on a sequence of events marked with a timestamp and other identifiers. Each event is an activity (a defined step in the business process). Each activity belongs to a case or a process instance (usually called a *trace*). Therefore, each trace is a sequence of events (or in this research a sequence of questions). Using specialized process mining tools we can identify and visualize underlying business process models from the vast data contained in the event logs [1,2].

IV. Proposed Method for E-Learning Process Model Discovery from Counterexamples

The basis of the proposed method is the domain ontology that contains all the concepts from the domain knowledge together with their superconcept–subconcept relationships. The domain ontology will be constructed automatically using the method of FCA from the selected set of semantically annotated questions. Resulting ontology will be the knowledge base, which will be used to construct new learning paths and also check, fix or improve previous learning paths identified from the e-learning system's event log data. We set following restriction on the learning paths: each sequence of questions must respect the hierarchical order of their concepts from the ontology. Therefore, all learning paths should cover a set of questions starting with the easier or more general questions, and then gradually advancing to heavier or more specific questions.

The overview of our method is shown in Fig. 3, and afterwards we explain all the major steps in more detail.

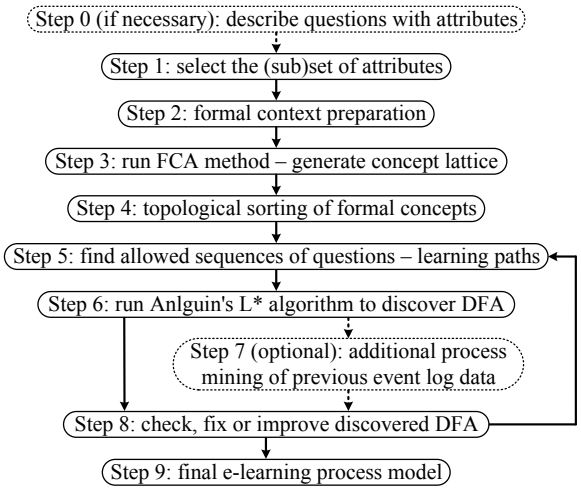

Figure 3. Our method for discovering e-learning process models

Step 0: If necessary, semantically annotate questions from the e-learning system database, with an adequate predefined set of attributes.

Step 1: Decide on the scope of the ontology – select complete set of attributes to get the entire ontology (whole domain knowledge), or select only a subset of attributes to restrict the size of the resulting ontology (focus on a part of the domain knowledge, e.g. a specific unit or lesson).

Step 2: Automatically prepare the formal context based on the set of selected attributes in Step 1.

Step 3: Automatically run the Formal concept analysis method (e.g. *Concept Explorer* program [13]), which finds a concept lattice – an ontology of the domain knowledge.

Step 4: Topologically sort the concept lattice (partially ordered set) to get corresponding linear list (totally ordered set) of formal concepts (e.g. using *tsort*, a *Linux* command line program [19]).

Step 5: From the linear list of formal concepts extract allowed set of learning paths.

Step 6: Run the Angluin's L* algorithm (e.g. *libalf* framework [18]), and answer its membership and equivalence queries and provide counterexamples, so it can discover a DFA, which will accept all the learning paths listed in Step 5. This automaton is the basic e-learning process model.

Step 7 (optional): Run an additional analysis of previously collected data on manually prepared practice tests from the e-learning system's database and event logs. Use process mining tools (e.g. *ProM* [20]) to identify process models from the recorded traces (learning paths).

Step 8: Analyze how the discovered basic e-learning process can be improved or fixed. Optionally, compare the discovered basic e-learning process model from Step 6 and process models from Step 7. If necessary, return to Step 5 adding new allowed learning paths to the set of sequences of questions, else proceed to Step 9.

Step 9: We get the final, refined e-learning process model, which can be implemented in an e-learning system.

V. RESULTS AND DISCUSSION

We will present two examples of applying proposed method for discovering e-learning process model using data from our e-learning system *WebOE*. System's database contains almost 3300 questions of various types. Furthermore, available questions are static, parameterized or automatically generated based on a simple template. Stored questions are already semantically annotated using a predefined set of 50 attributes [12], therefore in our examples we can skip the Step 0 of the proposed method.

A. First example

For this simpler example we have chosen only a small subset of attributes – 10 attributes, which cover basic notions of direct current (DC) circuits. We have also randomly chosen 7 questions that have those attributes (Step 1). One of those questions is shown in the Fig. 4. This is an automatically generated question with a subset of attributes (*resistance*, *Ohm_law*, *voltage*, *current*).

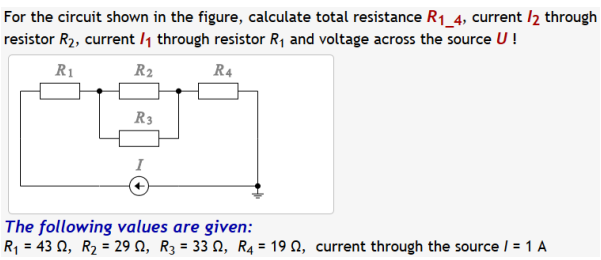

Figure 4. A question automatically generated from a basic template

For the Step 2 of our method an input for the FCA method (formal context) is automatically prepared (attributes are obtained from the database). The formal context is shown in the Fig. 5. Note that the question shown in the Fig. 4 corresponds to the question 0 in the Fig. 5.

	current	resistance	voltage	Ohm_law	potential	power	Kirchhoff_laws	real_source	superposition	Thevenin
0	×	×	×	×						
1	×	×	×	×	×					
2				×		×	×		×	
3			×					×	×	
4	×	×	×	×		×	×			×
5	×	×	×	×	×	×	×	×	×	
6	×	×	×	×	×					

Figure 5. Formal context for the first example

Step 3 results with the concept lattice shown in Fig. 6. This is our domain ontology and it contains 13 formal concepts (enumerated FC1–FC13), and 20 edges.

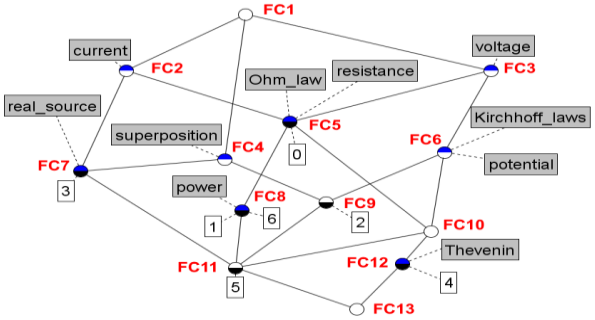

Figure 6. Concept lattice for the formal context in Fig. 5

In the Step 4 we topologically sort formal concepts from the concept lattice in Fig. 6. We get the following topological sort of formal concepts: **FC1 → FC2 → FC4 → FC3 → FC5 → FC7 → FC8 → FC6 → FC9 → FC10 → FC12 → FC11 → FC13**. Remeber that there can be multiple valid topological sorts of the same DAG, this will be addressed in our second example.

In the Step 5 we extract a list of objects (questions) from the topologically sorted list of formal concepts. We see from the concept lattice in Fig. 6 that the formal concept FC8 has two objects (question 1 and question 6). This means that we will get two different learning paths, which both correspond to the topological sort of the concept lattice found in the Step 4: **0316245** and **0361245**.

Afterwards, in Step 6 we use Angluin's L* algorithm to discover DFA which accepts all learning paths. We decided that the DFA must accept both the complete and incomplete learning paths. This often occurs in practice, when the students don't complete the practice test. In this case we identified 10 incomplete learning paths. Therefore, we will consider in total 12 learning paths: 0, 03, 031, 0316, 03162, 031624, 0316245, 036, 0361, 03612, 036124, 0361245. We define that the alphabet has 7 symbols (questions): 0, 1, 2, 3, 4, 5, 6. Furthermore, as we take the role of the Teacher we know that the target language is L_1 = (ε, 0, 03, 031, 0316, 03162, 031624, 0316245, 036, 0361, 03612, 036124, 0361245). Note that we added the empty word ε. The entire Learner–Teacher interaction is shown in the Fig. 7.

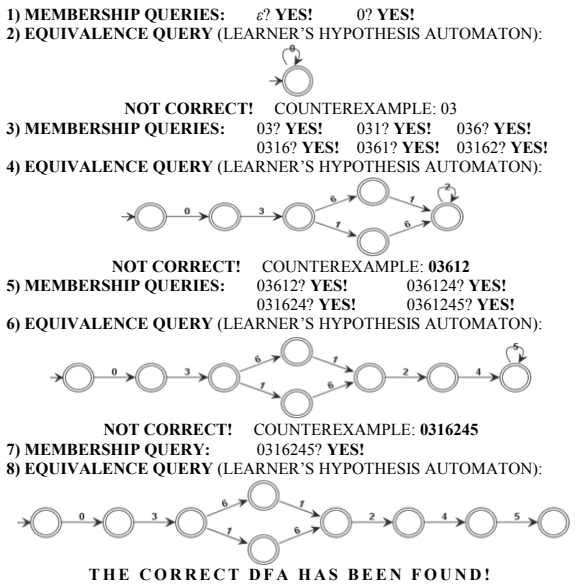

Figure 7. Process of discovering DFA for the language L_1

B. *Second example*

We will also present a more complex example, where we have randomly chosen 10 questions from *WebOE* database, which cover a subset of 12 attributes that sufficiently describe various types of three-phase electric power system problems. In this case all the selected questions are static or parameterized. We show the automatically prepared formal context in Fig. 8 and the resulting concept lattice in Fig. 9.

	resistance	capacitance	inductance	impedance	Millman_theorem	AC_power	3phase_star_sym	3phase_star_asym	3phase_delta_sym	3phase_delta_asym	3phase_neutral	3phase_faults
0						×	×				×	
1	×	×	×	×	×			×				
2				×		×		×			×	
3				×		×		×			×	
4	×	×	×	×		×				×		
5	×	×		×				×			×	
6	×	×		×				×				
7				×			×					
8	×			×					×			×
9	×				×	×		×			×	×

Figure 8. Formal context for the second example

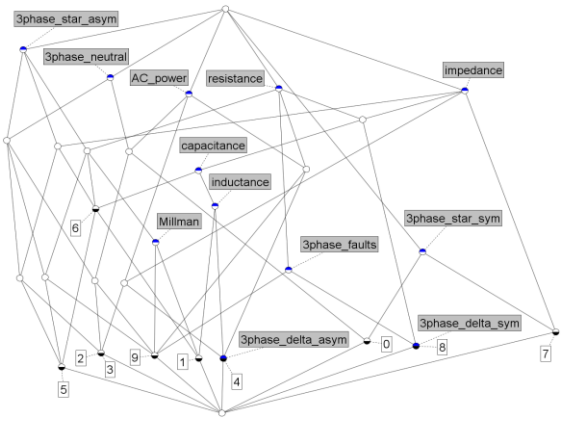

Figure 9. Concept lattice for the formal context in Fig. 8

Concept lattice in Fig. 9 contains 31 formal concepts and 64 edges, which makes it much more complex than the concept lattice from the first example (Fig. 6).

Concept Explorer program allows us to save the description of the generated concept lattice in a text file. From that text file we extract the structure of the concept lattice as a list of connected pairs of nodes (formal concepts). Afterwards, we topologically sort the formal concepts using *tsort* program. If we just change the order of node pairs in the input list, the *tsort* program will generate different valid topological sorts of the same DAG. We have used this technique to obtain seven different valid topological sorts of the formal concepts in the concept lattice in Fig. 9. From those topological sorts we have identified 10 different complete learning paths: 9320567418, 9230567418, 3290564718, 2390564718, 9320564718, 9230564718, 3290567418, 2390567418, 9320547618 and 9230547618. Furthermore, from this list we have also identified 55 more different incomplete learning paths. Using Angluin's L* algorithm we want to discover a DFA with an alphabet (0, 1, 2, 3, 4, 5, 6, 7, 8, 9), which will have to accept language L_2 consisting of an empty word ε and 65 learning paths (10 complete and 55 incomplete). The discovered e-learning process model (DFA) is shown in Fig. 10. The resulting DFA is more complex than the DFA from the first example (Fig. 7) because there are more questions and more different ordering options. However, note that the DFA is still far simpler than the corresponding concept lattice in Fig. 9. The DFA has 21 states and 25 transitions, and the concept lattice has 31 nodes and 64 edges.

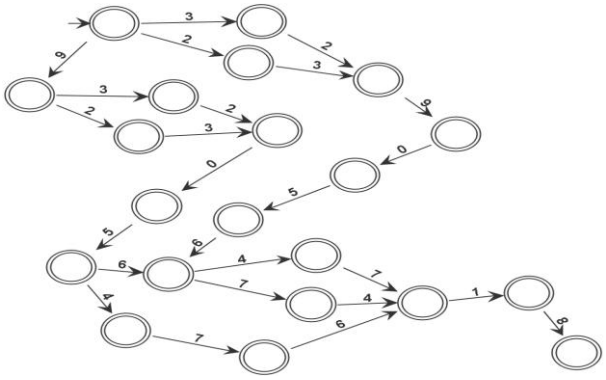

Figure 10. Discovered DFA in the second example

C. *Refining discovered e-learning process models*

In the optional Step 7 of our method we could use process mining tools to analyze event log data of the previously recorded practice sessions. We can reuse the same process mining methods and techniques used for business process analysis by the principal researcher in [2]. Our e-learning system contains a lot of manually entered predefined practice scenarios, or practice test where the order of questions does not necessarily respect the superconcept–subconcept relationships in the questions' ontology. Often, the order of the questions in those manually authored practice tests is random. Therefore, the process mining will identify many new e-learning process models from the event logs, which will not all make much sense. But, we could use our method to

compare those event log process models with the process model derived in Step 6 (for the same set of questions). Then, we could decide to fix old practice tests, or to refine our ontology (Steps 0 – 3).

In the Step 8 we analyze the e-learning process models from the Step 6 (and the optional Step 7) and check if they can be improved (or fixed). We can consider this as the *process repair* in process mining terminology. In the first example the discovered e-learning process model (Fig. 7) is very basic. Therefore, we can return to the Step 5 of the method and e.g. decide to double questions 4 and 5 that appear in the learning paths. Note that in our case student will not get pairs of identical questions 4 and 5 in a row, because we selected questions that are parameterized or even automatically (randomly) generated (as in Fig. 4).

After repeating Steps 5 – 8 we would get a new, refined DFA, shown in the Fig. 11. As we are satisfied with the result, we move to the Step 9 and start to implement these new learning paths in the adaptive e-learning system

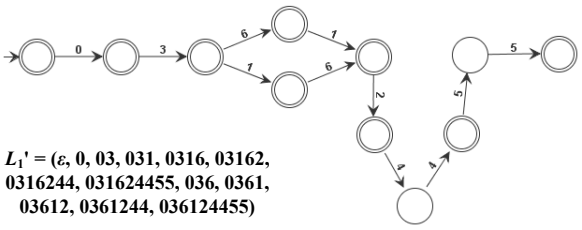

Figure 11. Refined DFA which now accepts the language L_1'

As one can see from the results, our proposed method can be used to identify e-learning process models from a domain ontology. In our examples we used the knowledge domain of basic notions of electrical engineering, but the method can be used for any knowledge domain. Note that the main prerequisite for the application of the proposed method is a semantically annotated set of questions with a set of defined attributes that adequately describes the chosen domain.

VI. CONCLUSION

In this paper we have presented our method for e-learning process model discovery from counterexamples. We have shown that using Formal concept analysis, topological sorting algorithms and Angluin's L* algorithm we can discover e-learning process models of various complexity from the underlying domain ontology. We can use process mining methods and techniques to further refine those process models. Finally, we can implement all the discovered e-learning process models as new learning paths in adaptive e-learning systems.

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How faculty from Rijeka and Split use Web-based scientific literature: analysis based on four variables

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Abstract - **We have explored the extent to which faculty use various web sources of scientific literature. The findings were analyzed in relation to four variables: age and gender of study participants; field of science in which they work; their practices of exchanging scientific literature. The questionnaire was sent to employees at the Faculties of Humanities and Social Sciences, as well as to the employees of various science faculties in Croatian cities Split and Rijeka. It was found out that there are significant differences in use of web portals. More than half of participants from the fields of social sciences and humanities use very frequently Croatian portal Hrčak, in relation to only 4% of participants from the field of natural sciences. For participants in humanities the Croatian portals are most important. Scientists from the field of social sciences mostly use foreign portals. Scientists from the field of natural sciences are the most frequent users of pirate portals. It was established that older participants use most frequently Croatian portals. Younger participants most frequently use foreign and pirate portals. Croatian and foreign web portals are most frequently used by female participants, while male participants are most frequent users of pirate portals.**

Keywords - web sources of scientific literature; faculty; Hrčak; Google

I. INTRODUCTION

Various web sources of scientific literature are available to faculty in Croatia. However, there is not much research about the use of these web sources by faculty. One of the few scientific papers on this topic is written by M. Duić, B. Konjevod and L. Grzunov. In this paper, published in 2017, the research goal was exploring to what extent scientists and teachers at the Faculty of Humanities and Social Sciences, as well as at the Faculty of Science at University of Zagreb, use various web sources of scientific literature [1]. Authors also explored their practices and attitudes related to availability and use of scientific literature accessible on the web. The findings have shown that Google scholar is the most popular web source for finding and accessing literature. Participants often use other web sources, such as, Research Gate, Science Direct, Hrčak, Academia.edu, DOAJ. There were also approximately one fifth of participants who use pirate web portals, such as, Sci-Hub and Library Genesis. It is important to note that huge majority of participants confirmed that they are not satisfied with the offer of international scientific literature which is available in Croatia through subscription by scientific institutions.

II. AVAILABILITY OF SCIENTIFIC LITERATURE IN CROATIA

The finding that huge majority of study participants are not satisfied with the offer of scientific literature is alarming. These study participants are members of the most reputable and largest faculties at University of Zagreb and therefore it could be expected that they should have an adequate access to scientific literature. But majority of them claim that there they don't have adequate access[1]. Based on that finding, the following question could be asked: If the faculty doesn't have adequate access to scientific literature, how could they achieve their scientific and teaching goals? The same question could be asked in relation to other faculty members in Croatia. Although there is deficiency of research studies about this topic, it could be assumed that this problem is present not only in most reputable and large Croatian faculties, but in other faculties as well. It is important to notice that this problem of unavailability of scientific literature could be more pronounced in countries, such as Croatia, which doesn't have sufficient financial resources to cover the expenses for expensive subscriptions for web databases containing scientific literature. However, even scientific organizations in economically more developed countries have financial problems with payment of these subscriptions. For example, an advisory council of reputable Harvard University claims that largest scientific publishers have made scientific communication unsustainable and limiting for academic activities. Therefore, the university wants that its scientists publish papers in open access journals [2]. The problem of expensive, unsustainable subscriptions for scientific databases is described in literature as *the publishing crisis*. I. HebrangGrgićdescribes the problem in more detail [3] [4]. She states that long before the advancement of digital publishing, commercial publishers were buying many scientific journals. Their goal was to rise up the prices of journal subscriptions and acquire more profit. Gradually, the high prices have caused canceling of subscriptions by libraries and other institutions. These processes have led to insufficient availability of information for scientists. If some subscribing institution doesn't have enough

financial power or the institutional will to pay for the subscription, researchers and teachers will stay without access to scientific papers and other materials which they need for their work. They are therefore motivated to find alternative ways for accessing the required literature. One possibility is to ask other Croatian or foreign researchers and teachers to send them literature. Another possibility is that they buy required literature at their own expense which is a legitimate way, but it is probably not financially sustainable. They could also try to find required literature by using free web sources, such as, Croatian portal of open access literature Hrčak [5]. Or they could use international portals, such as, Google Scholar [6], ResearchGate [7]. They could even use pirate, hidden digital libraries. Pirate libraries are digital libraries which contain a huge amount of digital texts often deposited without consent of copyright owners [8]. In these libraries the texts are freely available. They have many users from each part of the world. There are even used by many users from economically more developed, very rich countries [9]. Large and popular pirate digital libraries are Library Genesis [10] and Sci-Hub [11]. In this study we will explore the frequency of faculty's use of all these various web sources of scientific literature.

III. RESEARCH METHODOLOGY

The research goal of this paper is to explore the faculty' use of various web sources of scientific literature in relation to four variables. The research results were analyzed in relation to the following four variables: age of study participants (participants who don't have more than 39 years; participants who are at least 40 years old); gender of participants; field of science in which participants are working (social sciences, humanities, natural sciences); participants' practices of exchanging scientific literature (how often participants ask other persons to send them scientific literature). To acquire these insights, the questionnaire was sent to employees with teaching and research responsibilities at the two Faculties of social science and humanities in two big Croatian cities - Split and Rijeka [12] [13], as well as to the employees with teaching and research responsibilities of various science faculties in Split and Rijeka [14] [15]. The questionnaire was available on web and at the beginning of July 2017 the request for participating in this survey was sent by e-mail to 642 faculty employees: 281 e-mails for employees in Split, 361 e-mails for employees in Rijeka. During July and August 2017, the questionnaire was completed by 108 employees who work in different domains of knowledge, primarily in natural sciences, social sciences and humanities. About 17% of faculty employees filled the survey. Therefore, the findings acquired through this research are representative.

The questionnaire consisted of 19 questions and some of them contained additional questions. Through these open and closed questions we explored: demographic characteristics of participants (age, gender, work position...); frequency of use of particular web sources (Google Scholar, Research Gate, DOAJ, Hrčak, university library portals, pirate web portals...); frequency of asking other people to send them scientific literature; opinions about topics related to use of web for acquiring scientific literature: satisfaction with availability of scientific literature in Croatia; opinions about subscription to scientific databases, opinions about open access to scientific literature, etc. The questions were based on literature review, as well as personal insights and experiences about practices and important issues related to the topic. Namely, author of the paper is also a teacher and researcher at Croatian university and therefore had a good opportunity to gain many insights and experiences about faculty practices and opinions related to use of web sources of scientific literature.

The survey was anonymous because it allows participants to give more sincere answers about their practices and opinions. The anonymity is especially important because some delicate questions were asked. For example, participants were asked to express their practices and opinions related to use of illegal, pirate portals. Many findings were acquired through this survey, therefore, in this paper only part of these findings is presented and analyzed: the findings related to four variables mentioned at the beginning of this chapter.

IV. FINDINGS

Among 108 participants who answered the questionnaire there were about 65% female participants. The majority of study participants are 30 to 39 years old (about 43%). There are about 17% participants that are 40 to 49 years old, about 17% participants that are 50 to 59 years old and about 15% participants that are 20 to 29 years old. The questionnaire was filled by about 35% of participants who work at the University of Split and about 57% of participants who work at the University of Rijeka. It wasn't determined in which institution other study participants are employed. The majority of study participants are working in the field of social sciences (37%), there are about 31% of participants from the field of humanities and 22% of participants from the field of natural sciences. The smallest percentage of participants are working in the fields of technical sciences (about 6%) and interdisciplinary sciences (about 4%).

A. Analysis based on first variable: field of science

In Table 1 participants' answers are presented in relation to three fields of science in which majority is working: humanities (30.6% or 33 participants), natural sciences (22.2% or 24 respondents), and social sciences (37% or 40 participants).

In the first line of Table 1, we can see how often study participants use web portal Google scholar to access scientific literature. Participants were giving grades from 1 to 5 for this and other statements in questionnaire. Grades 1 and 2 indicate that they never or almost never use Google Scholar, while grades 4 and 5 indicate that they often or very often use that portal. It is important to note that same meaning of grades applies to all survey statements. Already at this first question, answers indicate significant behavior difference between participants from different fields of science. Namely, results indicate that 60% of participants from the field of social sciences often or very often use Google Scholar, in relation to about 37%

of participants from the field of humanities and social sciences. In the second line of Table 1, we can see how often study participants use portal ResearchGate to access scientific literature. There are only about 15% of participants from humanities who often or very often use this portal, in relation to 50% of participants from the field of natural sciences and 65% of participants from the social sciences who are the most frequent users of ResearchGate. In the third line of Table 1, we can see how often participants use portal Hrčak to access scientific literature. About 75% of participants from humanities often or very often use this portal, in relation to 65% of participants from the field of social sciences. Interesting finding is that there is not even one participant from the field of natural sciences who often or very often uses Hrčak. In the fourth line of Table 1, we can see how often participants ask authors to send them their published texts. Participants from the field of social sciences most frequently engage in this activity. There are about 32% of these participants who often or very often ask authors to send them texts. They are followed by participants from the field of natural sciences (25%), while the least inclined to engage in this activity are participants from the field of humanities (about 12%). In the fifth line of Table 1, we can see how often participants ask persons from Croatia who are not authors of requested texts, to send them these texts. Participants from the field of social sciences and natural sciences most frequently engage in this activity. There are about 25% of these participants who often or very often ask persons from Croatia to send them texts. The least inclined to engage in this activity are participants from the field of humanities (about 6%). In the sixth line of Table 1, we can see how often participants ask persons from abroad who are not authors of requested texts, to send them these texts. There are about 25% of participants from the fields of social and natural sciences who often or very often ask persons from abroad to send them texts. There are about 18% of participants from the field of humanities who often or very often ask persons from abroad to send them texts.

In three last lines of Table 1, we can see how often study participants use three types of web portals for accessing scientific literature: Croatian portals, foreign portals, pirate portals. In the seventh line of Table 1, we can see how often participants use Croatian web portals. These portals are mostly used by participants from the fields of humanities and social sciences - about 63% of participants use them often or very often. It is interesting that Croatian portals are often or very often used by only about 4% of participants from the field of natural sciences. In the eighth line of Table 1, we can see how often participants use foreign web portals. These portals are mostly used by participants from the field of social sciences - about 85% of participants from this field use them often or very often, in relation to about 70% of participants from the field of natural sciences and about 48% of participants from the field of humanities. In the ninth line of Table 1, we can see how often participants use pirate web portals. These portals are mostly used by participants from the field of natural sciences - about 33% of participants from this field use them often or very often, in relation to about 27% of participants from the field of social sciences and about 24% of participants from the field of humanities.

TABLE I. PARTICIPANTS' ANSWERS IN RELATION TO THE FIELD OF SCIENCE IN WHICH THEY ARE WORKING

	Humanities		Natural sciences		Social sciences	
	Sources of literature		Sources of literature		Sources of literature	
	grade 1 &2	grade 4 &5	grade 1 &2	grade 4 & 5	grade 1 & 2	grade 4 & 5
Google Scholar	36.4%	36.4%	37.5%	37.5%	28%	60%
Research Gate	60.6%	15.2%	33.3%	50%	20%	65%
Hrčak	3.1%	75.8%	79.2%	0%	17.5%	65%
Request to auth.	63.6%	12.1%	58.3%	25%	50%	32.5%
Request to pers. in Cro.	72.7%	6.1%	62.5%	25%	52.5%	25%
Req. to persons from ab.	60.6%	18.2	58.3%	25%	55%	27.5%
Croatian web por.	12.1%	63.6%	83.3%	4.2%	17.5%	62.5%
Foreign web por.	21.2%	48.5%	29.2%	70.8%	7.5%	85.1%
Pirate web por.	70.1%	24.2%	58.3%	33.3%	62.5%	27.5%

grade1 = never, gr. 2 = almost never, gr. 4 = often, gr. 5 = very often

B. Analysis based on second variable: age of participants

In Table 2 participants' answers are presented in relation to their age. The answers of participants who don't have more than 39 years are presented, in relation to the answers of participants who are at least 40 years old. There are 62 participants (57.4%) who don't have more than 39 years, and there are 38 participants (42.6%) who are at least 40 years old.

In the first line of Table 2, we can see how often study participants use portal Google scholar for accessing scientific literature. Younger participants use considerably more often this portal - about 53% of younger participants (up to 39 years of age) often or very often use this portal, in relation to about 34% of the older participants (40 years of age and older). In the second line of Table 2, we can see how often participants use portal ResearchGate for accessing scientific literature. About 50% of younger participants often or very often use this portal, in relation to 33% of older participants. In the third line of Table 2, we can see how often participants use portal Hrčak for accessing scientific literature. Here, the situation is somewhat different. There are about 56% of older participants who often or very often use this portal, in relation to 47% of younger participants. In the fourth line of Table 2, we can see how often participants ask authors to send them their published texts. In this activity there is also primacy of older participants of which 33% often or very often ask authors, in relation to about 15% of younger participants. Older participants are also more inclined to ask texts from people who are not authors, but who could have them. Namely, in the fifth line of Table 2,

we can see how often participants ask persons from Croatia who are not authors of requested texts, to send them these texts. About 24% of older participants often or very often ask them for texts, in relation to about 13% of younger participants.

In the sixth line of Table 2, we can see how often study participants ask persons from abroad who are not authors of requested texts, to send them these texts. About 33% of older participants often or very often ask them for texts, in relation to about 16% of younger participants. In the seventh line of Table 2, we can see how often participants use pirate web portal Sci-Hub. Younger participants are much more often using this portal - about 24% of younger participants use it often or very often, in relation to about 9% of older participants. In the eighth line of Table 2, we can see how often participants use pirate web portal Library Genesis. It is interesting that this portal is used evenly by young and old participants - about 15% of all participants use it often or very often.

TABLE II. PARTICIPANTS' ANSWERS IN RELATION TO THEIR AGE

	Participants who don't have more than 39 years		Participants who are at least 40 years old	
	Sources of lit. grade 1 & 2	grade 4 & 5	Sources of lit. grade 1 & 2	grade 4 & 5
Google Scholar	25.8%	53.2%	50%	34.8%
ResearchGate	29.1%	50%	52.2%	32.6%
Hrčak	35.5%	46.8%	23.9%	56.5%
Request to authors	62.9%	14.5%	52%	32.6%
Request to per. in Cr.	62.9%	12.9%	63.1%	23.9%
Req. to per. from abroad	64.5	16.3	52.2	32.6
Sci-Hub	59.7%	24.2%	76.1%	8.7%
Library Genesis	75.8%	14.5%	84.8%	15.2%
Croatian web portals	40.3%	41.9%	26.1%	52.2%
Foreign web portals	14.5%	71%	26.1%	63.1%
Pirate web portals	59.7%	30.6%	71.7%	17.4%

grade1 = never, gr. 2 = almost never, gr. 4 = often, gr. 5 = very often

In three last lines of Table 2, we can see how often study participants use the following types of web portals for accessing scientific literature: Croatian portals, foreign portals, pirate portals. In the ninth line of Table 2, we can see how often they use Croatian web portals. These portals are mostly used by older participants - about 52% of older participants use them often or very often, in relation to about 42% of younger participants. In the tenth line of Table 2, we can see how often participants use foreign web portals. In opposition to Croatian portals, the foreign portals are mostly used by younger participants - 71% of younger participants use them often or very often, in relation to about 62% of older participants. In the eleventh line of Table 2, we can see how often participants use pirate web portals. These portals are also mostly used by younger participants - about 31% of younger participants use them often or very often, in relation to about 17% of older participants.

C. Analysis based on third variable: gender of participants

In Table 3 participants' answers are presented in relation to their gender. There were 65.7% or 71 female participants and 34.3% or 37 male participants. In the first line of Table 3, we can see how often participants use portal Google scholar for accessing scientific literature. Female participants are the most frequent users of this portal - about 53% of female participants often or very often use Google scholar, in relation to about 30% of male participants. In the second line of Table 3, we can see how often participants use portal ResearchGate for accessing scientific literature. Female participants are also the most frequent users of this portal. There are about 51% of female participants who often or very often use ResearchGate, in relation to about 27% of male participants. In the third line of Table 3, we can see how often participants use portal Hrčak for accessing scientific literature. The difference in favor of female participants is even more pronounced. It is used often or very often by 62% of female participants, in relation to about 30% of male participants.

TABLE III. PARTICIPANTS' ANSWERS IN RELATION TO THEIR GENDER

	Woman		Man	
	Sources of literature grade 1 & 2	grade 4 & 5	Sources of literature grade 1 & 2	grade 4 & 5
Google Scholar	25.4%	53.5%	56.8%	29.7%
ResearchGate	31%	50.7%	54.1%	27%
Hrčak	21.1%	62%	48.7%	29.7%
Croatian web portals	22.5%	59.2%	56.8%	21.6%
Foreign web portals	9.9%	74.7%	37.8%	54.1%
Pirate web portals	73.2%	19.7%	48.7%	35.1%

grade1 = never, gr. 2 = almost never, gr. 4 = often, gr. 5 = very often

In three last lines of Table 3, we can see how often study participants use three types of web portals to access scientific literature: Croatian portals, foreign portals, pirate portals. In the fourth line of Table 3, we can see how often they use Croatian web portals. These portals are mostly used by female participants - about 59% of female participants use them often or very often, in relation to about 22% of male participants. In the fifth line of Table 3, we can see how often participants use foreign web portals. It is interesting that these portals are also considerably more often used by female participants - about 75% of female participants use them often or very often, in relation to about 54% of male participants. In the sixth line of Table 3, we can see how often participants use pirate web portals. These portals are more often used by male participants - about 35% of male participants use

them often or very often, in relation to about 20% of female participants.

D. Analysis based on fourth variable: practices of exchanging scientific literature

In Table 4 participants' answers are presented in relation to the frequency with which they are asking other people to send them scientific literature. In "Part 1a" and "Part 1b" of Table 4, we can see characteristics and answers of participants who almost never or never ask other people to send them scientific literature. There are 38.9% of participants who belong to this group, i.e., 42 participants who answered with grades 1 and 2, the following question: How often they ask other people to send them literature? In "Part 2a" and "Part 2b" of Table 4, we can see characteristics and answers of participants who often or very often ask other people to send them scientific literature. There are about 9.3% of participants who belong to this group, i.e., 10 participants who answered with grades 4 and 5, the following question: How often they ask other people to send them literature?

TABLE IV. PARTICIPANTS' ANSWERS IN RELATION TO THEIR PRACTICES OF EXCHANGING SCIENTIFIC LITERATURE

	Part 1a. Participants who never or almost never ask others to send them scientific literature		Part 2a. Participants who often or very often ask others to send them scientific literature	
	Participants' characteristics		Participants' characteristics	
Woman	64.3%		90%	
Man	35.7%		10%	
Social sciences	28.6%		60%	
Humanities	31%		10%	
Natural sciences	26.2%		30%	
	Part 1b. Sources of literature		Part 2b. Sources of literature	
	grade 1 & 2	grade 4 & 5	grade 1 & 2	grade 4 & 5
Google Scholar	45.24%	31%	10%	70%
ResearchGate	45.2%	33.3%	20%	70%
Sci-hub	76.2%	16.7%	60%	0%
Croatian web portals	42.9%	38.1%	10%	70%
Foreign web portals	33.3%	52.4%	10%	80%
Pirate web portals	73.8%	16.7%	60%	20%

grade 1 = never, gr. 2 = almost never, gr. 4 = often, gr. 5 = very often

In "Part 1a" of Table 4, we can see characteristics of participants who never or almost never ask other people to send them scientific literature: female - 64.3%; in the field of social sciences - about 28%; in the field of humanities - 31%,; in the field of natural sciences - about 26%. In "Part 2a" of Table 4, we can see the characteristics of participants who often or very often ask other people to send them scientific literature: female - 90%; in the field of social sciences - about 60%; in the field of humanities - 10%; in the field of natural sciences - about 30%. From these findings it is evident that there are considerable differences in characteristics of participants who never or almost never ask other people to send them scientific literature, in relation to characteristics of participants who often or very often ask other people to send them scientific literature.

In "Part 1b" and "Part 2b" of Table 4, we can see answers of participants about the use of particular web portals. We can see that participants, who never or almost never ask other people to send them scientific literature, considerably less often use almost all web portals, in relation to participants who often or very often ask other people to send them scientific literature. Participants who never or almost never ask other people to send them scientific literature are using pirate portals with the similar frequency with which these portals are used by participants who often or very often ask other people to send them scientific literature.

V. CONCLUSION

Findings indicate that there are significant differences in using web portals, in relation to various groups of study participants. For example, more than 60% of participants from the fields of social sciences and humanities often and very often use Croatian portal Hrčak, in relation to minor 4% of participants from the field of natural sciences. This finding could be explained in various ways: maybe the portal Hrčak doesn't contain many journals from the field of natural sciences; maybe many scientists from that field don't know about existence of Hrčak. Also, the significant factor in explanation of this finding could be that research topics of scientists from the field of natural sciences are more general, less connected with a specific region or country. Namely, they explore natural phenomena which are similar or same in the whole world. Therefore, it is natural that these scientists are primarily oriented to international web portals which contain literature from the whole world.

Another interesting finding is that scientists from the field of social sciences are most frequent users of foreign portals. The pirate web portals are the only portals which are not used most frequently by scientists from the field of social sciences. They use pirate web portals with the similar frequency as scientists from the humanities, while scientists from the field of natural sciences are the most frequent users of pirate portals.

It was also established that older participants are using Croatian portals about 10% more often than younger participants. In opposition to this finding, younger participants are more often using foreign and pirate portals. It is possible that different groups of users have different levels of knowledge about the existence of various types of web portals. This could be an explanation why there is a significant difference in level of use of different types of portals. For example, it could be assumed that many members of scientific community

don't know about the existence of pirate web portals. Another possible explanation could be a difference in attitudes toward acceptability of use of pirate portals. Older participants may be more disinclined to use them because of their illegal status or possible consequences.

Surprising finding is that Croatian web portals are often and most often used by about 60% of female participants and only by about 20% of male participants. There are also considerably more female participants who often or more often use foreign portals, while male participants are more frequent users of pirate portals. Another interesting finding is that female participants are significantly more inclined to ask other people to send them scientific literature. Among the study participants who often and very often ask other people to send them texts, the huge majority are female participants - 90%.

In this research, we didn't explore reasons and circumstances which could explain why there are considerable differences in behavior between various groups of participants. Further research could help to identify and explain these reasons and circumstances. Other aspects could also be explored. For example, practices and opinions of the faculty from other fields of science: art, technical or biomedicine fields.

If we synthesize insights about the most frequent users of three different types of web portals, then these users can be described as: a) the most frequent users of Croatian web portals are participants from the field of social sciences and humanities, participants of older age and female participants; b) the most frequent users of foreign web portals are participants from the field of social sciences, participants of younger age and female participants; c) the most frequent users of pirate web portals are participants from the field of natural sciences, participants of younger age and male participants.

Of course, there also are other profiles of users of these portals, but this compact description of the most frequent users of particular types of portals, could be helpful as a foundation for thinking about how to prepare and conduct additional research about users. It could also be helpful to create activities of building and enhancing specific web portals.

We hope that insights from this research will be helpful for the creation of better web portals and other information sources and for finding new ways to expand the circle of their users. We also hope that these results will be stimulating and helpful for further research on related topics.

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Enhancing digital competences of Croatian teachers of informatics - Oracle Academy use case

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Abstract **- In the field of European and Croatian education, it is especially emphasized the objective of digital competences development for all citizens. In achieving this goal, the key stakeholders are teachers of informatics and theirs teaching competences. Rapid development of information technologies poses great challenges to teachers in the field of their vocational training and appropriate curricula. This paper describes the experience of training them within the Oracle Academy program. Certain quality indicators of the conducted trainings have been collected with self-assessment of teachers in the field of programming and database competences.**

Keywords - Digital competences, Education and Teacher Training Agency, Oracle Academy

I. INTRODUCTION

Strategic EU documents [1] and associated policies [2] point to the importance of digital competences of all EU citizens and express the need to link different stakeholders (member states, companies, social partners, non-profit organizations and education providers) in achieving this goal. These guidelines are also incorporated into Croatian strategic documents [3]. The implemented pilot projects within the Republic of Croatia [4] state the particular importance of digital competence of teachers and appropriate measures that should be applied in practice. The digital competence framework is elaborated in detail for all stakeholders in Croatian schools: teachers, principals and administrative staff in [5].

According to [6], the following areas of e-competence (digital competences) of teachers are emphasized:

- Computer system: Computer hardware and Computer operating system
- Office documents: Text, Tabular Calculation, Presentations, Databases
- Multimedia: Graphic Format, Audio Format, Video Format, Educational Software
- Web Access: Internet Search, E-communication, Online Document Management, Web 2.0 Tools, LMS - Learning Management System, HTML, CSS, JavaScript
- Programming: Algorithms, Programming Languages

According to the above mentioned classification, this paper places particular emphasis on digital competencies from databases and programming, with examples of good practice where teachers can acquire them. An example of good practice is the cooperation between Croatian Education and Teacher Training Agency (ETTA) and Oracle Academy (OA) in various educational programs associated with programming in Java, which included more than 200 teachers during 2016, 2017 and 2018. During the pilot training it was necessary to research the satisfaction of the teachers with the quality of the OA trainings. Prior to the implementation of the training for a large number of participants, self-assessment of teachers in the area of competence in programming and databases was explored. Based on the conducted research, future activities by ETTA and OA will be carried out, which will probably contribute to the new curriculum for IT classes that is expected to be implemented in 2018.

II. EDUCATION AND TEACHER TRAINING AGENCY

At 2017, there are 32249 teachers in Croatian primary schools [7], and 26410 in secondary schools [8]. The Croatian education systems currently employ 481 full-time teachers of informatics in primary and secondary schools. In the same time, 766 teachers are teaching informatics with some other course to full teaching load.

The ETTA is a public institution that is independent in carrying out its business and business in accordance with law, founded by the Republic of Croatia and the Ministry of Science and Education performs the rights and duties of the founder of the Agency. The Agency's activity is to conduct professional and advisory jobs in education and training. The Agency also participates in the monitoring, improvement and development of education in the field preschool, elementary and secondary education, adult education and education of children of Croatian citizens abroad and children of foreign nationals [9].

III. ORACLE ACADEMY

Oracle Academy [10] introduces Oracle Corporation [11] global program to support all education stakeholders in the acquisition of various computer-related competencies. In the fiscal 2017 program has invested globally 3.75 billion USD in various ways in educating students and teachers in the field of computer science. Within the EU initiative [2] in December 2016 Oracle

announced a three-year investment totaling 1.4 billion USD in direct and in-kind support of computer science education throughout the EU member states. The Oracle Academy program is active in Croatia since 2015 and is currently gathering more than 200 Croatian primary and secondary schools [12].

As a part of the OA program, there are several courses in the field of programming competence, intended for teachers as well for their students. In the area of education of elementary school teachers, short programs (workshops) based on the use of Alice [13] and GreenFoot [14] software tools are recommended. In addition, it is possible to acquire more advanced competences in the area of programming at the Java Fundamentals, Java Foundations and Java Programming courses [15].

Within the Oracle Academy program, it is possible to acquire database competences so there are courses available for teachers and students: Database Foundations, Database Design and Programming with SQL [15]. The particular advantage of this program is its prior recognition within other national qualifications frameworks such as the Scottish Credit and Qualifications Framework (SCQF) or by international professional associations such as the International Society for Technology in Education (ISTE) and Computer Science Teachers Association (CSTA) [16].

IV. Implemented Training Activities

In co-operation with ETTA and the OA several cycles of teachers training in the field of programming competences during 2016 and 2017 were conducted. Completion of activities started in January 2018 is expected in April 2018.

In March 2016, approximately 60 teachers of informatics were trained at Alice and GreenFoot workshops.

In July and August 2017 was carried out Java Fundamentals training for approximately 50 Croatian teachers of informatics after which 38 of them got corresponding Oracle Academy Final Exam Certificate. In this course teachers are introduced to concepts, terminology and syntax of object-oriented programming and steps needed to create basic Java programs using interactive development environments like Alice, GreenFoot, and Eclipse. Practical examples are visible during this course so participants can experience the power of computer programming alone.

This activity was an excellent foundation for a new education based on Java Foundations course which began in January 2018. This course deals with teachers of informatics that are already familiar with object-oriented concepts and Java programming basics. Learning outcomes at this course are comparable to Oracle's professional certification Java Foundations Certified Junior Associate (Exam: Java Foundations - 1Z0-811) [17]. In this training, 256 elementary and high school teachers were initially involved with the aim of speeding up their competences in the field of programming in modern programming languages. The stated goal is strategically aligned with the existing reform of the teaching informatics curriculum with the expected implementation in the school year 2018/2019. Training is planned combination of two training sessions in the classroom (at the beginning and end of course) and through the 13 webinars of 90 minutes each.

All webinars are implemented on a Cisco Webex software [18] through which participants attends online classes with the option of retrieving the recordings later. During the webinar, participants can interact with the lecturer using chat or audio communication and with responding to the short questions from the presented teaching material. The system records all participants activities (e.g. whether they actively follow the lecture) which can be subsequently analyzed. The lecturer combines such data with the results of short quizzes for every teaching unit and makes a conclusion on the success of the education process. All teaching materials are available on a separate Oracle system for e-learning called iLearning with the application of the assessment. Finally, participants must create an own project and solve the midterm and final exams thus obtaining a corresponding OA certificate.

V. Structural Training Indicators

The first survey was conducted after pilot education on Java Fundamentals course during August 2017 on 32 questionnaires were received from the 50 engaged teachers. The main purpose of the pilot survey was to get insights in the participants' satisfaction with the program through several dimensions: course load, training materials, trainer and knowledge assessment, and based on these results, to find gaps that need to be addressed. The results are encouraging. As presented in Table 1, most of the participants expressed a high degree of agreement with positively related statements related to aforementioned teaching dimensions. For instance, more than 68% of participants stated that they agree or completely agree with the course load is in accordance with their competences, and more than 87% of the participants agreed or completely agreed that they want to participate in the following Oracle Academy training events.

Other surveys (shown in Tables 2 to 8) were conducted in the beginning of Java Foundations course during January 2018. In total, 194 questionnaires were received from the 256 teachers who participated in education. Of these, 98 of them are employed in secondary school and 96 are working in elementary school.

According to the self-assessment of teachers according to their competences in the area of programming and databases which are presented in Table 2 and 3, it is obvious that teachers have insufficient competences. Namely, 59% of them have only basic competencies in programming (Table 2) and 55% of them have only basic competencies in databases (Table 3).

According to the self-assessment of teachers according to their competences acquired during their studies which are presented in Table 4 and 5, it is obvious that teachers have not gained enough competence in the field of programming and databases during the study. Namely, less than 9% of teachers have completely acquired

programming or database competences during their studies. The results are alarming, but understandable because of rapid development of information technology. Most importantly, these results indicate the need for additional education. An additional research should be made in the future for recently graduated teachers to determine the possible need to change the existing study programs that teachers of informatics are attending.

According to the results from Table 6, the state of professional development in the area of programming competences is good enough because 95% of teachers have been professionally trained in the last three years. According to the results from Table 7, 45% of teachers did not have any education in that area at the same time and that points to the urgent need for additional education.

During the Java Foundations course, satisfaction of participants was also initially tested according to the ETTA's methodology for professional trainings and the results are presented in Table 8. These results show the current satisfaction of the participants which are involved in the Java Foundations training program because the average rating is above 4.

TABLE I. SATISFACTION OF PARTICIPANTS ACCORDING TO THE OA'S METHODOLOGY FOR JAVA FUNDAMENTALS TRAINING (08-2017)

Answers/ Questions/	**I do not agree at all**	**I do not agree**	**I accept**	**I agree**	**I completely agree**
Course load is in accordance with my competences	0,00%	0,00%	31,25%	34,38%	34,38%
Training materials are available and understandable	0,00%	6,25%	21,88%	21,88%	50,00%
Teaching is supported by presentations and examples	0,00%	0,00%	15,63%	28,13%	56,25%
The instructor has clearly outlined the content and course program	0,00%	3,13%	9,38%	18,75%	68,75%
The instructor maintained the teaching on time and on a regular basis	0,00%	0,00%	0,00%	3,13%	96,88%
Knowledge assessment is appropriate	0,00%	0,00%	21,88%	40,63%	37,50%
The instructor behaved correctly in communication with the participants of the course	0,00%	0,00%	6,25%	6,25%	87,50%
I want to participate in the following OA training events	0,00%	0,00%	12,50%	21,88%	65,63%

TABLE II. SELF-ASSESSMENT OF TEACHERS IN THE AREA OF PROGRAMMING COMPETENCES

Answers/ Question	**Basic (I know how to compose a simple algorithm and realize it at least one programming language)**	**Medium (I know how to compose more complex algorithm and achieve it in the object oriented programming language)**	**Advanced (I know how to make a program solution in object-oriented programming language, according to the default specification and deliver it with complete documentation)**
In the area of competence related to programming (algorithms, programming languages) I evaluate my knowledge as:	59,28%	36,60%	4,12%

TABLE III. SELF-ASSESSMENT OF TEACHERS IN THE AREA OF DATABASE COMPETENCES

Answers/ Question	**Basic (I know how to make simple logical data model for the default problem, using entities and relationships)**	**Medium (I know how to create a physical database from the default logic model in a real database management system, eg MS Access, My SQL, MS SQL Server, Oracle ...)**	**Advanced (I know how to make more complex data views and procedures for editing them using SQL programming language)**
In the area of competence related to databases I evaluate my knowledge as:	55,67%	41,24%	3,09%

TABLE IV. SELF-ASSESSMENT OF TEACHERS ACCORDING TO THE PROGRAMMING COMPETENCES THEY HAVE ACQUIRED DURING THE STUDY

Answers / Question	**No**	**In smaller part**	**For the most part**	**Completely**
The competences related to programming (algorithms, programming languages) that I need in teaching, I have gained during my university education	9,28%	56,19%	26,29%	8,25%

TABLE V. SELF-ASSESSMENT OF TEACHERS ACCORDING TO THE DATABASE COMPETENCES THEY HAVE ACQUIRED DURING THE STUDY

Answers / Question	No	In smaller part	For the most part	Completely
The competences related to databases that I need in teaching, I have gained during my university education	27,84%	44,85%	18,56%	8,76%

TABLE VI. PROFESSIONAL TEACHER TRAINING FOR THE LAST THREE YEARS IN THE AREA OF PROGRAMMING COMPETENCES

Answers / Question	Yes - ETTA educations	Yes - CARNET educations	Yes - other educations	No
In the last three (3) years I have been professionally trained in the field of competencies related to programming	64,95%	24,74%	6,19%	4,12%

TABLE VII. PROFESSIONAL TEACHER TRAINING FOR THE LAST THREE YEARS IN THE AREA OF DATABASE COMPETENCES

Answers / Question	Yes - ETTA educations	Yes - CARNET educations	Yes - other educations	No
In the last three (3) years I have been professionally trained in the field of competencies related to databases	32,47%	9,28%	12,37%	45,88%

TABLE VIII. SATISFACTION OF PARTICIPANTS ACCORDING TO THE ETTA'S METHODOLOGY FOR JAVA FOUNDATIONS TRAINING (01-2018)

The criteria being assessed	Average grade (1-5)
The applicability of the training topic in existing teaching practice	4,04
The actuality of training contents	4,58
The training Importance for personal professional development	4,55
Communication and collaboration within a group during the training process	3,96
Clarity of presentation	4,35
Teaching methodology rating	4,5

VI. CONLUSION

Conducted activities from ETTA and OA cooperation and so far collected indicators from the actual implementation are encouraging. It is further encouraged by the fact that ETTA follows the latest EU guidelines in connecting with strong IT sector stakeholders in the activities of increasing the digital competence of teachers. Based on the data collected on the competences of teachers in the field of programming and especially databases, there is a need for additional education. More importantly, teachers do have interest in additional education. The set goals of ICT teaching reform in Croatian schools are very demanding in terms of implementation, but the use cases presented in this paper show that this is achievable.

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Video Makes the Coding Star?

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***Abstract* — This research study was devised to investigate and assess the impact on learning of providing video lecture recordings to a first year programming module of a university computing degree. The proliferation in the use of video lecture capture (LC) in universities worldwide presents an opportunity to analyse video watching patterns in an attempt to quantify and qualify how students engage and learn with the LC videos. The study considers behavioural trends of students towards watching LC videos and relates these factors to academic impact, especially focusing on academic attainment. The study finds that there are significant and measurable factors identifiable from LC video analytics that can be used to predict student academic performance early enough during a course to provide early warning indicators of struggling students, especially useful in mass education environments.**

Keywords*— *Video analytics, module score, programming, video lecture capture

I. INTRODUCTION

Increasing student demand and technical infrastructure improvements have seen an increase in the use of video lecture capture (LC) in third level education worldwide [1]. However, the effects of LC in the area of computer programming in terms of viewing behaviours and academic attainment is a relatively under researched area [2]. The increasing use of LC in university programming courses presents an opportunity to analyse video watching patterns in an attempt to quantify and qualify how students engage and learn with the videos and what impact that has on programming attainment.

There have been a number of studies dedicated to the general effects of videoing lectures with most of the research concentrating on student and faculty perceptions, student attendance and engagement (e.g. [3]; [4]; [5]). The majority of the research studies generally report positive benefits for learners. These include the argument that videoing lectures provides an extra resource that may complement students' studies [6]. Flexibility of learning is also a stated benefit with Prodanov [6] arguing "the commonly held benefit (for the students) is the ability to review material and catch up with missed lectures". The studies have also shown that students regularly stop, start and rewind recorded lectures to enable them to revisit points of the lecture they perhaps did not understand ([7],[8],[9]). The potential negative effects of video lecture capture have also examined [10]. One of the main concerns stated by lecturers is a potential impact on student attendance ([11], [12]). The concern from faculty appears to be based largely on the link between attendance and academic success. Nyamapfene [13] argues that, "class attendance is highly correlated to academic performance". This apprehension is reflected in the large volume of research specific to attendance on video lectured programmes. Nevertheless, in general the research has been positive with regard to the benefits of lecture capture for both students and faculty.

There is also an increasing body of research into the analytics of the engagement performance of educational videos especially with the rise in popularity MOOCs, (e.g. [14],[15],[16]) and blended learning. As illustrated in Figure 1 video viewing graphs generally consist of three stages. The start period is typically short in duration and has a sharp decline in viewing retention. The decline is linked with practice or accidental hits of the users. This period precedes the main body of the video which is the longest in duration and commonly contains a more gradual decline. The tail period shows a sharp decline, mainly due to the summary content that exists at that point in most LC videos.

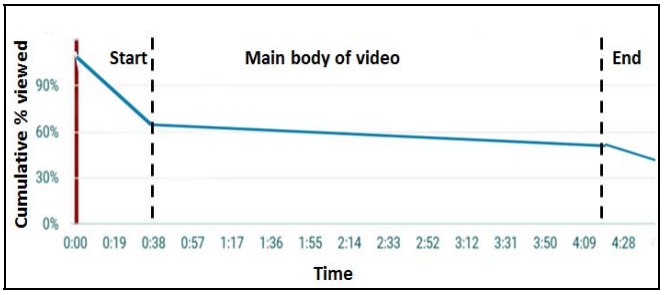

Figure 1 : Typical Video Engagement Graph

Note that viewing engagement graphs of LC video seldom have smooth lines, with many peaks and troughs as exemplified in Figure 2.

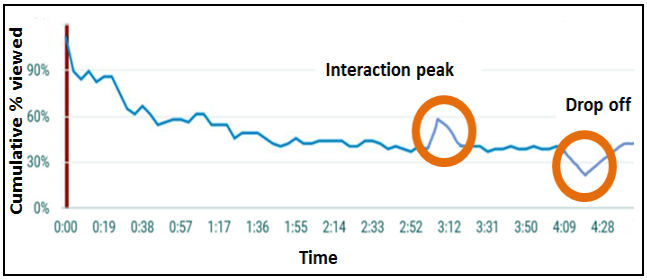

Figure 2 : Typical Engagement Graph with Peaks and Drop Offs

Low engagement areas show on the graphs as down turns (Drop-offs) and high engagement areas are shown as upturns (Interaction Peaks). A lack of drop-off is consistent with the students being consistently engaged with a section. It is therefore the interaction peaks and drop-offs that are of particular interest in video engagement analysis and may possibly be further related to the student learning engagement.

The spikes in the graph are normally indicative of student confusion, introduction of important concepts or engaging demonstrations [14]. The drop-offs can also reveal if important sections are skipped over. A dropout rate is defined as the percentage of students who start watching a video but leave before the video finishes. The audience retention (AR) rate is a cumulative measurement of the average percentage of the video that was watched. The analysis of the dropout rate and AR can reveal factors that affect why a student leaves or skips over content in a video [17]. An analysis of the dropout and AR rates suggests that when the student no longer perceives the material in the video as relevant then the video is skipped forward or stopped. Knowledge gained from video performance research coupled with easily accessible YouTube LC video analytics offers a potentially rich source of information that is currently largely untapped.

While the use of LC has increased in recent years, the same is also true of the current worldwide demand for computer science graduates, which has resulted in increasingly larger class sizes in universities. The challenges of effective delivery in these mass education environments are well documented, with one of the recurring themes being high attrition rates, especially in programming courses. Larger cohort sizes results in obvious increased difficulties in identifying struggling students. A lack of engagement is one of the reasons for the high attrition rates in university computing courses. The difficulties in individually tracking student engagement generally means that unless a student brings their issues to the lecturer's attention, any lack of engagement and progress is commonly only identified from the results of summative assessment or possibly from a noted lack of attendance at contact points in the course. The timing of either may be too late to provide effective support for the student. The ability to provide early warning engagement measures that assist in identifying such students would likely help with tackling course attrition. There are a number of existing research areas, aimed at addressing attrition, including aptitude tests ([18], [19]) and engagement monitoring [20]. However, most of the approaches to date either attempt to predict long term performance, but with a relatively low level of predictability, or attempt to identify those students that are not engaged but often not at an early enough stage where intervention efforts are likely to be most successful.

The frequency, timing, viewing profiles (rewind and replay) and view time of videos are all markers of engagement with the LC videos and potentially course engagement. Coupling this data with other likely engagement markers, such as lecture attendance may present an opportunity for early indications of a student's course engagement.

II. Research Objectives

Impact of LC Videos on learning performance

An investigation and analysis of the relationship of viewing patterns and module attainment. If any factors prove to be a significant impact on learning then it should be possible to construct a model to enable module score prediction. Indeed, if the factors can be quantitatively established early in a course then they have the potential to be leveraged as early warning predictors to identify struggling students.

III. Methodology

The study was conducted with a cohort of university students taking one compulsory double weighted yearlong module in Java programming over two semesters. The module was taught over a 24 week period with typically three one hour lectures per week. The course has been running for several years and the students from previous cohorts were generally found to be highly motived and engaged. Post course surveys of past students that were exposed to LC in the module found that 89% preferred to have access to videos of key moments of lectures rather than whole lecture recordings. A large scale study carried out by Guo concluded that "shorter videos are much more engaging" [14]. Guo also concluded that "on average students spent around 3 minutes on videos that are longer than 12 minutes, which means that they engaged with less than a quarter of the content" [14]. In keeping with these findings short vignette videos, similar to the process outlined by Watkins [23] were used in this study.

The lecture snippets consisted of the audio of the lecturer and video of on-screen projected content that concentrated on significant theoretical principles augmented by theory related programming walkthroughs or code development activities that were faithful in replication of the physical lecture. Generally, each lecture was supported by two to three videos of durations ranging from 5 to 30 minutes. The LC videos were hosted on a closed YouTube channel only available to the students in the module. The channel had analytics enabled which offered engagement reports for the videos. The on-screen projected content of the LC videos utilised the several pedagogically different formats, namely, 1.) PowerPoint slides with majority theory text based content, 2.) PowerPoint slides with majority programming code based content, 3.) Programming code walkthroughs and with the lecturer highlighting and explaining code and 4.) Real time programming and code development. With the lecturer manually entering and explaining the development of code in an Integrated Development Environment (IDE).

The majority of the video related data came from the analytics provided by YouTube. This enables access to data per individual video and per channel, including hits (views), audience retention, device usage and other various configurable engagement reports. A comparative study of the general performance of the videos was made using this data. In addition, YouTube analytics provides configurable viewing performance graphs for individual and selected videos which enable analysis of viewing behaviours including drop off and peaks. All students were surveyed about their viewing behaviours. The survey was completed after the module was finished and sought detailed feedback on how many videos an individual had watched, how often they watched each video, primary reasons for watching and explanations of common viewing behaviours such rewind and replay and stop. The attendance of the students was tracked via a mobile app created by the authors, with students registering their attendance at each lecture which was tracked to location and the time of the lecture to ensure authentic responses.

IV. RESEARCH QUESTIONS

An investigation and analysis of LC video viewing behaviours using video analytics to relate the significance of patterns found to module attainment. The aim is to investigate and add to the currently limited knowledge in these areas to better understand how the LC videos affect module scores. Ultimately the identification of any significant factors that impact on learning attainment has the potential to reveal student performance indicators. A better understanding of the effect of student performances related to video engagement patterns may open up the potential to provide early automated warning systems that could facilitate targeted interventions to help struggling students.

Research questions and investigations

- Does engagement with the videos negatively affect lecture attendance? An investigation and analysis of individual and group engagement with LC videos and an analysis of the effect on lecture attendance and module scores.
- Does a high viewing coverage (number of videos watched) positively affect module scores?
- Does the timing of when the students initially watch the videos positively affect student attainment? An investigation and analysis of when students watched videos throughout the course related to module scores.
- Does a high frequency of repeat of views (hits) positively affect module scores?

V. RESULTS AND DISCUSSION

Does high engagement with the videos negatively affect lecture attendance?

Individual student attendance was recorded at the start of each lecture via a mobile app developed by the authors. To ensure authenticity each student's profile was initially registered and authenticated with the attendance recording system. Subsequently each student simply registered their attendance during each lecture. It was not possible for the student to register attendance outside of the lecture time, nor was it possible to submit more than once per lecture and their location tracked. The study revealed that there was a continuous engagement throughout the module with the videos, with peak hits recorded at assessment times. Most previous research has generally found that lecture attendance is unaffected by the provision of LC. However a common concern remains that by providing a video version of the lecture that some students may opt to not attend the physical lecture. In this study the observed attendance was approximately similar to previous years' attendances for the module and also similar to other modules in the same course where LC was not provided. Further to these generalised observations it is of interest to analyse lecture attendance against the number of videos watched the students. As shown in Figure 1 and further analysed using a Spearman correlation test there was no significant difference between the number of videos watched in relation to lecture attendance (r=0.146 and p=0.209). This would suggest that the poor attenders did not compensate their lower attendance by watching the videos. In fact the highest attenders (top 25%) watched on average 79% of all videos whereas the bottom 25% attenders watched on average 73%.

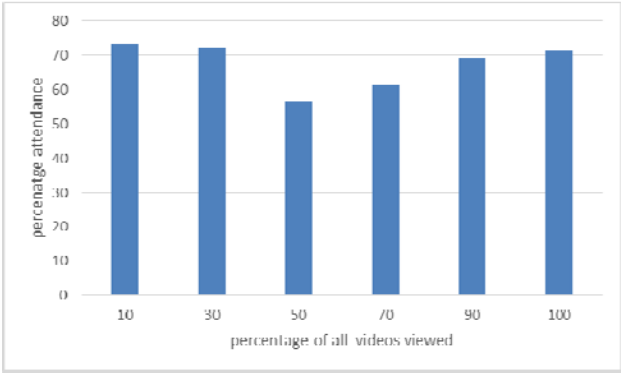

Figure 1 - the percentage of all videos watched in relation to percentage of attendance

In that regard it can be concluded that in this case the number of videos viewed did not affect the attendance at the physical lectures. It is also of interest to examine the relationship between lecture attendance and overall module score. As illustrated in Figure 8 a positive correlation was found between lecture attendance and module score (r=0.309, p=0.007). This indicates that similar to many other findings in the area that lecture attendance significantly and positively influences overall module score.

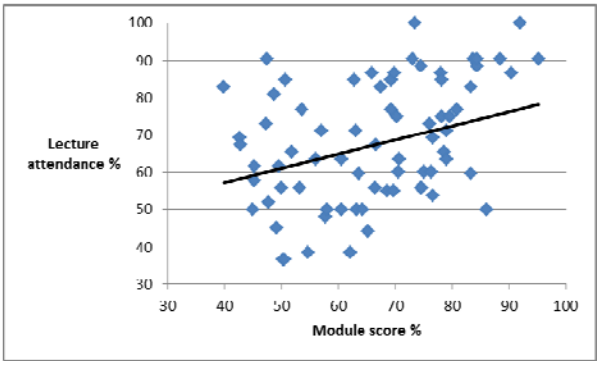

Figure 2 - Module score and lecture attendance

Does a high viewing coverage (percentage of all videos watched) positively affect module scores?

When considering overall module score and percentage of all videos watched there was little to separate the roughly equivalent numbers in the groups that watched greater than 90% of the videos (n=45), whose module score was 66.8% and the remaining students (n=40) that watched less than 90% who scored 66.9%. Indeed a further analysis using a Spearman correlation test found that there was no significant difference between the number of videos watched in relation to module score (r=0.265 and p=0.130). This suggests that the percentage of all videos viewed is not a potential indicator of future module score.

Table 1 - Grouping of percentage of all videos viewed and module scores

Videos viewed %	Module score	Number of students
> 90 %	**66.8%**	**45**
< 90%	**66.9%**	**40**

In fact, it is worth noting that the highest modules scores actually came from the group of students that watched the least number of videos. Of the group that watched less than a third of all videos (n=10) their average module score was 78%, which was 15% higher than the group that watched all the videos (n=16). This would suggest that the high end students' scores were not fully dependant on their number of all videos watched. Further qualitative analysis found that these students typically engaged with the videos if they found the underlying topics difficult or due to their individual learning styles, with some typical survey responses being: "most of the time I found the in-class lecture materials to be sufficient to understand the concepts in question"; "I prefer to learn theory from the lecture notes or a book which is probably why my percentage of videos watched is low."; and "I didn't watch many of the videos, as I felt I understood most topics from the lectures alone." Whereas, the feedback from the students that watched most videos was typified by responses such as, "I found that being able to re-watch lecture content had a tremendous impact on clarifying and helping me learn a specific topic", which suggests that their motivation for watching was on the basis of not fully understanding the topic and therefore needing to revisit and consequently their video views were higher. Overall, in this case, no evidence was found to indicate that a high video coverage positively affects module score; in fact it may be that lower engagement with LC videos (likely coupled with good attendance) may be indicative of a high performing student.

Does the timing of when the students watch the videos positively affect module scores?

The study found that there was a higher engagement with the videos at assessment time. This is not wholly unexpected as it would be anticipated that students engage more with module content closer to assessment time. However, when the students initially watch the equivalent video in relation to the physical lecture may have an influence on module score. On the basis that immediate watches (before or within a week of the lecture) may indicate a more engaged student in comparison to those that watched later (waiting at least a week) before watching the video or just before assessment time (assessment group). Figure 3 illustrates that 31% of the cohort watched the equivalent video within the immediate timing of the physical lecture, with the rest opting to watch some time later or only specifically at assessment time. Statically some evidence was found of a relationship between when the students watched the equivalent LC video in relation to the timing of the physical lecture ($p=0.02$, $F=3.407$, $df= 3,72$) and module score. The lowest module scores came from the watch later group (61.0%) compared to the combined immediate watch groups (67.9%) and assessment only groups (71.9%).

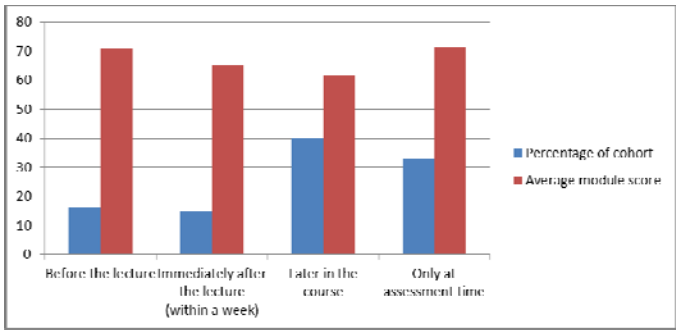

Figure 3 - timing of first time watches with associated module scores and percentage of videos viewed

Further analysis using a One-way ANOVA test revealed that the main notable difference was between the scores attained by the group that watched the videos at assessment time compared to those that watched the video later, with the average score of the assessment group being 71.9% (SD=14.5) with the latter group scoring 61.0% (SD=12.9). Also of note is the score attained by the combined immediate groups (67.9% SD=10.4) is also considerably better than the later watch group. It is likely that the students that waited until just before the relevant assessment before viewing the LC video were confident in their understanding of the topics and did not feel the need to use the videos for knowledge clarification and were using them for reinforcement (as illustrated by their relatively lower engagement with the videos). The students that watched the videos around the immediate timing of the lecture also performed well on average in the assessments in comparison with those that watched later.

In that regard it can be concluded that in this case the timing of when the students watch the videos did affect the module score. However, statistically only in the case for students that watched at assessment time in comparison to those that left the first watch to later in the course. Also of note were the differences in score between those that watch closer to the lecture time and the late viewers.

Does a high frequency of repeat of views (hits) positively affect module performance?

As detailed in Figure 4 beyond the initial watch there were a significant number of repeat hits for the videos. A representative view from the students in relation to re-watching the videos was that "I found that being able to re-watch lecture content had a tremendous impact on clarifying my knowledge on a topic, and also very useful for revision." However, this raises a pertinent question: does a high frequency of repeat views suggest that the student is highly engaged (and likely will do well in the module) or does it suggest that the student is struggling with the content (and will likely do less well in the module)?

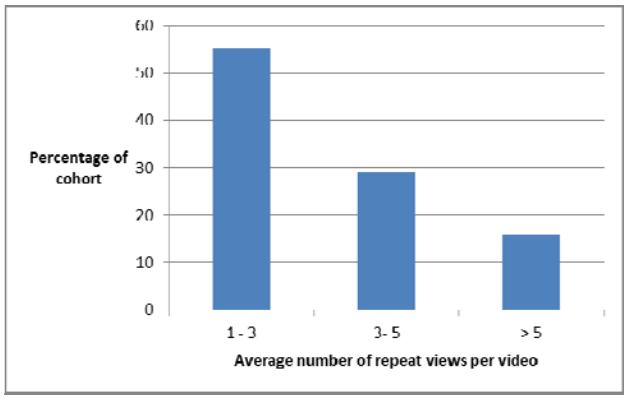

Figure 4 - Average numbers of repeat views

An analysis of repeat hits viewed against module score shows that those students that found the need to repeatedly watch the videos scored least in the module. In fact, of all the students that failed (n=12) 50% came from the group that watched the videos greater than 5 times whereas those with between 1 and 3 repeat views (n=55) only 2 failed. A more detailed breakdown by module scores is shown in Figure **5**, illustrating a trend of higher repeat views from the lower scoring students.

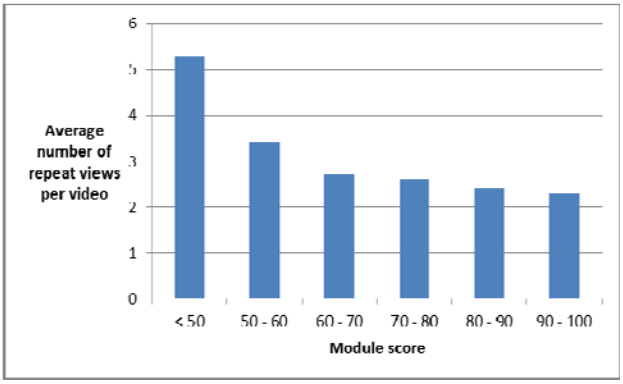

Figure 5 - Detailed breakdown of module scores and average repeat views

A further analysis using a Pearson correlation test shows a statistical significance between the module score and repeat views ($p<0.001$, $r=-0.365$). The students were surveyed in order to gain a better understanding of the motives for repeat views. The major reasons stated for repeat video views were either 1) to understand a topic (*Understand* group) or 2) revise a topic (*Revision and Assessment* group).

Table 2 –Motivation groups scores, attendance and video watching patterns

	Module score %	Lecture attendance	Average hits per video	Percentage of all videos watched
Revision and assessment (n=34)	**67.23**	**63%**	**2.8**	**72%**
Understand (n=36)	**66.12**	**65%**	**3.6**	**79%**

Grouping these into separate motivation based groups illustrates that there are few significant differences observed between the groups in terms of module score, lecture attendance, percentage of all videos watched (Table 2). There is however a higher average number of hits per video recorded for the *Understand* group. It could be reasoned that those seeking knowledge are watching again because, at least in part, they "don't get the concept" and therefore their average hits would be expected to high. Whereas those having a repeat view for revision are confirming knowledge and less likely to need multiple repeats views. Furthermore a closer examination of repeats hits correlated with the scores of the top middle and bottom end students shows that those that failed the module had 5.3 hits per video on average, whereas those that achieved scores between 50% and 70% recorded 2.9 hits with the top end students (>70%) recording less again with 2.6 repeat hits. This suggests that despite the multiple views those that failed the module remained unclear in understanding of the topic and keep reverting to the video for help (which it appears to not fully give them). It could be that identification of those that have multiple hits could identify students that may be struggling and interventions such as one to one teaching would likely be advantageous to overall attainment. In that regard it can be concluded a high number of repeat hits does not positively affect the module score. In fact, a high number of repeat views could be an associated behaviour trait of a struggling student.

6.3 Overall model

In summary the factors identified that have statistical significance to module score are 1) Frequency of repeat views of videos 2) Attendance and 3) Timing of first time views (especially in relation to watching the videos greater than a week after the equivalent lecture). With the exception of the latter factor, they are all relatively easy to measure and could be quantified early enough in the course to potentially provide warning indicators. A multiple linear regression to include all factors in one model was calculated to predict module score based on these factors. A significant regression equation was found ($F(3,72)=9.995$, $p<0.000$), with an R^2 of 0.295. Students predicted scores is equal to 64.60 +0.184(Attendance) -2.232(Repeat hits) -8.800(Watch later).

VI. General Discussion, Limitations and Future Study

It is likely that attendance directly contributes to module score. Previous research points to that conclusion, logically it is plausible to also suggest that those turning up at lectures would benefit their learning as this could readily translate into module score. Although, a similar literal translation of the regression model cannot be made for the Repeat hits or Watch Later factors. It would be misleading to suggest that every time a student has a repeat hit in a video their module score goes down. The model's worth is that it points to the fact that those students with high numbers of repeat hits are likely to score less that those that have a low number of repeat hits to understand a topic. As such the model serves in this case to highlight a behavioural trait of a struggling student.

In much the same way those that engage later in the video content are likely to do less well than those did engaged closer to the lecture. Although because there also exists a group that use the videos purely for confirmation of learning at assessment time, in terms of an effective an early warning indicator it is difficult to separate the late and assessment timed groups. Based on the model a student profiling classification profile using video analytics is presented in Table 3.

	Frequency of views	Timing in relation to lecture	Repeat views
High achievers	Low	Immediate or just before assessment	Few if any
Medium achievers	Medium to high	Immediate	Low to medium (until knowledge gained)
Low achievers	Very high	Later in the course (but generally before assessment)	Very high

Table 3 - Profiling students using video analytics

The students all had a very high regard for the videos which suggests that almost all the students used the videos to either learn or clarify knowledge. Yet there were a small number with a relatively low engagement that nonetheless tended to be the better scoring students in the cohort. The evidence points to these low watchers and high attenders being high achievers with their LC video watch motivations based mostly on confirmation of learning.

As acknowledged, the cohort of students was generally regarded as highly motivated therefore a similar analytical study with less motivated students would be of interest. As with many quantitative based studies the understanding of the responses would be further enhanced with a further qualitative study. The ability to expose and probe further into the areas of concern, such as Repeat views in relation to content difficulty would provide a greater understanding of the findings.

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Parallel Computing for Education using Single-board Computers

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***Abstract*— This paper describes the design, implementation, and practical use of a Computing Cluster using IoT Technologies in Engineering Education. First, the development goal and its expected application are explained. Current lectures in Computer Science, Computer Engineering, and Image Processing will benefit of the massive parallel computing cluster. Next, the design and implementation — carried out by a group of students — are described in detail. Finally, the practical use of the cluster including a test application is shown. Here, current super-computing methods like Message Passing Interface (MPI) and Open Multi Processing (OpenMP) are used to show the ability and functionality of the cluster.**

***Keywords*— Computing Cluster, IoT, Supercomputing, OpenMP, MPI**

I. Introduction

The trend towards multi-core computing systems is increasing. Due to the increase of processing nodes, new parallel software architectures and development methodologies are becoming relevant. In engineering education, this trend needs to be reflected, since tomorrow's engineers will have to face this challenge. CUAS decided to develop a multi-core computing cluster using low cost IoT nodes in order to facilitate several areas of education.

The lecture on Computer Engineering focuses on parallel software architectures like multi-threading, Open Multiprocessing (OpenMP), and Message Passing Interface (MPI) [1]. Multi-threading deals with the problem of how to increase software maintainability and decrease software complexity by splitting an application into several parallel hand-coded threads.

Open Multiprocessing (OpenMP) is used to increase the computing performance by automatically distributing sequential repeating code (like for-loops) into parallel threads within the same process and thereby within the same memory area.

Using the Message Passing Interface (MPI), processes can be distributed among several computing nodes via the network in order to increase the level of parallelism. MPI uses a distributed memory architecture. Both OpenMP and MPI are used in supercomputing architectures and can be combined in order to get the best possible system performance (see Fig. 1).

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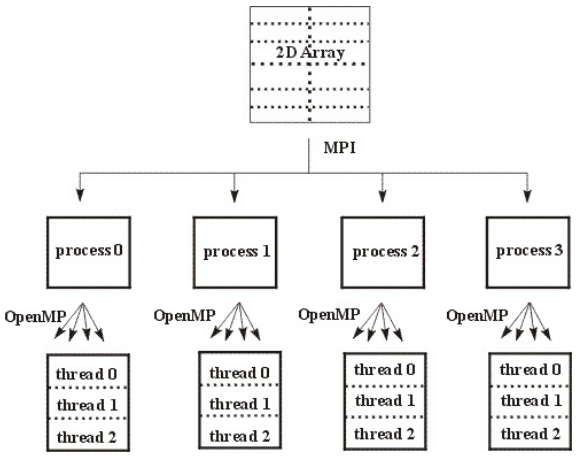

Fig. 1. MPI and OpenMP combined

Our computing cluster allows students to apply these advanced concepts first hand and thereby getting experienced with the design of parallel software architectures using real hardware.

The lecture on Digital Image Processing (DIP) provides students with the basics of image processing and analysis algorithms, especially the detection of image features. Simple image features are edges, corners, or areas of equally distributed information. Also, color information of images such as color statistics or color histograms can be used as features. Finally, methods like Histogram of Oriented Gradients (HOG) [2] or Hu Moments [3] are part of the group of more complex image features.

The extracted features can then be used to build image descriptors out of feature vectors, which themselves can be used for machine learning algorithms. For instance, object detection or image classification are typical machine learning tasks. In case of multiple object classes, this task is suitable for parallel computation.

II. Design

The first design of the computing cluster was done during a master thesis project [4]. The Linux-based computing cluster uses five Raspberry Pi 3 modules, one as a master and the other four as computing slaves. Linux is an advantage, since software like Ansible, which automates software provisioning, configuration management, and application deployment,

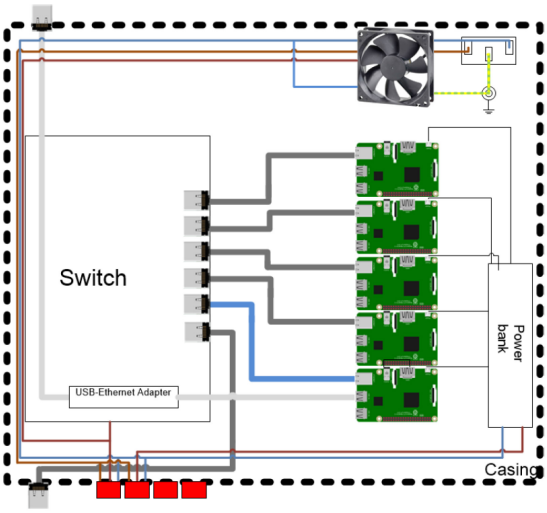

Fig. 2. First computing cluster block diagram

Fig. 4. 3D graphics of the large-scale cluster rack

is available [5]. Additionally, a managed Ethernet switch as well as power-supply and cooling concepts were developed (see Fig. 2).

The developed cluster is still functional (see Fig. 3). It is used as a test-system for student projects as well as the basis for the large-scale cluster.

III. Hardware Implementation

The large-scale cluster currently consists of 24 nodes, but will be extended to 96 nodes, thus providing 384 processor cores. Although full functionality is already provided, the following actions must be taken to ensure proper and reliable working:

- A mounting solution had to be found to group the Raspberry Pi single-board computers (SBC). We decided for a 19-inch rack system (see Fig. 4). Each SBC is mounted on a 3D-printed carrier, so that it can be easily removed and changed (Fig. 5).
- A power supply concept had to be established. The power lines to the SBCs are switched using relays on a Uniboard Pi. For the power connection to each SBC, it is not advisable to use the built-in micro-USB connector, as they are not very reliable. Therefore, power is connected to each SBC via the GPIO port, thus requiring additional safety circuitry.
- Additionally, a cooling system had to be designed, which can also be seen in Fig. 4 and Fig. 5. Figure 6 shows the absolute necessity for cooling the SBCs; the left image shows a temperature of about 40 °C on the SBC processor in the idle state, whereas the right image shows the same processor surface during high processor load, indicating a temperature of 73 °C.

IV. Software Implementation

The large number of computing slaves requires tool-support for software distribution, configuration and maintenance. Direct user I/O using keyboard, mouse and monitor is obviously not an option — instead a Secure Shell (SSH) connection is one possible solution.

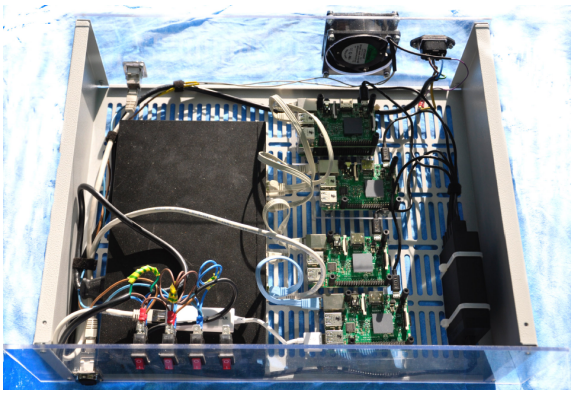

Fig. 3. First computing cluster

Fig. 5. 19-inch slot containing the computing nodes

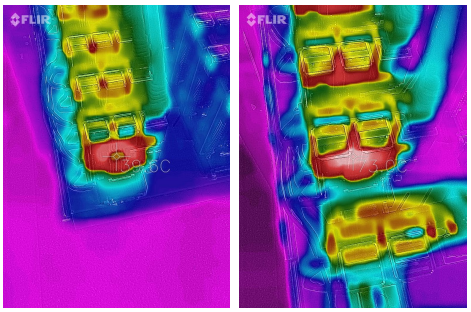

Fig. 6. Thermal images of the SBC; low processor load (left), high processor load (right)

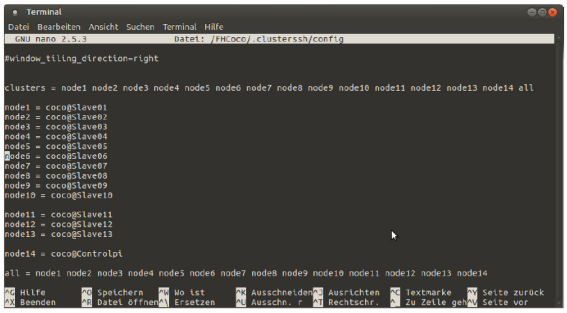

Fig. 7. CSSH configuration file

ClusterSSH [6] is an application which can manage multiple SSH session at the same time. With ClusterSSH (CSSH), the same commands you be performed on the cluster at the same time. This will ensure that all computing slaves are kept in sync. A configuration file (see Fig. 7) contains all computing slaves as well as their aliases and groupings. If the CSSH system is properly set up, a single command can be applied to several computing slaves at once (see Fig. 8).

In order to monitor the status of the computing slaves, a web-based interface called Dashboard was developed. The Dashboard provides a simple way to turn on and off individual slaves or groups of slaves. Furthermore, it indicates the current operating conditions like temperature and power consumption. Using the Dashboard, the user can start a parallel computation and monitor its progress. Finally, the dashboard also displays the current load of the individual slaves in terms of CPU load and memory consumption (see Fig.9).

During the next phase of Software implementation, several demo applications have been developed. As a first performance test, a distributed sorting algorithm, based on Bubble Sort and Merge Sort, has been implemented. On the master node (a Laptop Computer), the user enters the array size.

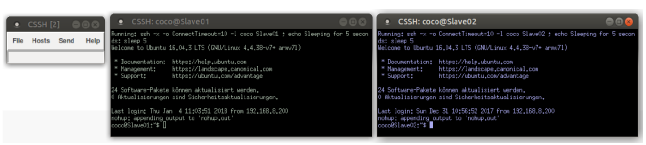

Fig. 8. CSSH connection with two slaves

Fig. 9. Dashboard to indicate several performance parameters

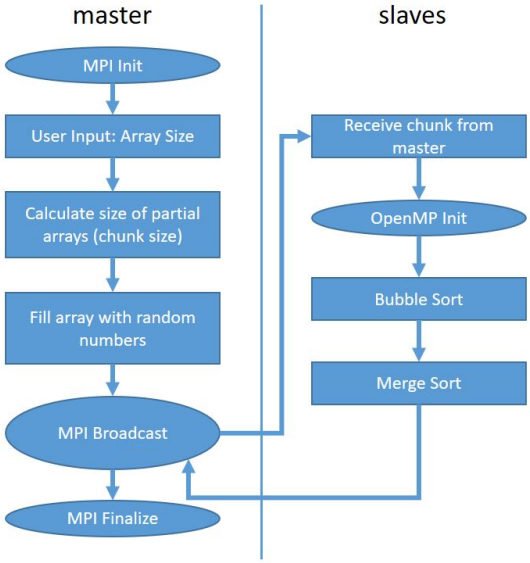

Fig. 10. MPI/OpenMP Bubble Sort/Merge Sort algorithm

Next, the array is filled with random numbers.

The array is split into several chunks according to the MPI distribution algorithm. The dataset is sent to the computing slaves where the actual sorting with Bubble Sort takes place. Within a computing slave, OpenMP is used to distribute the load among the individual processor cores (four per node). The last step is to merge the individual sorting results together and the sorted data set is sent back to the master (see Fig. 10).

As can be seen in Fig. 11, the time saving from increasing the number of computing nodes is substantial, increasing to a factor of almost 17 between the use of 1 node and 5 nodes. The main reason for this is that the required sorting time of the Bubble Sort algorithm rises more than proportionally with the number of elements, thus on the other hand leading to a higher efficiency by increasing the number of nodes, as the sorting array is split into partial arrays (chunks).

To be able to show the available computing power more graphically, a second demo application calculating the Mandelbrot set (see Fig.12) has been developed. Here, the user can experience firsthand the time duration differences between the computations on one slave versus using many or all slaves.

A first test setup was done to verify the increasing calculation speed with an increasing number of nodes. Here, the Mandelbrot set was calculated several times, using groups of 1, 6, 12, 18, and 24 nodes, respectively. The multiple calculations were realized by four zooming operations into

the image, which, due to the nature of the Mandelbrot set, forces each time a recalculation. The calculation times are shown in Tab. I.

Calculating the mean time — as also shown in Tab. I — and plotting it over the number of nodes gives the graph shown in Fig. 13. It can be seen that the calculation time reduction corresponds roughly with Amdahl's law [7], which can be expressed as

$$S(P) = \frac{1}{\alpha + \frac{1-\alpha}{P}} \leq \frac{1}{\alpha} \quad ; \qquad \lim_{P\to\infty} S(P) = \frac{1}{\alpha} \quad , \quad (1)$$

with S as the "speedup" of the calculation with P parallel processes and α $(0 \leq \alpha \leq 1)$as the sequential fraction of the program; in other words, the program part that cannot be parallelized.

V. Conclusion and Outlook

CUAS has accumulated a lot of experience in the field of Remote and Pocket Labs over time [8]. The use of IoT Technologies in education is a logical next step [9]. Since several projects have been based on the Raspberry Pi platform, we felt confident to begin the development of our Computing Cluster. The Cluster does not only allow CUAS to teach concepts of Supercomputing, Multi-threading and related topics, it also enables us to use its computing power for Digital Image Processing applications.

The next step will be the completion of the cluster to all 96 SBC, and to implement Machine Learning algorithms – based on different forms of Neural Networks – on it. Students will have the chance to test and try out advanced concepts and by doing so, they students will have a definite advantage in understanding and mastering these emerging technologies.

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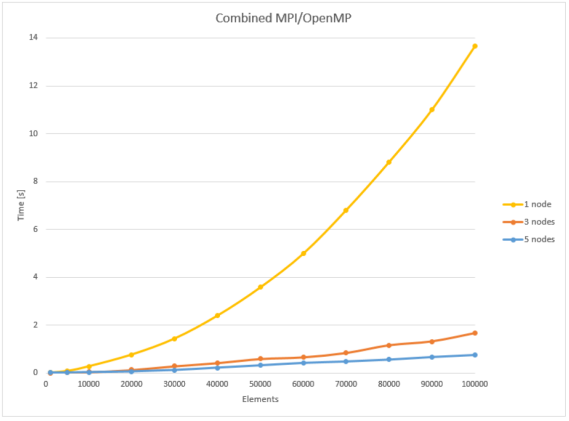

Fig. 11. Performance comparison of Bubble Sort using 1, 3, and 5 node(s) [4]

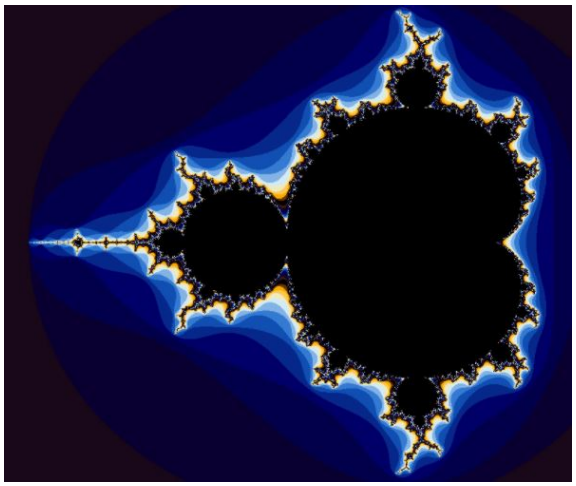

Fig. 12. Mandelbrot set

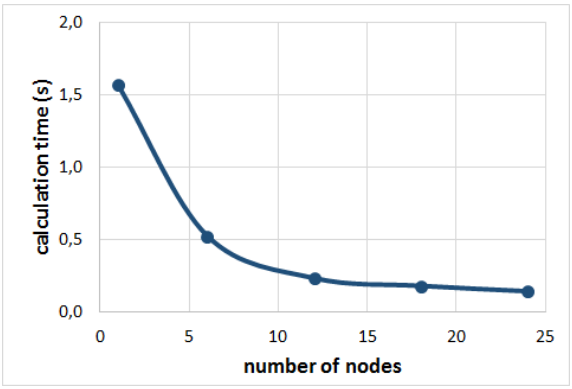

Fig. 13. Mean calculation time vs. number of nodes

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TABLE I

Calculation time vs. number of nodes

# nodes:	1	6	12	18	24
zoom 1:	1.54610	0.50285	0.22725	0.15204	0.11389
zoom 2:	1.57585	0.50797	0.23000	0.17219	0.13048
zoom 3:	1.56172	0.53328	0.23282	0.19451	0.15703
zoom 4:	1.59218	0.55390	0.23553	0.18969	0.15884
mean time:	1.5690	0.5245	0.2314	0.1771	0.1401

High education concept in applied systems design

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***Abstract* - Increasing complexity of industrial development and production require a well-designed didactic approach in challenging study fields in engineering. Such concepts can be reasonably applied to study programs in Master education due to the necessary prior knowledge in technical disciplines. Conventional teaching of the subject matter is normally related to one teacher and his field of study that often leads to a restricted view on the topic. Therefore, an essential element of our concept is the connection of different aspects of a problem and a close coordination between the involved professors.**

In this paper, we will report about a combined course in physics, control engineering, programming and practical implementation (lab) to show and teach the students a systematical procedure solving complex tasks. This is a typical demand of the industry, consisting of theory, modelling, simulation, implementation, measurement, data evaluation and verification. Based on a concrete example, the lecture concept is presented and discussed.

Keywords - Didactic concept, systems engineering, systems design, physics, control engineering, modelling, simulation, MATLAB, Simulink

I. INTRODUCTION

A typical common feedback of an evaluation done by first year students is related to the question: "Why do we have deal with that specific subject?" The main problem especially at the starting phase of a study program is that the beginners do not see the interdependency of the courses. They have to familiarize themselves with a lot of new scientific concepts and technical terms. Our approach to overcome at least partially that problem we implemented a project based learning course already at the beginning of the bachelor program where the students need knowledge of different disciplines like mechanical construction, programming and intuitive control concepts. Thereby the main objective of the course is not delivering an optimized solution for the proposed task, but recognizing the missing skills. This self-cognition is the best intrinsic motivation for young people. They see that solving complex tasks can only be managed by combining knowledge of different fields. The general ability to apply the linkage between different topics can generally be achieved at the last part of a study program.

Considering all these points encouraged us to install an integrated course at the beginning of the Master's Program Systems Design. Most required prerequisites are available at that stage. Increasing complexity of industrial development and production require a competence oriented integrated approach. Due to the fact of a limited training period a tight realization is performed.

A. Problem definition

We start our program by defining the ultimate goal as a representative of a typical complex task in systems design. In our case we focus on the overall understanding of the rotary inverted pendulum regarding physical and control aspects including modelling and simulation. One of the big advantages is that several experimental setups are available at CUAS laboratories.

B. Traditional approach

Conventionally the following courses are required to solve the task:

- Mathematical and physical modelling
- Control engineering
- Simulation and visualization (MATLAB)
- Lab-exercise

In the case that all the courses are presented in an isolated way there are a lot of specific disadvantages:

- Physics: Basically the underlying theory is very complex and only selected, simple text book examples can be performed in class due to the limited time of the lecture. It turns out that modelling of real-world problems without computational help are nearly impossible.
- Control: Usually control design tasks start with a given mathematical model of the system. Often the physical background cannot be seen out of the corresponding equations by the students.
- Mathematical simulation: Often simulation is connected to mathematical numerical methods. There is the danger that the courses are given by mathematicians and computer scientists, who only discuss academic examples.
- Lab-exercises: Even if practical experiments are very motivating for the students, they often have no idea why a specific method works or fails without theoretical considerations.

C. Integrated teaching concept

It turned out to be a very good solution for our study program to combine the mentioned lectures.

First, the contents of the courses are exactly coordinated. This means that the involved teachers developed a common didactical concept for the solution of the given task (see A, problem description). Basically the courses are combined and performed in a team teaching way. In addition, the approach represents a flexible execution with a high penetration of all related topics.

Concrete advantages of the teaching method for the professors are

- The parent structure makes a more flexible partitioning of the topics possible.
- The professors are motivated to support the students even outside their own competence area.
- An assessment of students in terms of their competences is much more meaningful than an isolated mark.

Concrete advantages of the teaching method for students are

- The same nomenclature is used in all courses.
- There is a high chance that the students can handle the complex task. This creates a great personal sense of achievement.
- We observe a reduced drop out caused by a group dynamic and motivating effect. Weaker performance in a special subject can be compensated by higher performance in a different topic.

Secondly, we get the feedback that this kind of solution process fits perfect to needs and working practice in industry. One of the requirements for an industrial solution is that our course shows a high degree of automation. In the approach, this is also a main task.

After presentation of the concept and the task the students are asked to solve the problem, mentioned in A, manually. This means that they should swing up a pendulum in upright position and keep it there. We observe thereby always a very poor performance of all involved people! This increases directly the curiosity to solve the task with help of the proposed methods.

II. MECHANICAL PRINCIPLES

As a preparatory step, the content of "Mechanical Principles" was designed in order to provide the students with the necessary theoretical background and tools. In this course the participants learn sophisticated methods of mechanics, which enable them to find the equations of motion of complicated processes. Based on the Bachelor knowledge of Newton's equation [1], the subject of constraints is addressed. As an introductory example, the two dimensional pendulum is discussed. To set up the equation of motion using Newton's second law, the sum of all forces must be determined vectorially.

It is

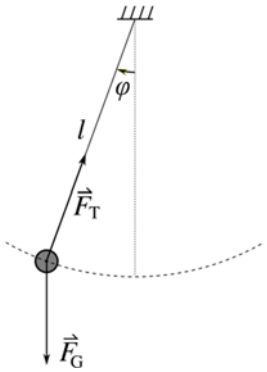

Figure 1. Constraint force at a two dimensional pendulum

$$\sum \vec{F} = \vec{F}_G + \vec{F}_T = m\ddot{\vec{r}} \tag{1}$$

This leads immediately to the question of the thread force $\vec{F}_T$, which is initially unknown. Therefore a general method is needed to calculate the so called constraint forces. In the class this is done by developing Lagrange's equations of the first kind (type 1). To get familiar with the new method, a few examples are explicitely calculated and discussed, e.g. a mass on an inclined plane and Atwood's machine, which is a representative of two body problem.

Often engineers are not interested in determing the constraint force(s). The focus is only on the equations of motion. So the next task is to eliminate the constraint forces from Lagrange's equations of type 1, which leads to the introduction of the concept of the so called generalized coordinates. After a complex deviation, Lagrange's equations of motion of the second kind (type 2) can be formulated for conservative forces as [2]

$$\frac{d}{dt}\frac{\partial L(q,\dot{q},t)}{\partial \dot{q}_k} - \frac{\partial L(q,\dot{q},t)}{\partial q_k} = 0 \tag{2}$$

with k=1..f and $L(q,\dot{q},t) = T(q,\dot{q},t) - V(q,t)$.

T is the total kinetic and V the total potential energy of the system, expressed in generalized coordinates q_k and generalized velocities $\dot{q}_k$. Also in this case practical examples are given, e.g. again the equation of motion of a frictionless mass on an inclined plane, this time without evaluating the constraint force, and the equations of motion of a spherical pendulum. Here and in the following example of the double pendulum the power of Lagrange's formalism is demonstrated impressively for the first time. The students are usually surprised by the simplicity of the usage of Lagrange's formalism, which is a pure scalar calculation in contrast the vector equations of Newton. At this point the participants are able to model a conservative system.

In real applications dissipative forces like friction and driving forces cannot be neglected. For this reason Lagrange's formalism type 2 must be extended to cover

also these cases. This is done by adding a further term Q_k. In the final form Lagrange's equations of motion can be written as [3], [4]

$$\frac{d}{dt}\frac{\partial L(q,\dot{q},t)}{\partial \dot{q}_k} - \frac{\partial L(q,\dot{q},t)}{\partial q_k} = Q_k \qquad (3)$$

Q_k are the s.c. generalised forces and include all non conservative forces, which cannot be written as a potential, e.g. driving forces $\vec{F} = \vec{F}(t)$ and/or friction, e.g. $\vec{F} = \vec{F}(\dot{\vec{r}})$.

A nice analytically solvable example is given by two cubeshaped masses $m_1 = m_2 = m$ of a dumbbell with a distance of l, which slip on a horizontal plane. The friction forces $\vec{F}_i^{fr}$ should be proportional to the velocities of masses with $\vec{F}_{1,2}^{fr} = -\gamma \vec{v}_{1,2}$. The motion can be described by the generalised coordinates of the center of mass $\vec{r}_c = (x_c, y_c)$ and the angle φ (see fig.2).

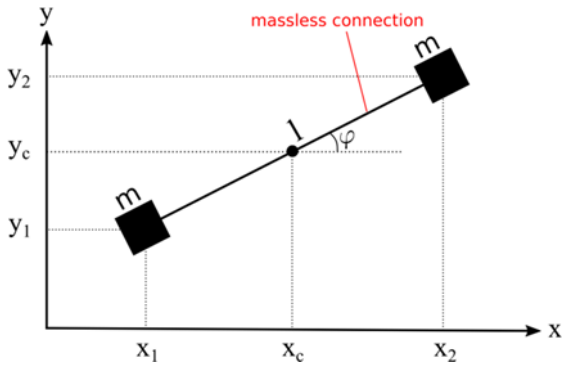

Figure 2. Sliding dumbbell with generalized coordinates

The final equations of motion deduced with Lagrange's formalism regarding the dissipative friction force F are

$$\frac{d}{dt}\frac{\partial L}{\partial \dot{x}_c} - 0 = -2\gamma \dot{x}_c$$
$$\frac{d}{dt}\frac{\partial L}{\partial \dot{y}_c} - 0 = -2\gamma \dot{y}_c$$
$$\frac{d}{dt}\frac{\partial L}{\partial \dot{\varphi}} - 0 = -2\gamma l^2 \dot{\varphi} \qquad (4)$$

These differential equations can be easily solved with the following result

$$x_c(t) = x_c(0) - \frac{m}{\gamma}\dot{x}_c(0)$$
$$y_c(t) = y_c(0) - \frac{m}{\gamma}\dot{y}_c(0)$$
$$\varphi_c(t) = \varphi_c(0) - \frac{m}{\gamma}\dot{\varphi}_c(0) \qquad (5)$$

A time resolved simulation of this result with MATLAB was performed and reflects a realistic impression of the situation. In the last part of the course the equations of motion of the rotary inverted pendulum were derived. The results are detailed described in the next section.

III. Control Example

The leading idea of the presented learning procedure is based on a top down teaching approach. In our case a typical control task has to be solved by the students.

A. Rotary inverted pendulum

The considered control task is related to the often used pendulum experiments (see fig. 3). Here we elaborate on a pendulum connected to a bar with length l_{bar}, which is rotated. The length of the pendulum is denoted by l_{pend}, the corresponding mass by m. The rotational movement of the bar (J_{bar}) is produced by a DC-motor. Therefore, an amplified analogue voltage is applied to the drive. The

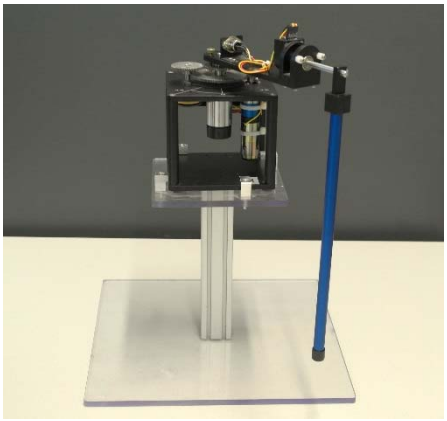

Figure 3. Rotary pendulum experiment

main control task thus is to position the tip of the pendulum by an appropriate motor voltage. In order to solve the task in an appropriate way signals have to be measured and feed back. In our case the position of the bar and the position of the pendulum are known by measuring the corresponding angles (θ and α) using incremental encoders (see fig.4).

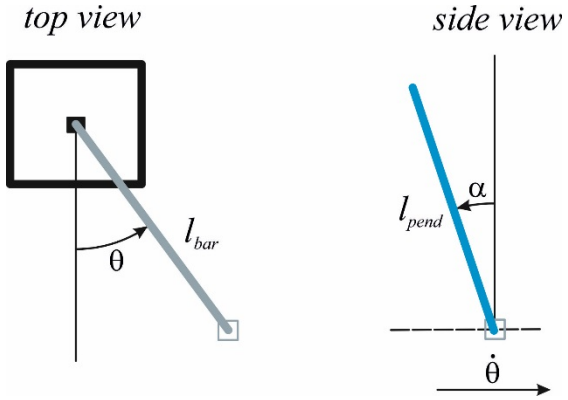

Figure 4. Rotary pendulum with important parameters and variables

One of the main advantages of our approach is the possibility and decision to start the control task by inspection of the real world realization of the system in our laboratory. Conventionally a control exercise starts by a given mathematical model, often a transfer function of the plant, i.e. G(s). Unfortunately, only for experienced students mathematical descriptions offer sufficient insight to understand the systems behavior clearly. Controlling the pendulum by hand together with measuring and

evaluation of the appropriate signals, e.g. pendulum oscillation, offers a deep understanding of the control task directly or in advance. In our case the frequency and the damping quantity of a damped oscillation is observed. (see fig.5).

Applying a simple PID controller to suppress the unwanted oscillation turns out to be an unsuccessful solution. This is independent of an additional difficulty of finding suitable values for the control parameters (K_P, K_I, K_D). Thus the need of an analytical analysis and design method based on a mathematical model of the system is obvious. In our case the underlying theoretical background [7], [9] and the needed calculation steps for gathering the mathematical model using the method of Lagrange is done together with the combined course

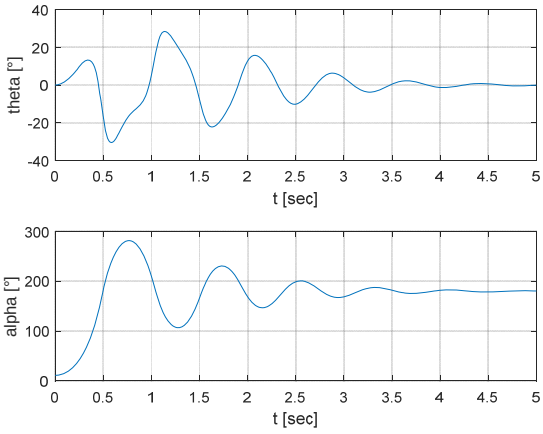

Figure 5. Simulation of uncontrolled oscillations

"Mechanical Principles". At that stage this intense step seems nearly natural to the students.

Even under well-established simplifications (i.e. mass point consideration) the device represents a system of order 4. Whereas in that case a time consuming hand calculation can basically be made, an automated procedure is for sure the preferred solution path. Following the introduced procedure in Chapter II we get as mathematical description two differential equations of second order

$$(J_{bar} + ml_{bar}^2)\ddot{\theta} - ml_{bar}l_{pend}(\ddot{\alpha}cos\alpha - \dot{\alpha}^2 sin\alpha) = \\ = \tau - b_{fric}\dot{\theta} \quad (6)$$

and

$$\frac{4}{3}ml_{pend}\ddot{\alpha} - ml_{bar}\ddot{\theta}cos\alpha - mgsin\alpha = 0 \quad (7)$$

Thereby the servo load gear angle is denoted by θ and the pendulum arm deflection is denoted by α, whereas the input voltage of the DC-motor is u. Using a simplified motor model, i.e. neglecting the inductance of the DC-motor, we get for the needed torque τ by the input voltage

$$\tau = k_1\dot{\theta} + k_2 u \quad (8)$$

Thereby the b_{fric} is a friction constant. The set of equations (1,2,3) represents now the system description that is basically used for simulation and controller design.

Therefore, a nonlinear state space model of the following form has to be calculated

$$\dot{\boldsymbol{x}} = \boldsymbol{f}(\boldsymbol{x}, u) \quad (8)$$

Thereby we use the following state vector:

$$\boldsymbol{x} = (\theta \quad \dot{\theta} \quad \alpha \quad \dot{\alpha})^T \quad (10)$$

It turns out that separating the equations for θ and α is

```
%% equations of motion rotatorial pendulum

syms lbar m Jbar Jpend lpend Tau bfric g
syms q1 q2 q1d q2d q1dd q2dd
% q1: angle of bar theta
% q2: angle of pendulum alpha

q = [q1; q2];
qd = [q1d; q2d];
qdd = [q1dd; q2dd];

vx = -lpend/2*q2d*cos(q2)+lbar*q1d;
vy = -lpend/2*q2d*sin(q2);
vp = lpend*q2d;

Q1 = Tau;
Jpend = m/3*(lpend/2)^2;
T = 1/2*m*vx^2 + 1/2*m*vy^2 + 1/2*Jpend*q2d^2 + 1/2*Jbar*q1d^2;
T = simplify(T);
V = m*g*lpend/2*cos(q2);
L = T - V

dL1 = diff(L,q1d);
g11 = jacobian(dL1,[q;qd])*[qd; qdd]  - diff(L,q1) - Q1 + bfric*q1d
dL2 = diff(L,q2d);
g12 = jacobian(dL2,[q;qd])*[qd; qdd]  - diff(L,q2)
```

Figure 6. Part of MATLAB Code for finding equations of motion

both time consuming and sensitive to errors and therefore assigned to the automated procedure. As a last step a simulation file is automatically generated to avoid transferring the equations from paper to MATLAB/Simulink by hand [8]. This is done in form of a standardized MATLAB function. This function can be

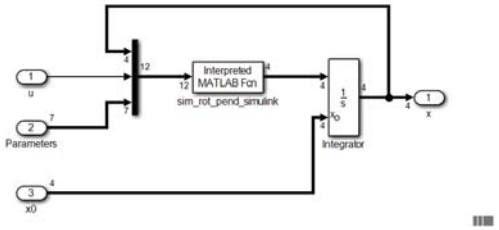

Figure 7. Simulink file for automated simulation

used for both MATLAB simulation and as content of an interpreted MATLAB function for Simulink environment (see fig.7).

B. Control design

Finding a suitable controller that guarantees the positioning of the pendulum in an appropriate way is the next step [5], [6], [9]. Having in mind the objectives of the included control course a state space controller of the form

$$u = -\boldsymbol{k}^T\boldsymbol{x} \quad (11)$$

is the proposed controller type. The control parameter $\boldsymbol{k}$ is found by allocating specific eigenvalues s_i for the closed loop system matrix. Here we used the values

$$s_1 = s_2 = s_3 = s_4 = -10 \quad (12)$$

Therefore, of course, a linearized model is needed:

$$\dot{\boldsymbol{x}} = \boldsymbol{A}\boldsymbol{x} + \boldsymbol{b}u \tag{13}$$

We use for the upright position of the pendulum the equilibrium state:

$$\boldsymbol{x}_e = (0 \quad 0 \quad 0 \quad 0)^T \tag{14}$$

and get as linear system description:

$$\dot{\boldsymbol{x}} = \begin{pmatrix} 0 & 1 & 0 & 0 \\ 0 & -14.52 & 39.32 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & -14.12 & 81.78 & 0 \end{pmatrix} \boldsymbol{x} + \begin{pmatrix} 0 \\ 25.85 \\ 0 \\ 24.89 \end{pmatrix} u \tag{15}$$

Again finding the linearized model is done in an automated way.

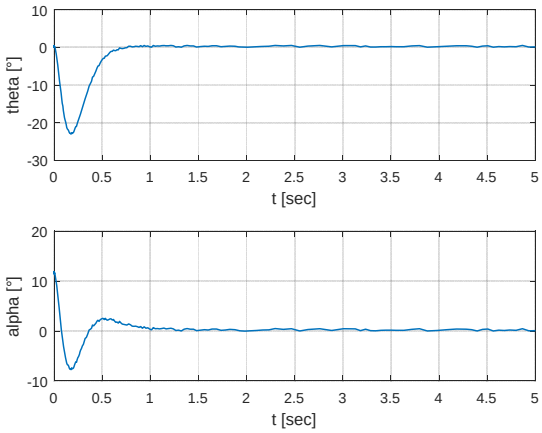

Figure 8. Controlled system for small $\mathbf{x}_0$

Applying the state space controller to the system a control of the upright position of the pendulum is performed. The trajectories of the corresponding angles for a small deviation from the equilibrium state, i.e.

$$\boldsymbol{x}_0 = (0 \quad 0.2 \quad 0 \quad 0)^T \tag{15}$$

demonstrates the behavior of the controlled system (see fig. 8). A lot of experimental testing is then performed by the students during their lab exercises.

IV. Students Feedback

Immediately after the course, a feedback from the students was obtained. In total, the module was evaluated very positively. In particular, the networked teaching and thinking was highly appreciated.

Finally, a few statements of the students on the course are cited:

"This is a very interesting course from both the theoretical and practical aspects."

"Unlike classical lectures I really liked the overall structure of the module."

"Particularly useful was that a uniform nomenclature has been used throughout the whole course."

"Too bad that there are no more courses of this type."

V. Conlusion

In this paper a holistic teaching approach was introduced and evaluated. The idea of the concept was to combine different content dependent lectures to one course with the goal of being able to solve a comprehensive project task. This issue is typical of an industrial problem and an important skill especially for master graduates. It also includes the ability to work in a team.

The presented concept means a high motivation for the students with the simultaneous chance to look at a complex task and solve it under different aspects. In our case a small group consisting of eight participants attended the first run and gave an entirely positive feedback. Especially, the networked teaching was highly accepted. The response of the students encouraged us to expand and roll out this concept in future.

Acknowledgment

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Role of the User in Information Systems Development

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***Abstract* - We have focused our paper on the aspects important in adapting an Information System (IS) to the user's cultural background. We are interested both in the factors related to IS development and in the use of IS. Increasingly, ISs are being developed and used in a global context. We have perceived differences in expectations of functionalities, architecture, structural properties, information search practices, web-based system properties, and user interfaces. One conclusion would be that a high quality IS reflects user behavior in its use context. In that case, the system has to model its user one way or another. Until now, the topic has been handled without meaningful effort to model user behavior. Current publications cover a wide variety of rules on how to take into account cultural differences in the IS context. In this paper, our aim is to study the current state-of-the-art of user modeling – modeling the human being as an IS user. We start with general aspects related to the role of the user in IS development and alternatives to adaptable systems. The findings are applicable in the educational context as well. More and more, the use of computers and ISs is becoming an essential part of studies: the use of MOOCs (Massively Open Online Courses) as a part or replacement for traditional face-to-face classes; flipped learning methodology emphasizing the significance of self-learning; and blended learning, including quite often computerized study content. Our focus is on the global context, in which students represent different cultures and the IS is globally available.**

Keywords – user; information system; adaption; context; information systems development; requirements engineering; user modeling; user adaptable; human behavior modeling.

I. INTRODUCTION

The role of the user in information system (IS) development is twofold: First, user expectations are embedded in the system's structure and functionality during the development process and secondly, an IS has to be built that is able to adapt to the needs of different users during its use. In addition to the *users,* there is a wide variety of other stakeholders (client, customer, management, government, legal, etc.), whose wishes and requirements must be taken into account in IS development. In this paper, to simplify the text, we will use the term "user" to cover all of the above, because ultimately an IS is developed for users to meet their needs as a part of real business processes.

In our paper [1] we have pointed out that increasingly, an IS is developed for "faceless users" by "faceless developers". Developers and users do not know each other, and the development work is done by globally distributed teams. As a result, the traditional (face-to-face) way to execute development tasks is not possible, nor is traditional (face-to-face) teamwork. Problems in culture-sensitive parts of the development life cycle may appear, as well as in the culture-sensitive features of the final artifact (software). *Formulation of concepts* is also culture-sensitive: people in different cultures have a different approach to handling abstract structures of concepts and concepts may have different semantics. Therefore, the same conceptual model does not meet the expectations of all interest groups. Paper [2] handles this topic from the point of view of the database schema.

In this paper, we first discuss the two above-mentioned approaches to taking user expectations in IS into account and answer the following two questions:

1. How to embed user expectations into the system's structure and functionality during the development process (Section 2);
2. How to build such flexibility in the system that it adapts to the needs of different users, especially taking into account their cultural differences (Section 3).

Although the approach is general, the discussion also answers the question "What must be taken into consideration in the acquisition of educational software and what kind of properties must it have?"

This leads us to the central *research problem* of this paper: *How to model the user of an IS, both in general, but especially in a multicultural context*.

The role of user modeling in IS is a culmination of Sections 2 and 3. In Section 4 we introduce briefly how to analyze cultural differences. Section 5 covers a review of alternative user modeling approaches. This is based on a light mapping study (heuristic, non-systematic) without

aspiring to the perfection. Section 6 summarizes the paper. 2018.

II. THE USER AND THE DEVELOPMENT PROCESS

Several standards and process manuals handle software processes having high capability and maturity. The series of ISO 15504 standards [3] and CMMI [4] represent models of the *plan (process) oriented* approach in software development. The role of interest groups is clearly defined as a part of process specifications. Nowadays, *agile development* (see the principles of e.g., the SCRUM development method in [5]) has been widely adopted, even in the development of large ISs. The main principles of SCRUM cover the user joining the software development team as an essential member, partitioning the system to allow incremental / iterative development, and immediate integration of the increments into the system in a sequence of releases.

Independently of the development approach (plan-driven / agile), the system (including every increment) is developed in a sequence of development phases (Figure 1). The aim of the first development steps is to elicit and analyze user expectations carefully to build the foundation for the IS.

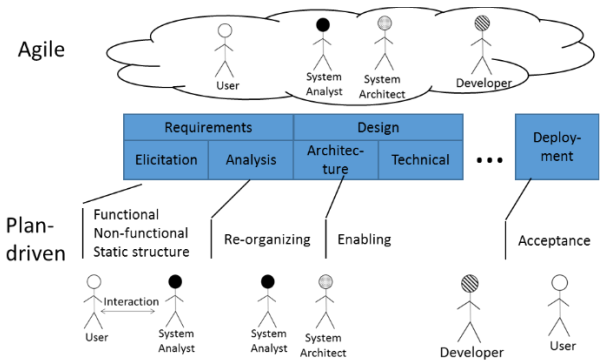

Figure 1. The user's role in the IS development "life cycle"

The *requirements baseline* covers functional and non-functional requirements and the static structure of the system in a well-organized and analyzed form, as agreed in the interaction between the system analyst and the key interest groups. *Functional requirements* define the functionality (operations) of the system. *Non-functional* system properties are *quality aspects* that provide guidelines, restrictions, and presumptions for the development work; one of these is *adaptability* in the heterogeneous set of unknown users. The *static structure* of the system (in the requirements phase) indicates the *conceptual structure* of the system as seen by the key interest groups, i.e., the *user's internal conceptual model* of the system as documented by the system analysts. All this points out the role of system analyst as an *interpreter, organizer, digger, and bookkeeper* of the requirements identified, and the role of the user as a master and owner of the system.

The role of design is to transfer the requirements baseline to *system design*. Architectural design *embeds* (a part of) the *non-functional features* into the system functionality and structure; some of these features may also indicate requirements (e.g., traceability) for the development process.

In the case of adaptation requirements, *architecture design is an enabler* that builds adaptability into the system structure and functionality. In practice, this means features that allow the system to modify itself in different use cases, its learning capability, its capability to recognize its users, etc. From the technical point of view, it is a question of following the principles of suitable *architectural styles* [6] and the use of suitable *design patterns* [7]. These provide the means for the loose binding and changeability of system components even in the runtime, in addition to the flexibility built in the system's static structure. One of the technical solutions is to embed a *user model* into the system; this is the focus of the rest of our paper.

III. THE ADAPTATION CAPABILITY OF THE SYSTEM

There are several opportunities to include user-based adaptability in the IS. We separate three alternative approaches to implementing adaptability:

1. Systems that are adapted by the user to fulfill their expectations (*user adaptable systems*);
2. Systems that recognize the users and adapt their behavior (*user recognition systems*);
3. Intelligent (dynamic, learning) systems that recognize the use context and the user (*context recognition system*).

The classification is analogous to the classification of Fisher [8], which separates two main approaches – adaptable and adaptive. The two latter of our approaches /Approaches 2 and 3 belong to the category of adaptive systems (systems adapt themselves dynamically).

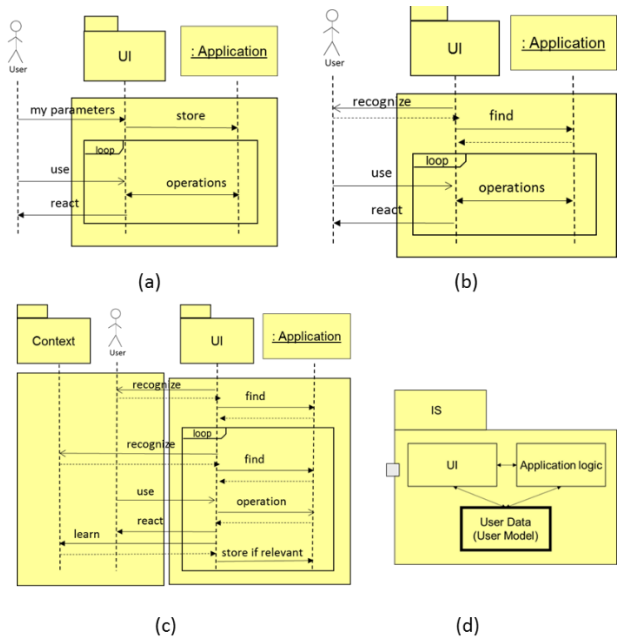

Figure 2. Adaptive ISs – three basic models and IS structure

In all three cases, the system must be able to store *user related data*, to manipulate it (learning capability), and to use it to modify the system's runtime behavior according to

the expectations of an individual user. Figure 2 illustrates the rough structure of the three solutions and its user interaction in the form of a UML sequence and package diagram.

The simplest form of adaptive system – the *user adaptable system* - is based on parameterization. The system provides an interface in which the user defines values for the parameters. The values are interpreted by the system, which modifies its behavior according to the parameter values. This approach is static: the modification opportunities are limited to predefined properties only, and the alternative parameter values must be predefined (Figure 2a). In this case, the user interaction follows the same procedure during the whole use session and the *user model is simply the data structure*.

The user recognition system (Figure 2b) recognizes its user automatically. Alternatives for implementing user recognition vary from hidden (cookie type) to active (login). In this case, the user parameters are stored in the system in advance – either stored by the user (as above) or recognized by the system automatically. These may also be changeable (learning capability), but the value space is predefined; as a result, the adaptability extent is static as above. In this case the *user model is represented by the data structure and related functionality*.

Context recognition systems are dynamic: in addition to recognizing its users, the system also takes into account the (dynamic) use context (Figure 2c). Therefore, the system must have access to context-related data to implement the adaptability. Because the context changes during or between the use sessions, the system needs access to the context constantly. A good example of context is the location data in mobile applications, in which the context is based on the sensor values of the mobile terminal. Context data may be distributed – either stored in the client application or the server side. For example, some of the Huawei mobile phones have an application processor (currently Kirin 970) that implements context analysis in real time. In this case, *the user model has a distributed (or not) data structure*, whose contents are changed according to the changes in the use context, and applied in changing IS behavior.

Figure 2d illustrates the IS structure as a UML package diagram. The system consists of the user interface (UI), application logic (and the data repositories needed by it), and *user data*, which we call the *User Model*. In the simplest case it is only a data table in the application, whereas in more complex cases it may be a *dynamic structure* representing the *IS's understanding of the dynamics of the user*. The rest of this paper focuses on this topic. From the software structure point of view, we would like to point out the importance of separating the application logic from the user model; it provides high level flexibility in the IS architecture via software interfaces applying design patterns, see e.g. [7] as an integration solution.

IV. RECOGNIZING CULTURAL DIFFERENCES

There is a wide variety of models for analyzing culture-based differences in human behavior and expectations. In our studies, we have applied the models of Hofstede [9], Lewis [10], and Hall [11; 12] as the main sources.

The model of Hofstede is based on the analysis of six cultural dimensions [10]:

- Power Distance (PDI): the extent to which power differences are accepted.
- Individualism / Collectivism (IDV): the extent to which a society emphasizes the individual or the group.
- Masculinity / Femininity (MAS): refers to the general values in the society - hard/ soft values.
- Uncertainty avoidance (UAI): refers to the extent that individuals in a culture are comfortable (or uncomfortable) with unstructured situations.
- Long-term / Short term orientation (LTO): refers to the extent to which the delayed gratification of material, social, and emotional needs are accepted.
- Indulgence / Restraint (IVR): acceptance of enjoying life and having fun vs. controlling life through strict social norms.

Cultures have different index (dimension) values that define their cultural stereotype. The Trompenaars model [13] follows the structure of Hofstede, with partially different dimensions in analysis.

Lewis divides cultures into three basic stereotypes: *linear-active, multi-active, and reactive*. Some of the national cultures are representatives of these three basic types, others lie somewhere between (in a triangular structure). Quite interesting, especially from the multicultural communication point of view, is the work of *Hall* [11; 12]. His model divides national cultures according to *context dependency in communication;* he divides cultures into high- and low-context cultures according to the level of "hidden information" and exactness of messages.

A brief overview of the above-mentioned models is included in a previous paper of ours [14]. There, we have also *combined Hofstede's cultural stereotypes, Lewis' communication-related aspects,* and used *Hall's high/low context classification* in one multidimensional model. In another paper [15], we have handled the concept of *cultural distance* as a mathematical multidimensional structure to be able to explain the difficulty level in collaboration between different cultures (a longer distance indicates the need for more careful focus on organizing multicultural collaboration).

In her studies (see e.g. [16]), Reinecke has clearly contributed to the idea of human modeling in IS design. She has applied Hofstede's dimensions in implementing a test tool for measuring cultural differences in the use of IS. The MOCCA tool has close to 40,000 user interface variations available for different user preferences, especially based on national cultures. The idea of MOCCA is to find a *good match between the user model included in the IS and the mental structure of the real IS user*. This idea is easy to generalize even outside the original scope (cultural

differences): a good quality IS models the behavior of its user; the better the fit between the user model built into the IS and the user's real mental model in the use case, the higher the user's satisfaction.

V. USER MODELING IN INFORMATION SYSTEMS

User model

In Section 3 we defined the concept of the user model as a component of IS having the following features:

- It includes the data storage that is able to store data values representing the properties of an individual user;
- It supports dynamics (changes in the data values) based on the user's behavior and the use context (adaptability in new situations, learning capability, etc.);
- There may be dependencies between the data fields of the model that are based on functional interaction between the model's data elements.

The two first properties are implementable as a data structure and its interaction with application logic. The third property requires dynamics that are implementable, e.g., in the form of a class (conceptual, object) model defining dependencies and functionalities between the elements; some of these may be external to the system.

We implemented a light mapping study [17] of the existing literature. The aim was to deepen our insight of the topic, especially from the point of view of our research problem as specified in Section 1. The search terms used were "*modeling human behavior in IS*" (2.4 M findings in Google Scholar) and "*modeling of human behavior in IS development*" (2 M findings) to cover both of the aspects discussed in Section 2. The findings cover a wide variety of contexts, e.g., crisis management, security-related issues, urban development, simulation of a human being, agent-based implementations, human behavior in certain contexts, artificial intelligence related approaches, etc., which we excluded. For more detailed analysis we selected some of the most interesting studies, which met our *objective* goals, especially the coverage of cultural differences.

Reinecke's user model

Reinecke (and Bernstein, [16]) has built a test tool, MOCCA, that is used for analyzing the user's national culture based preferences in IS usage. The model has been published as a class diagram that applies Hofstede's dimensions as the key parameters of the user (Person); see Figure 3.

The model takes into account the user's adaptation based on the influence of foreign cultures ("hasFormerResidence"; leads to the definition of the concept "*adapted national culture*") and implements user dynamics as the functional connections between diagram classes. The model also takes into account the nationality of the user's parents (#hasNationalityMother, #hasNationalityFather).

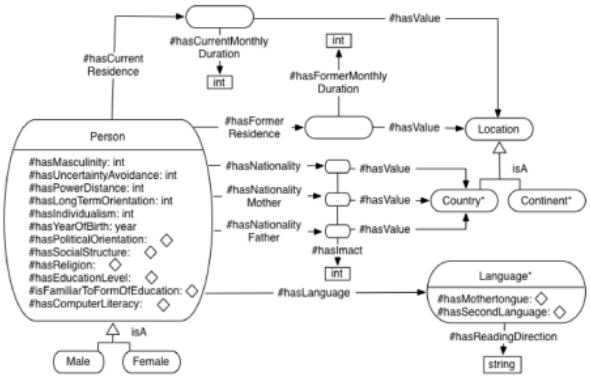

Figure 3. User model by Reinecke [16]

With reference to Figure 2d in this paper, the class diagram represents its "User Model" component.

Phaedra and Permanand – a student model

Phaedra and Permanand [18] have introduced a student model that takes into account a student's demographic factor value (Figure 4). The class diagram (student model) describes the student's cultural and demographic properties.

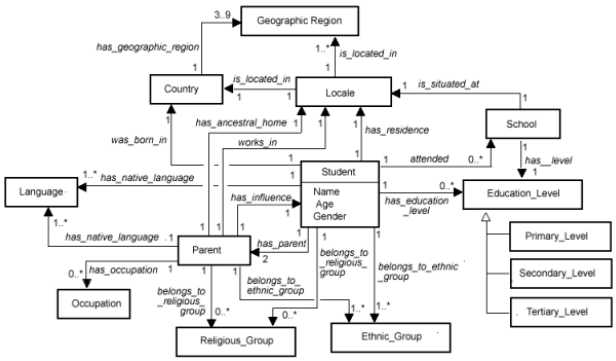

Figure 4. Student model by Phaedra and Permanand [18]

The model (contextual student model, cultural profile) quantifies the student's expression of socio-cultural group traits and preferences. It was used to indicate the expectations and attitude of students in the field of culturally aware tutoring systems. The key factors cover Locale (residence, country, place of birth), School (and educational level in it), Ethnic and Religious Group, Parent (Locale, Occupation, Language), and student's native language. The class diagram represents the "User Model" component in Figure 2d.

Dafoulas and Macaulay – cultural differences in virtual software teams

Dafoulas and Macaulay [19] have modeled the dynamics of multicultural virtual software development teams (Figure 5, upper part). The model lists important factors to take into account in managing the team and organizing its work. The model is multidimensional. It recognizes five dimensions of culture that affect the behavior of an individual: national, organizational, professional, functional (tasks), and team (as a subculture inside an organization). The authors point out the

importance of the professional culture. Software professionals worldwide belong to the computer subculture, which is stronger than any other culture. For example, "a Russian programmer would be more similar to an American peer than to a Russian marketing manager." In addition to the cultural frameworks mentioned above (Hofstede, Lewis, Hall, Trompenaars), this framework refers to the work of Fukuyama (trust as a factor, [20]) and Lessem & Neubauer [21]. The authors also refer to numerous other theories and surveys included in the model (not handled in detail in the original source).

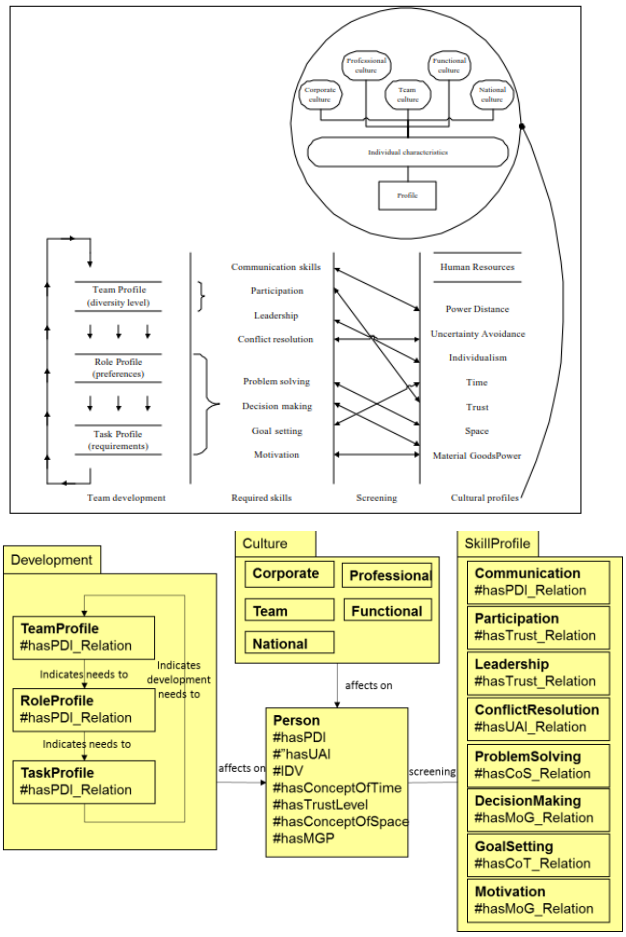

Figure 5. Framework for using cultural model dimensions in virtual software teams [19; Authors]

The model maps the requirements for team development and required skills to the cultural profile. *Team development* is an iterative process, in which the team (diversity) profile indicates the requirements for the role (preferences) profile and further to the task (requirements) profile. This continuous improvement focuses on the required skills, in which the recognition of cultural profiles plays a central role. This model belongs to the category of "management and leadership models." Unlike previous models it does not represent a conceptual model of a user. For this paper we performed a small "exercise" and transferred the original model to follow the same presentation as the earlier ones (Figure 5 lower). In this form it represents the user model component in Figure 2d.

Blanchard et al. – intercultural communication conceptual model

The aim of a *conceptual model* is to define the relevant concepts of the target and their relations to each other. One approach is to use the diagram representation (as in Figures 3 and 4), or a kind of dependency diagram (as in the original part of Figure 5). If we are interested only in the relevant concepts and their structural dependencies, a *mind map* is very clear, simple, and widely used for such purposes. Blanchard et al. [22] have introduced a conceptual model of intercultural communication, as illustrated in Figure 6.

Based on a literature review, Blanchard et al. [22] found theoretical evidence that the way people interpret and react to their environment is significantly dependent on their culture. In human-related technologies the Western context dominates; all trials and tests are done in the Western context, independently of the final target. They introduce a simplified *conceptual model of intercultural communication* using the mind map as a presentation tool. The model includes the following elements:

- *Cultural elements*: Basic cultural units of information. It consists of *cognitive cultural elements*, and *cultural non-verbal communication* (communication system shared by a cultural group).
- *Cultural body language (CBLA)*: Behavioral elements associated with meanings: this association results from a sociocultural perspective (i.e., not learned). Some of these are abstract and some concrete.
- *Non-cultural (innate) elements* cover behavioral primitive elements (gestures, postures, facial expressions) and some innate non-verbal communication elements.
- Additional concept classes in the model include the role of context, culture, and cultural group, enculturated individual aspects, cultural group cohesion, and a variety of descriptors (manifestation of a culture in practical situations).

Transformation of this conceptual model to an IS user model is not straightforward, but it is possible. It includes only the required concept structure: the dynamics (functional connections, learning from external sources) are not specified. However, it gives an excellent list of the relevant aspects to take into account in user modeling. Because of space limitations we have not dealt with the model details, which can be found in the original source. We feel that understanding the basic idea is possible even without the details.

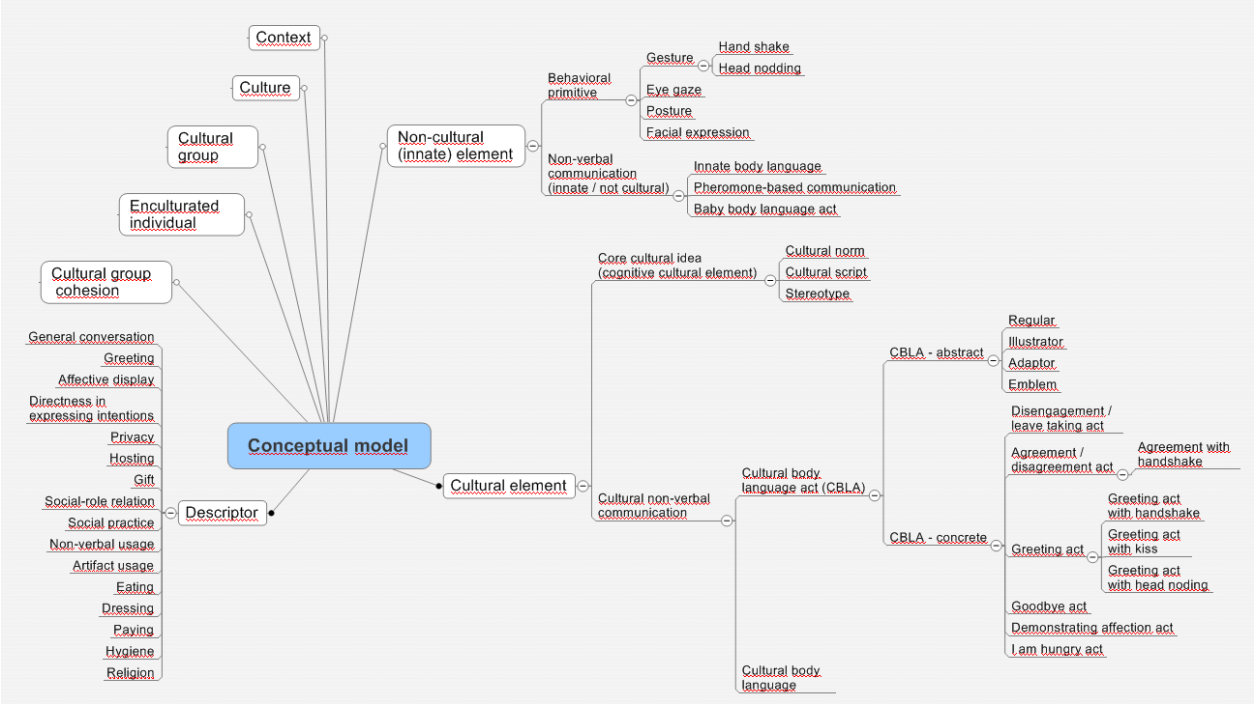

Figure 6. Intercultural communication conceptual model

Other findings

In addition to the few papers introducing a real user model, the literature review resulted in a lot of interesting findings indicating how to take the user's role into account in IS development and in its implementation.

The paper of Damaševičius [23] discusses the organizational, social, cultural, and psychological aspects in the software development process, and reflects the findings in software product properties. The paper introduces a taxonomy of the other disciplines that it is relevant to take into account in software engineering.

Dugdale [24] has published a report that focuses on human behavior modeling in complex socio-technical systems. The work combines *cognitive engineering* and *multi-agent technology* in modeling human behavior (especially human *interaction*). The report itself is a summary of long-term (14 years) research work, with *crisis and emergency management* as its application area. In this field, context- and culture-independent communication is needed to provide means for collaboration between heterogeneous actors.

The paper of Fisher [8] takes a similar starting point as we have in our paper: "*Designers of collaborative human-computer systems face the formidable task of writing software for millions of users (at design time) while making it work as if it were designed for each individual user (only known at use time.*") He approaches the problem from the user modeling point of view (as we do). He distinguishes two basic approaches to make IS adapt to the user's needs: *adaptable systems* are changed by users and under their control (passive system) and *adaptive systems* are active, based on the dynamic adaptation of the system itself to take into account the user and the environment. The models introduced remain abstract, focusing on human-computer interaction principles (general structure charts), without touching on the user model. The paper of Johnstone and Tate [25] approaches the same interaction problem from the *information contents* point of view; the models introduced are also structural system models without an explicit user model.

From the perspective of psychology and behavioral sciences, the topic is dealt with in several papers. We examined two papers (by Huitt [26] and by Johansen et al. [27]) superficially without finding any exact contribution to this paper. However, this approach would be worthy of more careful examination in the future, especially in building the user's mental structure as a part of the user model. In this case the model already approaches an *artificial intelligence* based solution having elements of (deep) learning and heuristics, which is an approach that we have excluded now but found interesting for future studies.

VI. CONCLUSIONS

To conclude this paper we introduce our previously published contribution [2] to the discussion as a starting point for this paper. It includes a simple user conceptual model as a mind map presentation (Figure 7). This model indicates the important factors of an individual to be taken into account in developing an adaptive IS.

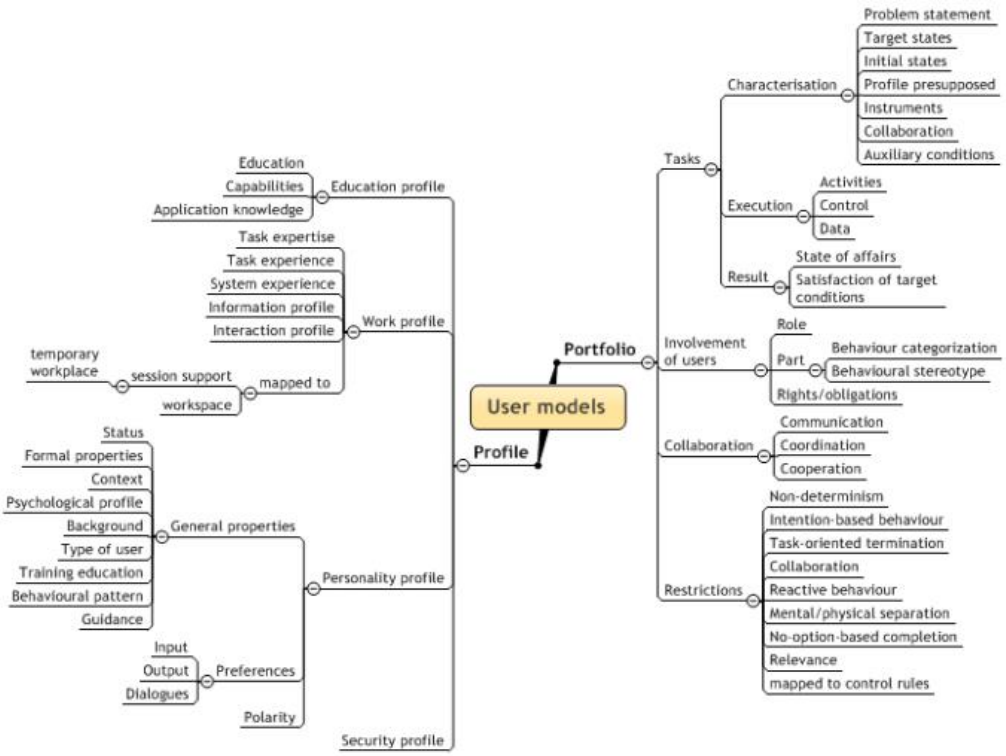

Figure 7. User modeling in adaptive IS

The *personal properties* category of the model covers a personality profile (nine general factors and three dialog preference related factors), a work profile (six factors), and an education profile (three factors). The *portfolio category* includes task-related parameters, a user involvement description, and the type of collaboration and restrictions to be taken into account. A high quality IS implements a good fit between these user profiles and usage portfolio.

Based on this model, we have developed more complex structures for other purposes - human-computer interaction with input, output, and dialog interchange as its components, a user profile specific properties model combining user abilities, HCI preferences, collaboration forms, personality and global behavior in a single mind map.

In this paper we have tried to find means for structuring user properties as an embedded part of the IS itself. Our approach provides understanding about the important factors to be taken into account in user modeling. The studies introduced in this paper (Section 5) and the discussion related to the adaptation structure of IS (Section 3) provide a good starting point for our future work in merging our approach based user models IS?? IS user models based on our approach?. The results of this paper are generic. The relevance to the conference theme comes from two directions: (1) in adaptive systems it is a question of (computer) learning, and (2) every educator should be prepared to validate the educational systems to fulfill the expectations of the students using them. The main principle must be that the system adapts, rather than its user.

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Technology meets Psychology: Psychological Background in Virtual Realities

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Abstract
In recent years, virtual realities (VRs) have become an important resource for various applications such as entertainment, architecture, therapy and learning. Previous research already investigated the effects of psychological processes such as immersion, flow and involvement in context of VRs. However, there are also more basic psychological processes such as perception and attention which both play a crucial role when creating and using VRs. Due to perceptual processes we perceive input from our environment and create a subjective reality in our mind which often does not correspond to the objective reality. Due to attentional processes, we are able to filter relevant information that is processed via our senses from all perceivable information. In the current study, we interviewed technicians about their degree of awareness and knowledge about such attentional and perceptual processes in general and within VRs. The findings showed that there is a lack of knowledge regarding these processes, suggesting that there is need for a broader discussion of the topic. This work aims to be the first step towards this direction.

Keywords
virtual realities; perception; attention; technicians.

I. INTRODUCTION

In recent years virtual realities (VRs) have not only become popular in fields such as entertainment [1] but also in learning [2-3], rehabilitation [4] and even therapy [5]. In general, VR is typically used to describe systems in which objects are created within a virtual environment and the user can interact with these objects to a certain extent. There are several ways how a virtual reality can be created [6]. For instance, in a windows system, a user can enter an interactive virtual world whereas in a vehicle-based system, the user is driving a "vehicle" and the visual environment is virtual (e.g. plane simulation). In a cave system, a room is provided, equipped with displays on each side that project a virtual reality. The advantage of such a system is that a user can move and interact with the system freely. In immersive VR systems, the experience of the VR is intensified by various additional input systems such that several senses (e.g. sight, auditory, etc.) are addressed. Finally, in augmented realities, computer-generated objects are superimposed on real objects.

In the beginnings of VR, technical aspects were in the main focus (e.g., which hardware and software is needed in order to provide a realistic impression of the world). However, regardless of the technical approach used, to successfully create a VR it is also essential to be aware of which psychological factors contribute to such environments and also how they contribute. For example, social interactions, embodiment, engagement, immersion (i.e., the extent to which users are involved in the learning experience) and user presence are psychological processes that have already been investigated in previous research on VR [7-10]. However, other-more basic- psychological factors such as attentional or perceptual processes are often not considered, although these processes are relevant in order to use VRs not only in research but also in (clinical) practice [11]. Furthermore, it is still unclear if basic cognitive (and memory) processes are the same in virtual environments as in real-world settings [12]. To this end, a basic knowledge about attentional and perceptual processes is a key for the successful use of such technologies.

A. Attention and perception

Attention and perception have been investigated since the early days of Psychology. Due to our senses, we are able to receive and perceive input from our environment and to create a subjective reality in our mind. However, this subjective reality often does not correspond to the objective reality. One famous example is the "Müller-Lyer Illusion" [13] first demonstrated by Carl Franz Müller-Lyer in 1889 (see Fig. 1). Although the upper line in Fig. 1 seems to be longer than the lower one (subjective reality) both lines are indeed equal (objective reality). Furthermore, we are also not able to process all information that we receive from our environment because our physiological capacity is limited. For instance, if you look at the scene in Fig. 2, you might have the feeling of rich and detailed perception, but if you try to retrieve all these details afterwards, you might not be able to do so (e.g., you might have missed that there is a crane in the top right corner). Generally, research indicates that about four objects can be held in working

memory [14]. Because of the limited physiological capacity, attention is necessary to filter relevant information from all perceivable information.

However, even if we might have some idea what "attention" means, attention itself is not a single concept but rather subsumes various processes [15]. For instance, if you look at Fig. 2 again, some of the objects in the scene might attract and/or guide your attention more than others. Previous research has indicated that factors like color, orientation, size or movement guide our attention [16]. For instance, the palm tree in Fig. 2 is quite salient. Therefore, you might have looked at the palm first when starting to explore the scene before going to the next area of interest (e.g., the people in the scene). There are several models which aim to predict which regions of a scene might attract attention [17]. For instance, in Fig. 2b, a possible scan path (i.e., the order of regions one would fixate due to the saliency of the different regions) was computed using Saliency Toolbox (www.saliencytoolbox.net). According to this analysis, the legs of the man at the right side of the scene would be fixated first, followed by the green cover on the left. According to the model, the palm (or parts of it) would be fixated afterwards.

A famous experiment that further supports the idea of limited and selective attentional processes is an experiment of Simons and Chabris [18] who had participants watch a scene with students wearing either white or black T-shirts playing basketball and count the number of passes of the "white" team. While doing so, a man wearing a gorilla costume passed through the scene. The results revealed that about half of the participants did not recognize the gorilla (although some of the participants that did not recognize it even looked at it [19]. This finding was also replicated within virtual environments: When Suma, Clark, Finkelstein and Wartell [20] had participants walk through an immersive virtual environment their results revealed that participants hardly noticed even large changes in the surrounding environment.

In the current study we were interested in the prior knowledge of technicians (students) on these basic perceptual and attentional psychological concepts presented above. We were also interested in how they rate the importance of these processes with regard to VRs. The aim of this study was simply to get a first understanding of the attitude of future technicians towards the importance of these processes in their field of work. To answer these questions, we developed a structured interview.

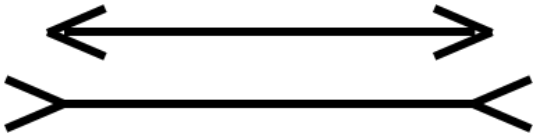

Figure 1. .Müller-Lyer Illusion. See text for details.

2.A.

2.B.

Figure 2. 2.A. Scene used for the interview (see also Table 1, Question 9). Participants' task was to assess the sequence of inspections by writing a number on the areas (e.g. 1 = first inspection point, 2 = second inspection point, etc.) 2.B. Order of inspections of the same scene based on a saliency model (www.saliencytoolbox.net).

II. METHODS

A. Design, Material and Procedure

In order to investigate the knowledge and the awareness of technicians (students) of perceptual and attentional processes we developed a qualitative structured interview that consisted of 11 questions (often followed by sub-questions; see Tab. 1). The questions ranged from very broad questions such how they define "attention" and "perception" in general and specific within VR. Furthermore, we asked specifically for some details, e.g. the study with the invisible gorilla [18] (Question 8 in Tab. 1).

Table 1. Questions of the structured interview (Note that the questions are slightly rephrased/shortened compared to the interview).

1.	Previous experience on VR? (if so, please describe)
2.	In what way is Psychology important in VR?
3.	How would you define attention and in which way could it be important within VRs?
4.	How would you define perception and in which way could it be important within VRs?
5.	How many objects do you think can you perceive at the same time?
6.	How could Psychology help improving a VR?
7.	Do you know any perceptional phenomena?
8.	Do you know the experiment with the invisible gorilla [18] and if so please explain?
9.	"Palm Tree Picture" (see Fig. 2): How do you think people would inspect this picture?
10.	Why do you think sometimes people remember objects of a scene, that weren't there?
11.	Think back to the Picture: (Fig. 2): Which objects do you keep in mind easily/badly? Which different kinds of memory do you know?

The oral interview was carried out at public (but quiet) places at the University of Graz or Graz University of Technology. For most of the questions, the interviewer (one of the authors) took written notes of the respective answers. Question 9 at Tab. 1 referred to the scene in Fig. 2a and asked the participants to set a sequence of inspection according to how they believe one would inspect the scene (1 = first inspection, 2 = second inspection, etc.). Participants pointed to the picture and the interviewer wrote the numbers on the picture, according to the participant's indications. In two further questions (Questions 10 and 11, respectively), we also asked participants about their previous knowledge of memory systems (long-term memory & short-term memory, [21]).
All questions were asked in English; however, all participants were German speaking and preferred to answer the questions in German. All in all, the interview took about 15 min.

B. Participants

Four participants (2 females; *M* age: 26.3 years, *SD* age: 2.3) took part in the interview. All of them were students at Graz University of Technology. Participants gave informed consent prior participation. Moreover, the study was approved by the local ethics committee.

III. RESULTS

The questionnaire consisted of the 11 questions in Tab. 1. Two of four participants reported in question 1 (Q1) that they had worked with VR before, namely within university courses (e.g. programming). Two participants however stated that they did not have any knowledge in the field of VR, one of these two stated to have played a VR game before.
When asked in what way Psychology might be important for VRs (Q2) one participant stated that Psychology is like a "tool" when it comes to creating VRs. Two participants also emphasized that Psychology is a component which should be considered in context of VRs and one claimed that "further work has to be done." One person said that it would be difficult to think about Psychology in context of VR and that more knowledge would be needed.
When asked about the definition of "attention" in general (Q3), two participants stated that attention is important to concentrate on a certain object; one further participant defined it as "putting focus on a certain object." One participant said that the impact of attention is often underrated. However, all four participants thought that attentional processes are important when it comes to VR.
With regard to the definition of "perception" (Q4), the answers were more widespread: Participants named factors such as "certain things might be different for one person than for another person", "impact of the sense" and also just "to be aware that an object is there". However, again all participants agreed that perception is important in context of VR.
When participants were asked to estimate how many objects one can perceive at once (Q5), the estimates were 2, 5, 20 and 20-30 objects, respectively. One of the participants also differed between conscious (2 objects) and subconscious perception (6 objects). Q6 showed that there is a bright variety of thoughts on how Psychology could help when creating a VR: The answers ranged from "realizing experiments that would not be possible otherwise", evoking certain emotions, direct the attention on something in order to guide the behavior in the VR or also take Psychology into consideration when modelling the VR. Q7 showed that all interviewed students of a technical subject knew some perceptional phenomena, for instance, optical illusions were named often (e.g. moving circles, mirages).
Two of the participants had knowledge of the experiment with the invisible gorilla (Q8, [18]). As a reason for the misperception of the gorilla during the basketball game, these two stated that attention plays a role here as the participants in that study concentrate on something else and this often leads to misperception. When asked about whether they think that they would recognize the gorilla themselves, one participant stated that he would most likely not perceive it, whereas the second participant stated it would depend on his concentration. Two participants were not aware of the experiment with the invisible

gorilla [18]. In this case, the experiment was described to them after the end of the interview.
In Q9 we had the participants mark the sequence of fixations in which they think the scene in Fig. 2 would be inspected. All four participants pointed to the stem of the palm tree and thought it would be an important feature, because it is very prominent in the picture. The other nominations varied between the different participants and concerned e.g. the sky and the people (see Fig. 3 for details). When asked about whether one would retrieve objects that were actually not there, two out of four participants stated that the picture might be linked to personal experiences or memory. One participant said that if there was, for instance, an umbrella, perceivers might automatically think of raindrops (and might incorrectly retrieve them afterwards). One participant did not believe that one could retrieve objects that were not in a previously presented scene. Finally, Q11 revealed very diverse thoughts of which objects are kept in mind more easily than others. All four participants agreed in the point that the palm tree would be remembered best. Asked for the different memory systems they knew, all four participants were able to state short-term memory and long-term memory as memory systems. Two participants thought that the palm tree memory was in short-term memory at that moment and the next day it would be in long-term memory.

IV. CONCLUSION

In the current paper, we provide first insight into the knowledge and awareness of technicians on basic psychological processes in context of VRs.
All in all, the interviews showed that knowledge about basic psychological processes was rather superficial, however we detected a strong interest in Psychology, as well as awareness that Psychology is an important component when it comes to create VRs (see also the answers to Q2). Psychological knowledge has been shown in some fields (e.g. memory systems such as long-term memory and short-term memory, partly also on the work of Simons and Chabris[18]). In other areas we detected a lack of knowledge (e.g. at the object-memory span asked in Q5 the answers stretched from 2-30 objects). Participants were however very interested in Psychology as a subject and very optimistic to learning more about it.
We are aware that the interview and the questions asked in the interview were themselves rather superficial and that further and more detailed experiments are necessary, of course also involving a more substantial sample size. However, as mentioned above, the general aim of this study was to go a first step towards the important result of bringing the two fields of Technology and Psychology closer together. Future research should include more differentiated questions and a bigger sample size, as well as the extraction of a user-friendly guideline of psychological facts when it comes to creating, applying and working with VRs. This seems to be of big interest, as future research is forecasted to merge fields together and a broader knowledge and proficiency of different fields of science will become more and more important. In sum, the current study revealed interesting insight in future technicians' awareness of Psychology and sets a first direction, which is important to follow.

3.A.

3.B.

3.C.

3.D.

Figure 3. Answers for each participant (A, B, C, D) for Question 9 in the interview. Note that, for better readability, we re-labeled the scenes based on the answers of the participants.

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Is Big Brother Watching You? A Computational Analysis of Frequencies of Dystopian Terminology in George Orwell's 1984

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***Abstract* - George Orwell's 1984 is considered by many to be a classical work of modern English literature with tremendous influence. It has been translated into many languages and is still one of the most read works to the present day. The word "Orwellian" is used in present-day English language to describe a totalitarian utopia, i.e. dystopia. The terms and literary concepts in the novel have been the subject of a vast critical acclaim, whereas the novel's terminology used by Orwell is still being massively utilised in media, political science, education, popular culture etc. Linguists claim that terms such as "Big Brother", "thoughtcrime", "Room 101" and others are in common use since the publication of the novel in 1949. The aim of this paper is to demonstrate, through the use of a computational analysis of frequencies of dystopian terminology in the text of George Orwell's 1984, that it is possible to measure how the Orwellian concept is created, constructed and structured in the novel. Such a computational approach might provide deeper, objective, unbiased and consistent insights into the phenomenon of dystopia in fictional literature.**

Keywords* - *computational frequency analysis; natural language processing; terminology analysis; dystopia; information science

I. INTRODUCTION

Eric Arthur Blair (Motihari, Bihar, British India, present day Bengal, 25 June 1903 – London, 21 January 1950), better known under the pseudonym George Orwell, was a British writer and journalist.

His two most critically acclaimed works, Animal Farm and 1984 (also "Nineteen Eighty-Four"), continue to be the subject of literary critique to the present day.

Orwell's work, considered by many to be a classical work of modern English literature, has seen resurgence in the last year due to daily global politics and political speech in the media, promoting his novel 1984 once again to the top of bestseller lists. That is also why this work will be the interest of this article.

Orwell's novel and the Orwellian concept, in particular its inherent dictionary of Newspeak, the fictional language used in 1984, can be used as a blueprint for the interpretation of newly-coined terminology as, for example, alternative facts.

Using a method of evaluation of the most frequently used words from the Newspeak vocabulary, the authors analyse the frequencies of words which are presumed to construct the terminology of the dystopian element in the novel.

The aim of this paper will, therefore, be to demonstrate that it is possible to measure how the Orwellian concept is created, accentuating, with the chosen research method, the construction and structure of Orwell's 1984.

Through the use of a computational analysis of frequencies of dystopian terminology in the text of 1984, the authors might, with such an approach, provide deeper, objective, unbiased and consistent insights into what one may call the phenomenon of dystopia in fictional literature, more precisely, into one of the most acclaimed and well-known works of the previously stated literary genre.

One very important advantage of the computational statistical analysis is that it is language-independent and that it can be applied on various types of text, or on various translations of the very same text, which is very interesting when used in philology.

This opens up different possibilities, especially in language education and literature research. The frequencies analysis allows to research various linguistic and textual phenomena, including those that form the basis of literary research.

Other educational purposes will be presented through the related work section of this paper, which shows the various applications of this method. The computational analysis of frequencies can be implemented in a variety of higher education fields. Furthermore, all citations that are listed in the aforementioned section originate also in the educational process.

II. MOTIVATION AND RELATED WORK

Orwell's work is the subject of scientific research in various fields to the present day.

"After newly elected President Trump's spokesperson identified a whole new category of "alternative facts", to cover dissimulation, once again Orwell provided the intellectual apparatus to describe and appreciate the

perpetual doublethink of politics. It is gratifying that Nineteen Eighty-Four shot to the top of the bestseller lists yet again as people struggled to understand the new alternatively factual political universe, but worrying that it should be necessary." This reference [1] demonstrates the continuity of the applications of Orwellian terminology in political science and media research, as well as the popularity and reception that 1984 has on readers and the general public.

It is interesting to note that the word "doublespeak", often associated with Orwellian terminology, is not used in the novel itself, but as [2] states: "The word doublespeak combines the meanings of Newspeak and doublethink. Doublespeak is language which pretends to communicate but really does not. It is language which makes the bad seem good, something negative appear positive, something unpleasant appear attractive, or at least tolerable. It is language which avoids or shifts responsibility; language which is at variance with its real and its purported meaning; language which conceals or presents thought. Doublespeak is language which does not extend thought but limits it". As George Orwell wrote in Nineteen Eighty-Four [3], "Even to understand the word "doublethink" involved the use of doublethink".

According to [4], it may be possible to summarise Orwell's art and political intentions: "Orwell rests near the canonical center of deliberately political twentieth-century writing, but the tendency of academic criticism when it turns to Orwell at all, since the 1970s, has been – as with so many writers – to uncover the political unconscious at work in his writing, which is to say its uglier, less controlled, more symptomatic ideological flaws and extrusions. Orwell's writing identifies explicitly as democratic socialist, and such affiliation raises challenging questions for interpretation."

When reviewing Orwell's fictional dictionary of the Newspeak language, [5] states "As such, language emerges to be mind control tool, with the ultimate goal being the destruction of will and imagination [6]. One of Orwell's most important messages in 1984 is that language is of central importance to human thought because it structures and limits the ideas that individuals are capable of formulating and expressing [7]. These beguiling phenomena of language on human mind can be explained with the integrated issues between psychology and language, which means psycholinguistics in one word".

From a historiographic point of view, according to [8], "Beyond the well-recognized theme "Big Brother" or "Big Brother is Watching You" rests another very important yet frequently overlooked subject of George Orwell's novel 1984. This less acknowledged cornerstone notion of the book centers on the triad of history, historical memory, and the historian".

As shown in [9], it is possible to manipulate translations of Nineteen Eighty-Four: "Results of the study revealed some distortions embedded in the target texts which were overshadowed by ideological aspect and patronage network. The outcomes of the manipulated terms were different in various categories which revealed the manipulation aspects in the texts translated".

Natural language processing (NLP) techniques focus very often on word occurrence statistics [10]. Analysing frequencies of words is common in NLP, as very frequent words might provide deeper insights into certain phenomena.

Earlier research has shown that it is sometimes very useful to calculate the distribution of words over frequencies [11], or for instance, to assess the ratio of the total number of words and the number of distinct, i.e. unique words [12, 13].

Furthermore, plotting frequencies using a logarithmic scale, as a data visualisation approach, is also very convenient, as it does not alter the data itself, compensates for the skewness towards large values [11] and, therefore, emphasises data features that would not be easily distinguishable if both variables had been plotted using a linear scale.

Also, a research [14] has shown that applying logarithmic scales can reveal whether a given dataset follows the Zipfian distribution.

Moreover, plotting of frequencies helps to understand the intrinsic dataset patterns, to detect outliers and to discern other aspects of a given dataset [15].

Some recent research [16] has shown that calculating descriptive statistics might be very useful in analysing specific datasets, such as twitter corpora.

Some other research has shown, that, when it comes to terminology extraction, several approaches can be used: automatic (purely statistical), language-based (purely linguistic) or hybrid (using both statistical and linguistic knowledge) [17].

In addition, sometimes calculating precision, recall and F-measure, while using terminology filtering and reference lists can be beneficial for analysing corpora [18].

In order to evaluate the "keyness" of terms, with respect to a reference list, different string distance metrics can be applied, such as Levenshtein, Jaro-Winkler, Jaccard coefficient or tf–idf (term frequency–inverse document frequency) [19].

III. RESEARCH

The following subsections describe in detail the analysed dataset, the research methodology and applied natural language processing techniques.

With a precise statistical approach, the conducted analysis will show how a text is constructed using certain words.

A. Dataset Acquisition and Preparation

The authors of this paper analysed George Orwell's novel 1984, also known as "Nineteen Eighty-Four". The whole text contained in the novel was used as the dataset in this experiment.

The novel was made available free of charge as an e-book, i.e. a digitised version of the printed book, at the website of the Project Gutenberg Australia. It was

acquired in January 2018 and downloaded from http://gutenberg.net.au/ebooks01/0100021h.html.

Once the novel was downloaded in HTML format, essential data preprocessing steps were carried out. First of all, the content of the novel was copied raw, without any formatting, and in paragraph form to a plain text file. UTF-8 file encoding was used in order to ensure that the whole text was represented in a correct manner.

Then, the dataset was checked using regular expressions for unnecessary blank space characters (e.g. double blank spaces, running and ending space characters etc.) and cleaned afterwards. All redundant characters were removed. Furthermore, unessential text sections, such as author information, e-book identification number, publication dates, copyright notes etc. were deleted.

After the removal of empty lines, paragraphs were split into sentences/segments, also using regular expressions in Python.

Tokenisation was then performed using Perl. Tokenisation rules were also employed in order to specify delimiters and markers that do not designate the end of a given sentence.

B. Research Methodology and Applied Techniques

After the process of data acquisition and preparation, initial descriptive statistics were calculated: total number of characters (with spaces), total number of words, number of distinct, i.e. unique words, ratio of the total number of words and the number of distinct, i.e. unique words, total number of sentences/segments, maximal and minimal sentence/segment size (in words), average sentence/segment size (in words) and standard deviation (in words). The distribution of words over frequencies was also calculated.

These calculations or, in general, the use of NLP methods and descriptive statistics, enabled the authors of this paper to evaluate the frequency of words used in the novel, with the distinct aim to differentiate the frequency of appearances of character names and concepts (such as the "Party") from words of the fictional Newspeak language vocabulary.

Applying such a straight-forward method allowed the authors to interpret the structure of the novel through its unique style which was to be, the authors expected, one of rich vocabulary and specific terminology, allowing a deeper, objective, unbiased and consistent insight into the construction of a dystopian work of literature.

IV. RESULTS AND DISCUSSION

Descriptive dataset statistics and initial research results are presented in Table I.

TABLE I. DESCRIPTIVE DATASET STATISTICS AND INITIAL RESEARCH RESULTS

Total number of characters (with spaces)	611248
Total number of words	119508
Number of distinct, i.e. unique words	10451
Ratio of the total number of words and the number of distinct, i.e. unique words	11.44
Total number of sentences/segments	6570
Maximal sentence/segment size (in words)	146
Minimal sentence/segment size (in words)	1
Average sentence/segment size (in words)	18.19
Standard deviation (in words)	12.54

The dataset consisted, after preprocessing, of cca. 120 thousand words which were separated into roughly 6600 sentences/segments. The total number of characters, including spaces, was more than 0.6 million. Average sentence/segment size was approximately 18 words.

More than 10 thousand words were distinct, i.e. unique, which indicates that a relatively rich vocabulary was present in the dataset.

Still, the ratio of the total number of words and the number of distinct, i.e. unique words is more than 11. This means that on every 11 words comes one distinct, i.e. unique word.

The largest sentence/segment consisted of 146 words, whereas the smallest sentence/segment was only one word long (only 1 occasion). This resulted in a standard deviation of more than 12 words.

Table II shows the distribution of words over frequencies.

TABLE II. DISTRIBUTION OF WORDS OVER FREQUENCIES

Freq.	Number of words	% of distinct, i.e. unique words	% of words
1	**5181**	**49.57%**	4.34%
2	1615	15.45%	2.70%
3	835	7.99%	2.10%
4	536	5.13%	1.79%
5	372	3.56%	1.56%
6	261	2.50%	1.31%
7	193	1.85%	1.13%
8	165	1.58%	1.10%
9	109	1.04%	0.82%
10	100	0.96%	0.84%
>10	1084	10.37%	**82.31%**

More than 5 thousand words appeared only once (so-called hapax legomena) in the dataset. They accounted for almost 50% of all unique, i.e. distinct words and cca. 4% of the total number of words in the dataset. Words that appeared only twice (so-called dis legomena) in the dataset were represented with cca. 15% in the total number of distinct, i.e. unique words. Tris legomena, i.e.

words that appeared only three times, made up cca. 2% of all words in the dataset.

Moreover, cca. 82% of all words in the dataset appeared more than 10 times. This is partly expected, as the English language heavily relies on the very frequent use of function words, such as conjunctions, prepositions, pronouns, auxiliary verbs, interjections, articles etc., which are essential for composing grammatically correct sentences.

It is evident that the analysed dataset encompasses rich vocabulary and very specific terminology, since most of the distinct, i.e. unique words (almost 50%) appear only once.

Fig. 1 plots the trend line and the histogram of log-frequencies of words considering specific bins:

- 1 occurrence (3931 words)
- 2-10 occurrences (3817 words)
- 11-100 occurrences (945 words)
- 101-1000 occurrences (112 words)
- 1001-5000 occurrences (13 words)
- more than 5000 occurrences (1 word)

Log-frequencies use a nonlinear scale in order to depict a large range of different quantities. The histogram actually uses a logarithmic scale to plot one variable (frequency) that covers a large range of values, and another variable (specific bin) with a restricted range.

As one shift towards large-value bins, the plotted trend line starts to declining dramatically at some point.

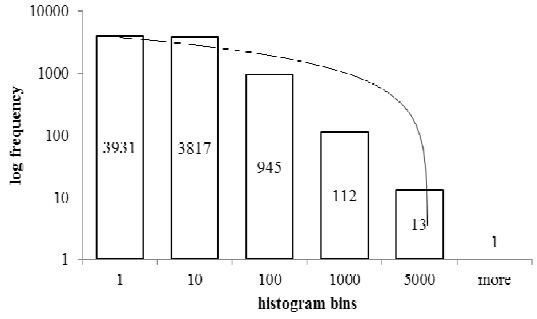

Figure 1. Trend line and histogram of log-frequencies of words considering specific bins.

Very few content words (e.g. nouns, verbs, adjectives, and adverbs) which provide semantics, i.e. meaning, are among the 150 most frequent words (see Table III). Case-insensitive words were extracted in order to cover all varieties of the same word.

TABLE III. ANALYSIS OF THE 150 MOST FREQUENT WORDS (CASE-INSENSITIVE)

Rank	Freq.	Word	Rank	Freq.	Word
1	6522	the	67	205	**brien (o'brien)**
2	3493	of	68	203	time
3	3118	' (apostr.)	84	156	moment
4	2575	a	100	125	war
5	2445	and	103	123	words
6	2348	to	105	121	years
7	2316	was	106	120	eyes
8	1968	he	116	108	**telescreen**
9	1920	it	120	106	people
10	1868	in	124	105	world
…			128	100	**julia**
27	527	**winston**	137	98	voice
53	289	**party**	142	97	word

Top ten of the most frequent words (tokens) are in fact function words: the, of, ' (apostrophe), a, and, to, was, he, it, in.

The word "winston" (ranked 27th) refers to Winston Smith, the main protagonist that the reader most identifies with in Orwell's novel 1984. Winston Smith is a humble, innocent, sympathetic human being, but he is suffering severely in a totalitarian system. He becomes more and more aware of the system's flaws and eventually loses his spirit and humanity fighting against the system.

The word "party" (appears almost 300 times) refers to the Party, the ruling power in Orwell's novel, which is outweighed only by Big Brother. The Party is a privileged oligarchical political class which controls and monitors its minions.

The word "brien" (o'brien) is ranked 67th, and refers to O'Brien, a fictional character and the main opponent of Winston Smith in the dystopian society which is governed by the ruling Party. O'Brien is a loyal agent of Big Brother and engages in a false flag operation to lure and find "criminals" that conspire against the system.

The word "telescreen" (appears more than 100 times) refers in the novel to a fictional surveillance and communication device which is operated by the ruling Party in a totalitarian system, in order to keep its citizens under permanent observation. It is equipped with a camera and a microphone which help to decrease the possibilities of conspiring against the system.

The word "julia" (ranked 128th) also refers to a fictional character, Julia, who pretends to be supporting Big Brother and the ruling Party. But in fact, she despises the system and discusses various topics with Winston Smith (her lover) in an "unorthodox" way.

Other generic content words that are very common, i.e. which are in the top 150, are: time, moment, war, words, years, eyes, people, world etc. They appear between cca. 100 and 200 times in the dataset.

Dystopian terminology, i.e. the characteristic words from George Orwell's fictional language Newspeak [20], does not appear very frequently, except for the term "telescreen", which appears even 108 times and is ranked

116th. Some other words from the Newspeak language appear as follows:

- more than 50 times: newspeak (84 times), big brother/bb (82 times), oceania (62 times), eurasia (58 times), free* (57 times),
- more than 20 times: ingsoc (38 times), goldstein (37 times), eastasia (35 times), doublethink (31 times), brotherhood (23 times),
- more than 10 times: vaporiz* (19 times), oldspeak (16 times), room 101 (15 times), thoughtcrime (12 times),
- other frequencies: chestnut tree cafe (9 times), hate week (9 times), floating fortress (8 times), doubleplus (7 times), memory hole (7 times), crimestop (6 times), unperson (5 times), ungood (5 times), crimethink* (4 times), minipax (4 times), minitrue (4 times), airstrip one (4 times), blackwhite (2 times), artsem (only 1 time), …

The asterisk that appears in some of the words above represents the Kleene star, an operator that is used in regular expressions to match any number of characters (0 or more).

V. Conclusion

Through the use of a computational analysis of frequencies of words, applied on the text of Orwell's 1984, with a special accentuation on terms and concepts that could be considered dystopian, or are part of the fictional Newspeak language vocabulary, the authors of this paper came to the conclusion that it is possible to measure how the Orwellian concept is created, constructed and structured in the novel.

The descriptive statistics demonstrate, through the use of an unbiased, objective and cost-efficient method, that the novel frequently uses words and concepts such as "Party", "time", "moment", "war", "people", "world", "voice" etc. to construct its narrative backbone. But, what is considered to be Orwell's innovation in dystopian terminology – words of the fictional Newspeak language vocabulary – do not appear very frequently.

In other words, the authors have shown that a non-frequent use of Newspeak dictionary throughout the text of the novel does not constitute the foundation of the construction of the Orwellian concept in 1984.

It is important to note, with an exception of the word "Telescreen", that in fact Newspeak words appear (through a method of context analysis) to be negative rather than affirmative, because they are interpreted through the perception of the main character and not the totalitarian regime that puts to use words like "Big Brother", "doublethink" etc. in an affirmative way, perhaps rendering them indecipherable to a computational analysis.

The authors would like to point out that the performed experiments were altogether based on word occurrence statistics. Such a "mathematical" approach yields problems related to the qualitative spectrum of data analysis.

This may, therefore, warrant another research on concordances of the fictional Newspeak words, in order to explain the context of such words in the novel. Nevertheless, more extensive analyses should be carried out in the future.

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Computational Concordance Analysis of Fictional Literary Work

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Abstract - **Fictional literary work, in the case of the dystopian genre, could be exemplified in the context of totalitarian utopia of George Orwell's novel 1984. The terms and concepts of the novel have been subject of a vast and storied critical reception, especially regarding the terminology concerning what makes this particular fictional literary work an ideal example of dystopian literature. Many of the terms used in 1984 have been in common use in the English language since the date of the novel's publication. The main hypothesis in this paper is that terms related to the Orwellian concept, such as "Big Brother" or "Newspeak", are applied in an affirmative and positive way, and that a computer is not suitable for distinguishing the totalitarian implications of those terms, as computers are inherently not able to put them in the context that is in fact a dystopian work of fiction and that the novel's characters employ these terms as a mean of, in the novel's expression, thought control. The aim of this paper is to examine, through the application of computational analysis of concordances, the possibilities to measure the true, totalitarian nature of the concepts and catchphrases used affirmatively by the characters in the text of Orwell's 1984.**

Keywords - computational concordance analysis; natural language processing; context analysis; fictional work; information science

I. INTRODUCTION

When approaching a term as vast and rich of meaning as dystopian literature, one literary work undoubtedly comes into mind – George Orwell's novel Nineteen Eighty-Four published in 1949.

Eric Arthur Blair, better known under the pseudonym George Orwell, was a British writer and journalist, renown for two works considered by many to be classical works of modern English literature – Animal Farm and Nineteen Eighty-Four (also known as 1984).

The authors analyse the second one in this paper, using computational concordance analysis, which will demonstrate the nature of the terms and concepts used in the selected novel. The question arises – if Newspeak, the fictional language used by the totalitarian regime in the novel, is used as means of propaganda and thought control, can a concordance analysis measure the true totalitarian nature of the concepts and catchphrases used affirmatively by the characters in the text?

Is it possible, with the use of computational concordance analysis, to extrapolate the true context, the meaning in between the lines of the terminology used in a work of the dystopian literary genre?

Using a select quantity of the most influential terms from 1984 (e.g. "Big Brother"), which are still being used in various fields, such as politics, the media etc., the authors will evaluate the analyses of contexts provided by the concordances.

II. MOTIVATION AND RELATED WORK

According to [1], "As part of the view which treated literary works as objects, independent of their historical and social contexts of production, the intentional fallacy refers to the argument that we do not (or cannot or need not) know the intention of an author in order to interpret his or her text. The text is autonomous; the author is irrelevant to its interpretation". There are "[…] various methods of computer-assisted text and corpus analysis: in particular, the use of concordances for studying patterns of language use".

Furthermore, according to [2], "Concordancing also continues to be important in literary research. Many literary works are now available in electronic form and concordancing software is used to investigate all aspects of literary language and authorial style."

The early approach to the topic was to evaluate the differences and representative possibilities of a literary work in printed and digital form. As [3] stated, "In certain important ways, then, the printed page is inherently incapable of representing the work accurately or fully. But electronic technology, in a very practical way, is now making it possible to retain a version which more closely approximates the essence of a work without disregarding all the mutations which exist in the manuscript and printed representations. When we examine complex literary material, such as the novels of Joseph Conrad, we begin to see the computer not merely as a tool for imitating traditional bibliographic operations, but as a new vehicle demanding a new and more complex understanding of the nature of basic literary problems".

New technologies, in this case the analysis of concordances, can be applied to the most ancient of literary texts. According to [4], "Classicists, both as teachers and scholars, are enjoying the fruits of the ongoing technological revolution. Classics teachers can now, with a few keystrokes, produce a customized concordance to any literary work we teach; we can

generate word-lists for our students in frequency-of-occurrence order for efficiency-guided vocabulary study. The Internet has become a world-wide burgeoning encyclopedia at our keyboard: we can pull in texts off the Internet – or scan them ourselves – and run search packages on them; we can pull in photos of vases, or of archeological sites and with a few more keystrokes turn them directly into transparencies for classroom use. Classicists, as well as any, know that Tasman got it right".

Furthermore, [4] cites Tasman's [5] quote that they deem prophetical in nature: "The use of the latest data-processing tools developed primarily for science and commerce may prove a significant factor in facilitating future literary and scholarly studies".

Reviewing the use of concordances in literary work, another important assessment was made by [6]: "Despite the impression one receives from the constant flow of computer-generated concordances from the world's presses, there remains much to be done: there is little likelihood that scholars will cease to need, and produce, concordances to authors whose works are worthy of the labours necessary to concord them – and many to authors whose works are not. Consequently, there is room in the literature for a modest examination of the form and arrangement of literary concordances which can draw from the leading examples of past years in order to determine the considerations which might best govern the production of new concordances".

The applications are varied, according to [7] "[…] the research techniques made possible by concordancers are no longer confined to the study of the Great Books, but are available to all academic disciplines which are concerned with the analysis of text: literary studies, media studies, descriptive linguistics and ... language teaching".

Concordances also have their use in stylometrics, according to [8], allowing a review of work done on the statistical analysis of "change over time" in literary style. Furthermore, [8] states: "The advent of the computer has meant that data for this purpose is now readily available in the form of a concordance or word-index to a literary work. The choice of the number of different words (types) in a text as a counting unit allows the stylometric analyst the freedom of working on the raw data and of operating a lemmatization according to norms which he can define himself, for example, the subsuming of singular and plural forms. This choice may run the risk of treating the individual written or printed word as unduly sacrosanct, yet, to date, no stylometrist has managed to establish a methodology which is better able to capture the style of a text than that based on lexical items".

Using an approach based on concordance analysis could aid in accentuating and capturing the style of Newspeak, Nineteen Eighty-Four's fictional language, avoiding a subjective approach to the text or, as [9] stated: "Orwell's writings have been the subject of almost constant exegesis since his death – and indeed even before in his all-too-brief ante-mortem moment of fame. But all too often, his critics and his admirers alike see him as a resource to justify their own prejudices and ideologies".

One research [10] has demonstrated that natural language processing techniques, such as concordance plots, can be utilised for the statistical analysis of word usage in tweets.

Another research has reported that, by statistically analysing word occurrences in specific corpora, language barriers can be overcome [11].

In conclusion, [12] has shown that specific software that makes use of hashed indexes, markers and suffix arrays, can be very effective when it comes to discovering concordances. More precisely, the CAT tool loads all of the mentioned data structures into memory, which enables fast lookups of concordances or its fragments.

III. RESEARCH

The following subsections describe the chosen dataset, the applied preprocessing steps and the technique of computational analysis of concordances.

The research focuses entirely on concordances which are examined quantitatively and qualitatively. Moreover, most of the research processes relate to the field of natural language processing (NLP), especially computational corpus analysis.

The chosen research methods have the potential to be nowadays adoperated in higher education, for purposes of academic curricula, and for an efficient extraction of relevant information and knowledge from a given corpus. The emphasis of this paper will be put on the philological aspect of computational text analysis.

A. Dataset and Preprocessing

George Orwell's novel 1984, i.e. its whole text was used as the basis for constructing the dataset in this experiment.

The novel itself was downloaded in January 2018 from the Project Gutenberg Australia website (http://gutenberg.net.au/ebooks01/0100021h.html), which hosts free digital e-books that are not subject to copyright restrictions. The digitised novel was acquired in HTML format and contained different formatting styles and fonts, which had to be stripped.

Therefore, data preprocessing was required. Preprocessing steps included the conversion of HTML to plain text with adequate encoding, inspecting and cleaning of redundant characters using regex, removal of irrelevant metadata text chunks, deletion of empty lines/segments, splitting text into sentences/segments and tokenisation. Most of the dataset preprocessing and natural language processing (NLP) tasks were accomplished by using authors' Perl scripts and Python programs.

B. Computational Analysis of Concordances

Once the dataset was cleaned and prepared adequately, initial frequency statistics were calculated and concordances were extracted computationally. Then, all automatically extracted concordances had to be analysed manually, in order to qualitatively determine the nature of the context.

Concordancing can be understood as the process of listing a word with its adjacent contexts [13]. Such a word is also known as a keyword in context (KWIC) [14].

Afterwards, for every keyword in different concordances, "physical" positions of word occurrences in the very same dataset, i.e. literary work, were plotted.

Case-insensitive words were used in regular expressions in order to cover all varieties of the same word.

The main intent was to identify the contexts of various terms that relate to Orwell's fictional language Newspeak, and to explore the application of Newspeak. Such a unique literary method was essential for developing the illusion of a positive sentiment and an affirmative attitude towards a radical repressive political system without any totalitarian implications.

In order to investigate this phenomenon, concordances were extracted computationally for the following words, which were chosen freely by the authors of this paper:

- Telescreen,
- Newspeak,
- Big Brother (also BB),
- Ingsoc,
- doublethink.

Telescreen represents a two-way television [15]. All Party members have one in every room of their apartment. Latest propaganda is being constantly communicated through such a device, and Party members are under permanent surveillance of the Party. Moreover, there is no way to change the channel or to turn off the telescreen, at least not for the lower-class members.

Newspeak is the official language of Oceania's people [15]. It is based on standard English and is extremely "politically correct". All words that deviate from the official political ideas have been removed from the language. Also, there was an attempt to decrease the overall number of words in general, in order to limit the range of ideas that could be expressed.

Big Brother (also BB) represents an (possibly fictional) individual [15]. He is the leader of Oceania's nation and is being worshiped almost as if he was a god. He represents the omnipresence of the all-seeing totalitarian government.

Ingsoc is short for English Socialism [15], a fictional political system of the totalitarian government of Oceania (one of the three super-states, besides Eurasia and Eastasia). Ingsoc, though apparently considered a very positive system in the novel, has its enemies which are led by Emmanuel Goldstein. Everything that is against the government policy is considered a crime against Ingsoc. Even doubting any of its principles is punishable.

Doublethink is a reality control mechanism [15]. It represents the power to hold two completely contradictory beliefs in an individual's mind simultaneously, and to accept both of them. It is described as "to know and not to know, to be conscious of complete truthfulness while telling carefully constructed lies, to hold simultaneously two opinions which cancelled out, knowing them to be contradictory and believing in both of them, to use logic against logic, to repudiate morality while laying claim to it, to believe that democracy was impossible and that the Party was the guardian of democracy, to forget whatever it was necessary to forget, then to draw it back into memory again at the moment when it was needed, and then promptly to forget it again: and above all, to apply the same process to the process itself, […] to consciously induce unconsciousness, and then, once again, to become unconscious of the act of hypnosis you had just performed, […] even to understand the word "doublethink" involved the use of doublethink".

E.g. Fig. 1 shows an excerpt of concordances of the keyword "big brother" (with some of its variations). The keyword is underlined.

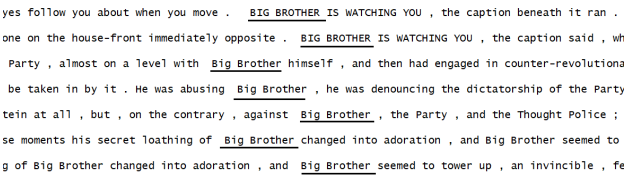

Figure 1. Concordance plot of the word "big brother".

The idea of this paper was to analyse whether a computer is suitable for detecting the true nature of the specific dystopian terms, i.e. for distinguishing the tyrannical and oppressive implications of those terms.

From Figure 1 it is quite obvious that computers *per se* are, in fact, not completely suitable for concordance analyses. Computers are good for crunching numbers and conducting quantitative mathematical operations, but, when it comes to qualitative processing and analysing of natural languages, which are very complex (due to semantics, ambiguity, idioms, collocations, complicated multi-word expressions and phrases etc.), it is often very difficult to crack the issues that arise from the languages' complexities.

Even though computers are inherently not able to put them in the correct context, i.e. to understand that the dystopian terms are being used as a mean of thought control, this paper wanted to investigate the possibilities to computationally extract and measure the essence of the harsh dictatorial concepts and catchphrases that are used affirmatively in George Orwell's 1984.

This enabled the authors of this paper, not only to understand the Orwellian concept in this chosen fictional literary work, but also to examine the relevance and magnitude of the utilisation of specific dystopian terminology in different contexts in the dystopian genre, in general.

IV. Results and Discussion

The following figures represent concordance plots for individual words, the so-called KWIC. All of the concordance plots are in this paper shown in a barcode-like manner. Each concordance plot is a visual representation of concordances, and marks with a vertical

line every “physical” position of a particular keyword of interest in the dataset.

Fig. 2 shows the concordance plot of the word “telescreen”. The word appears 108 times in the dataset, therefore, 108 vertical lines are present in the plot. The presented plot indicates a relatively even distribution of occurrences of the selected word throughout the dataset.

Figure 2. Concordance plot of the word “telescreen”.

When analysed manually, i.e. qualitatively, the word “telescreen”, when interpreted in its context through the use of concordance analysis, appears to give an overly negative sentiment: the results show it to be a “horribly dangerous” tool “to have in the room”, an instrument used by the totalitarian regime of the novel to exert control, a machine that bursts with trumpet calls, an iron voice, military voices and other heavy sounds that “bruised your ears”. Stylistically, it is undoubtedly represented as that what it truly is: a machine from which one can never be safe. The concordance analysis shows the true nature of the word in the text.

Fig. 3 shows the concordance plot of the word “newspeak”, which appears 84 times in the dataset. Most of the times, the word appears at the beginning and at the very end of the novel.

Figure 3. Concordance plot of the word “newspeak”.

Newspeak, “the only language in the world whose vocabulary gets smaller every year” appears in the novel, mostly in an affirmative context. Seen as a synonym for the regime (“Newspeak is Ingsoc and Ingsoc is Newspeak”), there are only a few instances where it is deemed a tool used to “narrow the range of thought”, and the context analysis in general lists a series of elaborations on the words of its vocabulary. As it is said in the novel, “The Revolution will be complete when the language is perfect”. With further reading through the concordances, one could argue that it is in fact visible from the context that this fictional language is used for oppressive purposes, but in general this conclusion is not intelligible from the concordances themselves.

Fig. 4 shows the concordance plot of the word “big brother/bb”. It appears 82 times in the dataset. The analysed word appears more frequently in the first half of the novel.

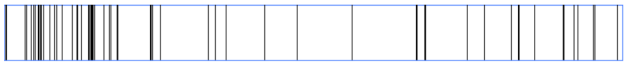

Figure 4. Concordance plot of the word “big brother/bb”.

Big Brother, the “invincible, fearless protector”, “full of power and mystery” and “wisdom and majesty” is, of course, “the guise in which the Party chooses to exhibit itself”. Nonetheless, form this analysis it is indecipherable that Big Brother is a negative figure – by the context of the sentences in which he appears, and by the context of these sentences themselves, Big Brother is shown affirmatively, almost like a protective father figure. It is interesting to note that the only instance when it should be represented in a negative manner, from the context it appears to the reader that it is a form of propaganda from the opposing side, that prints in large neat capitals the phrase “Down with Big Brother”. The term by itself has in general no real opposition.

Fig. 5 shows the concordance plot of the word “ingsoc”, which appears 38 times in the dataset. The word is mostly found at the beginning, and in the second half of the novel, especially at the end.

Figure 5. Concordance plot of the word “ingsoc”.

Ingsoc, meaning English Socialism in the fictional language Newspeak, as a word and a concept, is shown as negative by the context analysis. “Ingsoc intends to make all the other modes of thought impossible” and, furthermore, accentuates the concept of a “heretical thought” as one “diverging from the principles of Ingsoc”.

Fig. 6 shows the concordance plot of the word “doublethink”. The word appears 31 times in the dataset. The plot indicates an uneven distribution of occurrences of the word “doublethink”.

Figure 6. Concordance plot of the word “doublethink”.

Doublethink, a concept that is very influential in politics and media, in the novel, by its context alone, does not appear as negative, but it is a term used affirmatively for the Party-approved way of thinking.

In conclusion, the authors of this paper do not expect computers to understand social aspects of human society, but the aspect of a fictional society in a work of fiction. Perhaps, it may be suitable for a computer to distinguish the totalitarian implications in the text of the novel, but computers probably fail when it comes to discerning the “between the lines” aspects of totalitarian speech in the novel when used by characters who are promoting it in an affirmative way.

In addition, these concordance analyses have demonstrated that a computer can distinguish various perspectives of characters, which is especially interesting from a philological standpoint.

V. Conclusion

The main hypothesis of this paper was to show that terms related to the Orwellian concept, of which the authors selected a representative five words (“Telescreen”, “Newspeak”, “Big Brother”, “Ingsoc” and “doublethink”), were not suitable for a computer to distinguish their totalitarian implications.

That is mainly due to the fact that they were applied, in the novel, by members of the ruling totalitarian Party, in an affirmative and positive way. It has been shown that such a computational concordance analysis was not best

suited for distinguishing the totalitarian implications of those terms.

While the aim of this paper was to examine, through the application of computational analysis of concordances, the possibilities to measure the true, totalitarian nature of the concepts, the authors didn't take in regard that some of the terms were not used affirmatively by the characters in the text of Orwell's Nineteen Eighty-Four.

In fact, the words "Telescreen" and "Ingsoc" were not interpreted mostly by members of the Party, but through the perspective of the main character, which reveals their totalitarian nature.

The other three remaining words, "Newspeak", "Big Brother" and "doublethink", which are arguably more totalitarian in nature, are intelligible by the computer as totalitarian concepts and catchphrases adoperated for military and thought-control propaganda, as they are put in use by characters in the novel in an affirmative way.

These results emphasise Orwell's stylistic mastery, as he was able to represent totalitarian concepts both in an affirmative and negative, i.e. totalitarian-ideas-exposing, way, through the use of point of views of various characters, and, depending of what sentence is pronounced and by whom, sometimes even altering the context in which the characters apply a given term or concept.

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Implementing new technologies in publishing: enhanced printed books

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***Abstract* - Although reading e-books is becoming more popular, printed books are still dominant medium in the publishing industry. This paper describes an experimental project that implements new technologies in printed textbook publishing. A textbook for a university course was published and its content was enriched with three innovative possibilities that include usage of tablets, smartphones or personal computers. QR codes are printed in the book in order to extend content by linking the reader to verified internet sources. In addition, web application was developed to help in the learning process – the application is a quiz composed of ten one-choice questions for each book chapter (with 250 questions in the database that will be upgraded periodically). Prior to publication, the application was tested and the results showed that students are ready to accept new ways of learning. The application is a single-page application that executes its logic on client-side and is written mostly in vanilla JavaScript. Besides QR codes and web application, social networking is used to accomplish interaction between readers, author and publisher. Usage of social networks and application converts a printed book into an integrating resource.**

Keywords - application; e-learning; m-learning; publishing; social networking sites; text books

I. INTRODUCTION

Printed books are still dominant medium in the publishing industry. However, there are many possibilities of enhancing printed books by connecting them with electronic environment. Those possibilities can improve learning at all levels of education. In the centre of our interest are university textbooks. An experimental project will be described in order to analyse possibilities in small markets such as Croatian: a textbook in Croatian language was published and its content was enriched by using QR (quick response) codes, web application and social networking sites (Facebook and Twitter).

II. E-LEARNING AND M-LEARNING IN HIGHER EDUCATION: LITERATURE OVERVIEW

E-learning, as well as new concepts like e-books and e-textbooks, has been changing and supplementing its meaning with the development of new technologies thus making it difficult to define it. The e-book was originally considered a reader or a software, and today's definition of this term is focused on content. Authors Vassiliou and Rowley [1] point out the dynamic nature of this concept as well as the ongoing quest for e-book definition in line with technological achievements.

Explaining relation between distance learning (d-learning), electronic learning (e-learning) and mobile learning (m-learning), Gregoriev, Georgieva and Smrikarov [2] place e-learning as a subset of d-learning; and m-learning as a subset of e-learning, as shown in Figure 1.

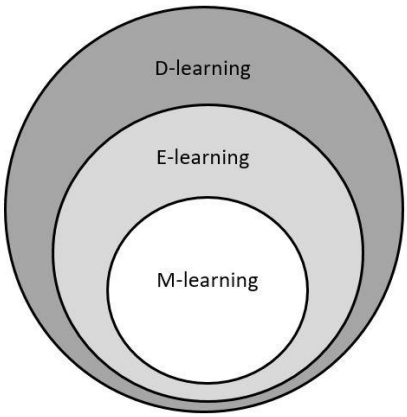

Figure 1. E-learning and m-learning as parts of d-learning [1]

The term *e-learning*, in theory, has different interpretations. The prefix *'e'* in the *e-learning* can refer to electronic learning or to learning enriched with technology (technology enhanced learning). Borgman [3] cites a simple definition which is appropriate for the purposes of this paper where e-learning is considered to be learning enhanced with the help of information and

communication technologies. Moore, Dickson-Deane, and Galyen [4] state that e-learning often overlaps with terms regarding distance learning or online learning. They emphasize that the design of a learning environment depends on the learning goal, target audience, access (physical, virtual and/or both) and the type of content. Authors of textbooks and publishers participating in the creation of educational content should be familiar with the good practice of applying educational technologies in the learning environment. The development of digital technology and Web 2.0 tools brings new guidelines in e-learning development such as collaborative learning and ever-greater interactivity of content. The popularity of using social networks in education, the rapid sharing of content and its display on all devices at any time leads to changes, and e-learning is becoming more and more mobile learning or m-learning.

Mobile wireless personal devices are transforming many segments of human society, including discourse of knowledge and enabling new forms of learning [5]. M-learning happens when the learner is not at a fixed location, or learning connected whit the advantages offered by mobile technologies [6]. That means that M does not stand only for *mobile technologies* but also for *mobility* – it overcomes physical barriers and can be practice regardless of place and time [7]. Crompton [8] defines m-learning as "learning across multiple contexts, through social and content interactions, using personal electronic devices". Sharples [9] explains m-learning as the process of learning through exploration and interaction amongst people and technologies. Portable technology is used to support curriculum learning in the classroom and personal mobile devices are used for learning on the move.

Some of the m-learning principles, according to Heick [10], are access (to content, peers, experts…), transparency (e.g. through social networking platforms), play (as an important characteristic of progressive learning), self-actuation, diversity and authenticity (that is impossible to reproduce in a classroom).

Technology development allows textbook authors to use text and images as well as the integration of other digital content such as sound, video and animation thus enriching the learning content with technology. At the turning point between print and digital educational content, or traditional printed textbooks and digital textbooks enriched with digital educational content, the emergence of hybrid products offers the benefits of both technologies, their comparisons and the application of the most effective educational technologies in educational processes.

The printed book is still dominant in education but new technologies are emerging and their introduction needs to be experimented with. Technology should be used in publishing to add value to the publishing product depending on the publishing field and content type [11]. Tian and Martin [12] see e-learning as an opportunity for educational publishing which, with its experience in the textbook production, can contribute to a higher quality e-learning environment that always includes technological companies, institutions, technology designers and other. The leader of a great research project *Network Generation: Strategic Research,* Don Tapscott [13] in his book, *Grown Up Digital*, tells teachers in one of the strategies for the digital age:

Don't throw technology into the classroom and hope for good things. Focus on the change in pedagogy, not the technology.

Ever since 2002, a major research project, the NMC Horizon Report has foreseen the introduction of technology in education, and lists trends, challenges and technologies from various industries that can be used to enrich learning. The report states that technology alone cannot transform education, but digital tools and platforms can accelerate teaching processes [14]. According to Garrison [15] there are no simple rules for good e-learning but what can help us is the answer to the question of what e-learning can do and the traditional teaching methods cannot.

Trying to use the best of both worlds to teach, the authors discover the potential of new visual technologies among which the Augmented Reality (AR) technology stands out. Lee [16] highlights the great potential of AR technology that "combines real world with augmented information in interactively seamless ways."

Dachselt and Al-Saiegh [17] point to many different attempts and examples in finding solutions for linking printed books and digital content. They suggest the concept of Projective Augmented Books (PAB), which "does not require fixed locations and expensive hardware and can be used almost everywhere and also combined well-known pen interaction as a natural mode of interaction with a visual augmentation of real surfaces."

Learning with the help of education books with augmented reality records good results with complex 3D concepts as well as in teaching students with difficulties on mastering curricula with textually dominant teaching materials [18].

This paper presents a hybrid-publishing product consisting of a printed textbook, additional digital content accessed by QR technology, a web application and content on social networks. The combination of educational technologies in shaping a hybrid-publishing product aims to provide more efficient and effective learning. Recognizing of the needs of students for learning that is more flexible and in the spirit of good teaching, students will meet well-known technologies; the well-known technology will be used in an innovative way, and alternative solutions will be offered for new learning practices that are unknown to some students or still unavailable.

The aim of this project compared to other AR integration concepts in education is the use of a combination of new technologies in order to provide students with a choice in access to content and more opportunities to master the required material.

III. REALISATION OF THE PROJECT

The production of book *Short History of Libraries and Publishers: with Codes and an Application* began in January 2017 when the manuscript and the application were sent to the University of Zagreb Committee for University Textbooks [15]. The committee sent the manuscript to two peer reviewers and in May 2017 the manuscript was accepted to be published in the University of Zagreb Textbooks Series (Manualia Universitatis studiorum Zagrebiensis). Publisher Naklada Ljevak from Zagreb included publication of the book into their plan, and in October 2017 Ministry of Science and Education of the Republic of Croatia decided to support financially publication of the book.

Plan was to publish the book in printed format, and to add three extensions to broaden the book content: QR codes were prepared to be printed in the book; web application was developed and tested; and social networking sites (SNSs) for the book were opened on Facebook and Twitter.

The book, the application and the content on SNSs are in Croatian language. Content that is available on some of the QR codes is in other languages (English, French, German and Spanish).

A. QR codes

QR code is two-dimensional machine-readable barcode. QR codes can be read by machine-vision systems that consist of optical laser scanners or cameras, as well as of barcode-interpreting software [16]. Figure 2 represents an example of a QR code (in this case, the code is link to the book web page on the publisher's web site).

The codes used in the book are supposed to be read by smartphones. The codes link the book to relevant content on the Internet. There are 139 QR codes printed in the book (95 printed in the text to illustrate it, and 44 printed at the end of the book, as additional codes).

Figure 2. QR code, webpage of the book, http://www.ljevak.hr/knjige/knjiga-21996-kratka-povijest-knjiznica-i-nakladnika

There are two main limitations of using QR codes in printed books – (1) the websites they are linked to can become unavailable and (2) readers of the printed book could not be able to use smartphones (either because they do not own one, or because they do not know how to use QR codes). To minimise the first limitation, only links to reliable sources were chosen, e.g. websites of libraries, of universities and publishers. The links are mostly to digital collections (e.g. Digital Incunabula Collection of Spanish National Library) or specific items in digital collections (e.g. digitized Gutenberg's Bible on the website of the British Library). Those institutions usually maintain their websites and care about long-term preservation of their digital collections, but some links could still become unavailable. In case of any change, readers will be able to find information about new links on the SNSs.

In order to ensure long-term availability of the sources behind the QR codes, publisher plans to maintain the list of URLs on the publisher's web site, i.e. on the webpage that is available in the book via QR code.

Figure 3. Part of the book cover, a QR code that links to the application is incorporated (www.povijestknjige.net), design by Luka Gusić

The second limitation of using QR codes is solved in the printed book in two ways. In the introduction chapter of the book the concept of QR codes is explained. If a reader does not own a smartphone, he can find all the links at the end of the book (in the List of codes), so he could access them through an Internet browser. One code is incorporated in the book-cover design. The code is link to the application (Figure 3).

B. The application

Web application was developed to help students and all the other users in learning process – the application is a quiz composed of ten one-choice questions for each book chapter. There are 8 chapters in the book and 250 questions in the database. Reader (user) choose the chapter (by clicking on the chapter icon) and starts answering the questions that are randomly chosen from the database. Figure 4 shows icon for the fifth chapter (*The Sixteenth Century*). Plan is to upgrade the database with new questions. All the questions are based on the content of the book.

The application is a single-page application that is written mostly in vanilla JavaScript. It can be easily used on any device thanks to the responsive design. Whether that's a mobile phone, a laptop or a desktop computer, the application adjusts itself to fit the screen size of the device it is running on.

All the logic is executed on the client machine in a way that once the application is loaded, it no longer needs

to contact the server. That kind of approach enables more fluid performance.

Figure 4. Icon from the application for the fifth chapter of the book, design by Fran Grgić

The icons used in the application are printed in the book at the end of each chapter. The application is available on the web[1] free of charge and can be used by anyone, even if they do not own or have not read the book.

Prior to publication, the application was tested. A link to the beta version was sent to all the students who have finished the course *History of Book and Libraries* at the undergraduate Study of Information Sciences at the Department of Information and Communication Sciences, Faculty of Humanities and Social Sciences, University of Zagreb. The book is a textbook for the course.

In December 2017 and January 2018, they were asked to answer a six-question questionnaire to evaluate the application. Five questions had rating scales (1 – poor; 2 – satisfactory; 3 – good; 4 – very good; 5 – excellent), and one question was open for commentaries. By the end of January 2018, 34 out of 40 students answered the questions.

The students' evaluation showed that they are extremely content with four parameters – the access to application, application design, content and clarity of the questions, and content and clarity of the offered answers. The average marks for the four parameters were all above 4.6. Students were also satisfied with the fifth parameter (the estimated time to complete the questions), but the parameter had the lowest average mark (3.18). The short time to answer the questions was the only problem discovered by the conducted user test. The results for all the parameters are in the Table 1.

The open question was optional and the comments illustrate results from Table 1. Some of the comments were:

"Excellent idea and realisation!"

"We definitely need more time for answering the questions."

"The design is very nice, but there is not enough time to answer the questions."

"The application is excellent."

"Very good tool for learning."

Based on the results, the application was modified and in final version more time for answers is allowed.

[1] www.povijestknjige.net

TABLE I. EVALUATION RESULTS FOR BETA VERSION OF THE APPLICATION

Parameter	**Average mark (on 1 – 5 scale)**
Content and clarity of offered answers	4.91
Access to the application	4.88
Content and clarity of questions	4.79
Application design	4.68
Estimated time to complete the questions	3.18

Other than the web application, future plans include developing Android and iOS native applications and deploying them to their respective application distribution platforms.

Moreover, introducing a score board, hall of fame, progress badges, etc. is the next big thing to implement since gamification has repeatedly proven itself a very powerful tool in e and m-learning.

C. *Social Networking Sites*

Facebook page[2] and Twitter profile[3] were opened to extend the content of the book. QR codes and links to access the pages are published in the book.

At the moment of publishing of the book (January 2018), the timeline of production was available on the social networking sites. Figure 5 shows a Facebook post, and Figure 6 shows a Tweet about some phases of the book production. It is planned to encourage interaction with the readers once the book is published, but everyone could interact on SNSs, even if they do not own, or have not read the book. New links and information that are connected to the content of the book will be published on SNSs. The content on SNSs will transform the printed book into an integrating resource – a resource that is changed by means of updates that do not remain discrete and are integrated into the whole [17].

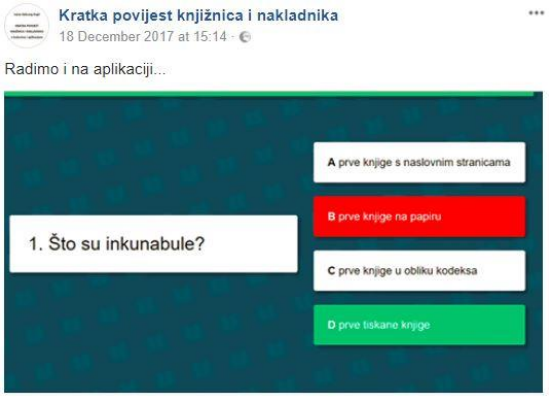

Figure 5. Facebook post on the page *Kratka povijest knjižnica i nakladnika* (Short History of Libraries and Publishers) – insight into a beta version of application, 18th December 2017

[2] https://www.facebook.com/pg/knjiznicenakladnici/posts

[3] https://twitter.com/pov_knjiz_nakl

Figure 6. Tweet from 10th January 2018 – the insight into a final layout

IV. CONLUSION

New technologies are entering the discourse of learning and teaching at all education levels, from primary schools, to higher education and lifelong learning. At the same time, printed books are still dominant way of communicating in science and education. Hybrid solutions in publishing industry include printed books along with the usage of new technologies, e.g. online courses, social networking sites, web or mobile applications.

The project described in the paper is a pioneer project in Croatian publishing industry. *Short History of Libraries and Publishers: with Codes and an Application* is the first academic book in Croatian language that uses QR codes, application and SNSs. Pre-evaluation showed that students are ready to accept new ways of learning. More evaluation is planned in the future – new questionnaires about the book will be published on SNSs every year to help enhance the changeable part of the book (the application and the presence on Facebook and Twitter).

In this case, printed book is enhanced and thus becomes a hybrid integrating resource, resource that is partly changeable (not the printed book itself, but expanded content that can be updated in web application and on social networking sites).

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Analysis of Student Behavior and Success Based on Logs in Moodle

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Abstract – Today, it is almost impossible to implement teaching processes without using information and communication technologies (ICT), especially in higher education. Education institutions often use learning management systems (LMS), such as Moodle, Edmodo, Canvas, Schoology, Blackboard Learn, and others. When accessing these systems with their personal account, each student's activity is recorded in a log file. Besides analyzing the raw data from log files directly, there is an option to use Moodle plugins that provide learning analytics and enable the faster analysis of students' behavior on LMS. In this paper, some of these plugins are presented. However, this paper is focused on analyzing the log files of a course implemented on the LMS Moodle at the Faculty of Organization and Informatics at the University of Zagreb. The results of the students' behavior, based on logs in Moodle, will be interpreted in terms of student success.

Keywords - LMS, Moodle, log files, student success, student behavior

I. INTRODUCTION

With the development and expanding availability of the Internet, different systems for electronic learning (e-learning) have also been developed, implemented, and used. At first, those systems, also called learning management systems (LMS), were very simple—they were basically just web pages listing the main information about study programs, courses, teachers, and contact methods. A few years later, however, more serious LMS began to be developed [1]. Developing LMS became an area of scientific research: in 2003, more than 40 academic journals were specializing in related topics [2]. LMS enabled the creation of personal profiles for students, the sharing of teaching materials, and most important, online communication among students and with teachers. LMS were mainly used to support face-to-face teaching [3].

Today, besides being a support for face-to-face teaching, LMS aid in the teaching of fully online courses and, even more extensive, fully online study programs [4]. In most cases, online teaching is related to the area of the higher education. Students can become masters in specific fields without leaving their home or physically visiting an educational institution. The whole teaching process, from enrolling in a study program, to attending classes, to teaching classes, to taking examinations, is done entirely online. In addition, some new phenomena in teaching activities have been developed as a result of LMS and online learning trends, such as Massive Online Open Courses (MOOCs) or Open Educational Resources (OER) [5]. Even though contemporary trends lean toward leaving the physical classroom entirely, in some scientific areas, that is not possible. However, very creative ways of e-learning are still being developed for such situations. They include combining LMS with web 2.0 tools [6] and even changing the teaching paradigm. One such example is a flipped classroom: students are taught theory at home and come to the classroom to work on projects with teachers and other students, and they then apply the theory they learned to solve problems [7]. The concept of the flipped classroom is opposite to that of the usual teaching process, where the basics are learned in the classroom and practical assignments are left as homework.

In Croatia, many higher education institutions use LMS to support teaching process. The most used LMS in Croatia, and specifically at the University of Zagreb, is Moodle (which is available as Merlin to all higher education institutions in Croatia, [8]). Depending on the number and intensity of the online activities that are supported by Moodle and used in practice, courses at the University of Zagreb can be categorized into one of three levels related to the application of e-learning in education [9], [10]. The highest level, Level 3, requires that all teaching materials be available online; the organization of the teaching process enables individualization within the process; and students assume an active role in terms of achieving outcomes and and other requirements. At this level, the teaching process can be conducted entirely online or be implemented as blended learning. Based on the document "Criteria for the Evaluation of Online Study Programs," prepared by the National Council for Higher Education in 2013, an online study program is a program in which a minimum of 50 percent of the courses are done online, and a course is considered to be an online course when a minimum of 50 percent of the teaching hours are done online [11].

Even though Level 3 represents very advanced e-courses in terms of e-learning, there are additional opportunities for increasing the application of e-learning in education. Current trends in Croatia have led to the implementation of a concept called learning analytics (LA) [12], [13]. When accessing an LMS with their personal account, students create a digital profile that is saved in LMS log files. The main idea of LA is to analyze the raw

data in log files and generate new knowledge (often through dashboards [14]) about students' behavior. This knowledge can then be connected to students' success in order to generate ideas for new activities that will decrease the negative effects of student behavior on student success and increase the positive effects of student behavior on student success. For example, if an analysis showed that the students who accessed teaching materials only one day before the test (student behavior) had unsatisfactory test results (student success), it is necessary to create activities that will influence them to access teaching materials earlier. However, LA is about even more than this; the goal is to analyze all the data retrieved through any system (e.g., LMS systems, library systems, e-portfolio systems, or student services systems), find connections between variables in log files, and make modifications to improve the teaching process (e.g., increasing the quality of lessons, increasing student satisfaction, and decreasing the dropout rate) [15].

In this paper, we are focused on the LMS Moodle. In Section 2, we will describe the LMS Moodle in greater detail, especially its plugins that are originally oriented to LA. In Section 3, we will present some papers in which student behavior has been analyzed using LA. Finally, in Section 4, we will present the most exciting results from the log file analysis of several courses at the Faculty of Organization and Informatics of the University of Zagreb.

II. THE LMS MOODLE AND LA PLUGINS

As said earlier, the LMS Moodle is one of the most used LMS in practice. Moodle is organized through plugins that represent specific activities and extra features that can be added to the fundamental feature of the Moodle: courses. The most used Moodle plugins, which come with basic Moodle installation, are Assignment, Attendance, Choice, Lesson, Page, Quiz, URL, Workshop, Folder, File, Glossary, SCORM Package, Feedback, and Database [16].

Here are some of the plugins that can be used in terms of LA (Moodle 2.9): Logs, Activity, Activity Completion, Live Logs, (Quiz) Statistics, (Course) Participation, Survey, Course Overview, Course Completion Status, Progress Bar, Events List, Activity Results Block, Configurable Reports, (Gradebook) Overview, Ad-hoc Database Queries, Engagement Analytics, Course Dedication, Graph Stats, GISMO, and Graphical Interactive Student Monitoring [17]. The current version of Moodle (3.4) includes the plugin Inspire Analytics. One of the most exciting features of this plugin is a model that predicts students who are at risk of non-completion (dropping out) of a Moodle course, based on low student engagement [18].

Additionally, there is always an option to develop your own plugin or adjust an existing one. One LA plugin contributed by external contributors is the SmartKlass™ Learning Analytics Moodle. Some of the features of this plugin include the identification of students lagging behind and the identification of students for which course content is not challenging enough [19]. If heatmap analysis needed, the plugins MAV [20] and Heatmap [21] can be helpful.

There are many other plugins available online, but before installing any of them, a more in-depth analysis is recommended. Plugins are installed on the level of the server, so it might be inappropriate to install a new plugin on a specific site if only 1% of the site managers and teachers will use it. Still, the analysis of log files can always be done.

III. RELATED WORK

Components of LMS offer various opportunities for the improvement of student learning and, accordingly, can impact students' final grades [22]. An LMS stores data about participants' actions in log files, which gives researchers information about student behavior. A log is a list of a students' events in which each line contains a time-stamp as well as one or more fields that hold information about the activity performed [23]. A Moodle log consists of the time and date it was accessed, the Internet Protocol (IP) address from which it was accessed, the name of the student, each action completed (i.e., view, add, update, or delete), the activities performed in different modules (e.g., the forum, resources, or assignment sections), and additional information about the action [23]. The stored data can be useful for data mining algorithms.

Romero, López, Luna and Ventura [24] noticed a trend toward the combined use of data mining learning techniques for the analysis of activity data. Having the data in an LMS provides various opportunities for the use of data mining methods to examine them [25]. Data mining can be useful to explore, visualize, and analyze data with the aim of identifying useful patterns in order to understand students' learning behavior and feedback. Teachers can then use this information when designing instruction and delivery. Data mining includes tasks and methods concerning statistics, visualization, clustering, classification, association rule mining, and sequential pattern mining [26]. Baker and Yacef [27] also recognized data mining as a promising field for the exploration of data from computational educational settings. Romero, Ventura, and García [28] describe the process of mining e-learning data step by step, with the guidelines about how to use data mining techniques for mining Moodle data. Kazanidis, Valsamidis, Theodosiou, and Kontogiannis [29] also proposed a platform-dependent framework for processing and analyzing data from LMS. Their framework consists of three steps: logging the data, data pre-processing, and data mining. Mainman and Rokach [30] divided data mining techniques for educational data into two groups: verification-oriented techniques (which rely on traditional statistics such as hypothesis tests, the goodness of fit, and the analysis of variance) and discovery-oriented techniques (which rely on prediction and description, such as classification, clustering, prediction, relationship mining, neural network, and web mining). Many authors have reported highly accurate predictions using different classification algorithms such as C4.5, EM, Naïve Bayes, and support vector machines [24].

Research in this area has recently become very significant. The key components of this literature review are the data and methods (tools and techniques) used to explain student behavior in LMS. A brief overview is presented in the following subsection, in which we cite the most current articles on the given topic. Cocea and Weibelzahl [31] identified learner motivation as a key factor in the quality of learning. One aspect of motivation is engagement. Thus, they analyzed 10 attributes related to pages, tests, hyperlinks (number of hyperlinks, average time), and glossary (number of times accessed, average time). Mogus, Djurdjevic, and Suvak [32] examined data (activity logs) obtained by students to detect the frequencies and priorities of students' choice of activities in the LMS. Their research aimed to determine whether students' activity logs correlate with their final marks. Observed activities included course view, assignment view, resource view, forum view, assignment upload, project upload, and final mark. The highest influences on students' marks were assignment view, course view, forum view, and resource view. The authors concluded that those four activities particularly influence learning effectiveness. The lowest number of logs were found to be the activities concerning forum view and discussion view. This suggests a need to encourage students to engage in communication within LMS. The authors' suggestion for future research includes reviewing a broader range of factors, a larger sample of students, a higher number of courses, and a greater range in the types of courses evaluated by studying students from different disciplines to investigate the influence of participants' gender.

Jovanovic, Vukicevic, Milovanovic, and Minovic [33] defined a classification model to predict whether a student would achieve excellent performance in a course. They defined clustering models that would detect groupings of students with respect to their overall performance and used a k-means clustering algorithm adapted for use over categorical data. Models were based on the following data: number of quizzes passed or failed; number of messages sent or read on the forum; total time spent on assignments, quizzes, and forum; and final mark obtained by the student in the course. Kotsiantis [34] used regression techniques to predict students' marks in a distance learning system. The stored data (virtual courses and e-learning log file) were shown to be useful in predicting marks. In 2013, Kotsiantis, Tselios, Filippidi and Komis [35] investigated ten different variables related to the students' activities: assignment_view, course_view, forum_add_post, forum_view, glossary_view, questionnaire_view, resource_view, user_view, and final course grade. Bovo, Sanchez, Heguy, and Duthen [36] grouped students by mining Moodle log data. The first objective was to define relevant clustering features. The second objective was to determine whether their students showed different learning behaviors. Their application uses data mining and machine learning methods to solve the problem of monitoring students in e-learning. Data used in the research consisted of login frequency; the last login time; time spent online; the number of lessons read and downloaded; the number of quizzes, crosswords, and assignments completed; the average grade obtained; and the number of forum topics read and created.

Recently, Gašević, Dawson, Rogers, and Gasevic [37] investigated the extent to which instructional conditions influence the prediction of academic success in a blended learning model. Variables from the LMS included information about the usage of the following Moodle features: forums, course logins, resources, assignments, book, quizzes, feedback, lessons, and chat. The data represented the number of times students used a particular feature. Compared to forums, course logins, resources, and assignments, features such as quizzes, feedback, lessons, and chat were not accessed by a substantial number of students. These were dichotomized into "accessed" and "did not access" categories. Statistical analysis included ANOVA, Chi-square test, and linear regression to explore the association between students' online interactions and students' marks.

IV. Research Description and Results

In this section, we present a case study of a Moodle course log collected from an actual class. This study examines activity logs from when students log in to the course, with the aim of detecting frequencies and finding patterns in students' choice of activities. The study aims to detect the relationship between the observed variables and students' final grades. The objective is to find out the impact of a particular activity in an LMS on a final grade. The following two research questions are posited: RQ1: To what extent are individual variables derived from log data a reliable predictor of academic success? RQ2: What is the level of similarity in student LMS usage between genders? To answer these research questions, a Moodle course log was collected after the spring semester of a blended course called "Business Decision Making". A total of 73 students registered with Moodle, and 180-minute teaching lectures and seminars were held every Wednesday.

Fig. 1 shows the distribution of logs by the overall grade students achieved in the course. The highest number of logs is achieved by the students with the highest grades, 4 and 5. To investigate if there is any correlation between specific activities on the LMS and student grades, we have performed correlation analysis.

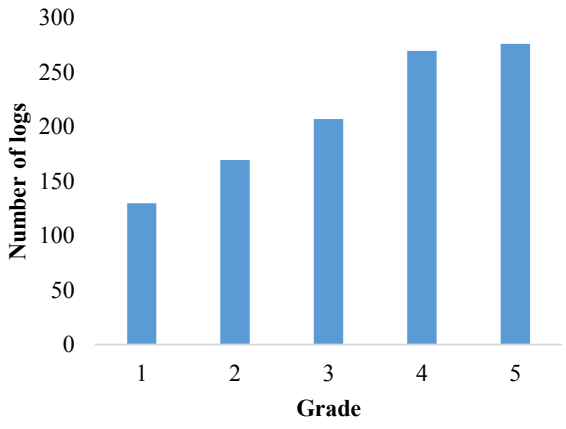

Figure 1. Frequency of logs by grade

TABLE 1. CORRELATION BETWEEN VARIABLES (*P < 0.05)

Variable	*Grade*	*File usage*	*Forum usage*	*Link usage*	*Assignment uploads*
Grade	-	0.35*	0.18	-0.01	0.08
File usage	0.35*	-	0.41*	0.05	0.19
Forum usage	0.18	0.41*	-	0.13	0.38*
Link usage	-0.01	0.05	0.13	-	0.09
Assignment uploads	0.08	0.19	0.38*	0.09	-

Table 1 examines correlations between achievement over the span of the course (measured by grades) and effort in files, forums, and link usage, as well as the assignments uploaded. The results indicate a statistically significant correlation among students' grades and the opening of files. The correlation is positive, which indicates that students with a higher frequency of file openings have higher grades. There is a lack of association between grades and other logs in the course. File opening is correlated with activities on the forum, demonstrating that students who are active in forum discussions opened files more often.

We have also examined students' activity by gender (Fig. 2). Female students have a higher number of logs than their male colleagues. Differences between genders is also visible in the average grade received. Female students have a higher average grade than male students.

According to experience of teachers of the course currently being studied, students often complete their assignments (e.g., write essays, answer questions, or study for exams) in the last moments before a deadline. The idea of next analysis is to determine the distribution of students' logs on the system on the days before the two exams.

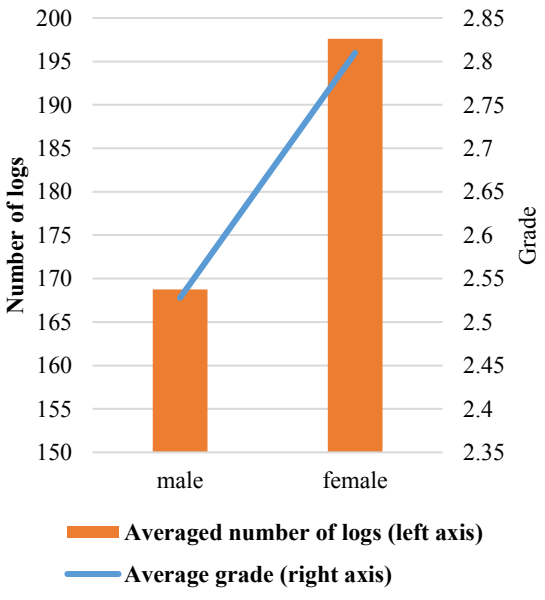

Figure 2. Analysis by gender

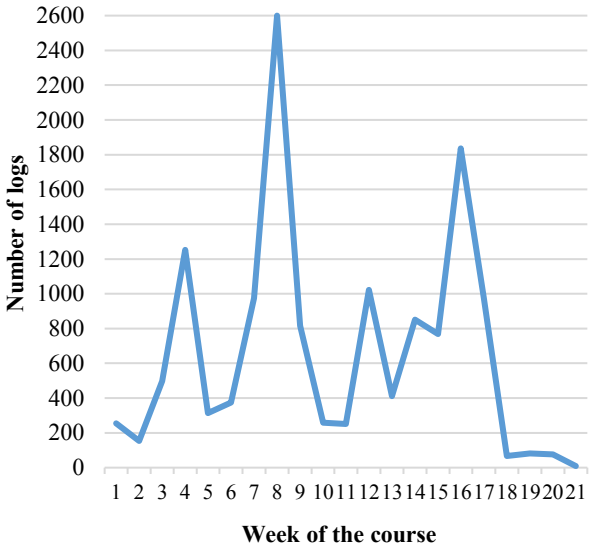

Figure 3. Distribution of logs per week

Fig. 3 presents the number of logs from the 1st to 21st week of the course. The 8th and 16th week of classes are the weeks during which tests were performed. The first test was held on 04-19-2017 (the 8th week of the course), and the second was held on 06-14-2017 (the 16th week of the course). We studied only these two weeks, and specifically, only the two days on which the tests were held. Weekly analysis showed that the highest number of logs appear on the day before test days.

Fig. 4 indicates course logs related to the days before test days. Page views occurred mostly between 17:00 and 20:00 on the day before the first test day (04-18-2017) and between 15:00 and 16:00 on the day before the second test day (06-13-2017). In both cases, there is a significant number of logs in the late hours of the day. During these times, the most students downloaded test materials and started to study. However, course activity during the late hours is more conspicuous for the first test than it is for the second.

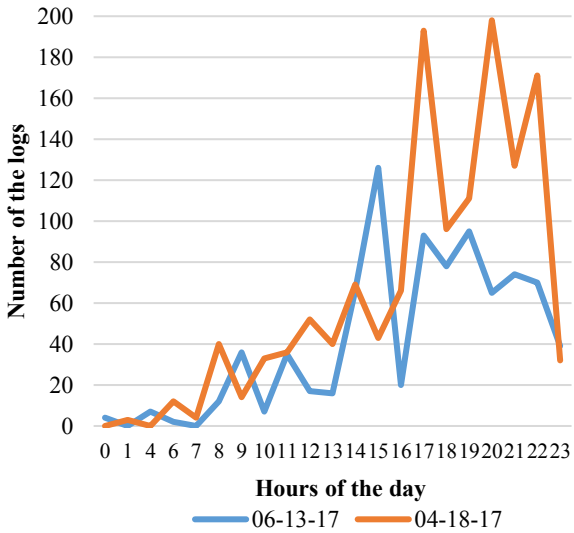

Figure 4. Distribution of logs on the days before exams

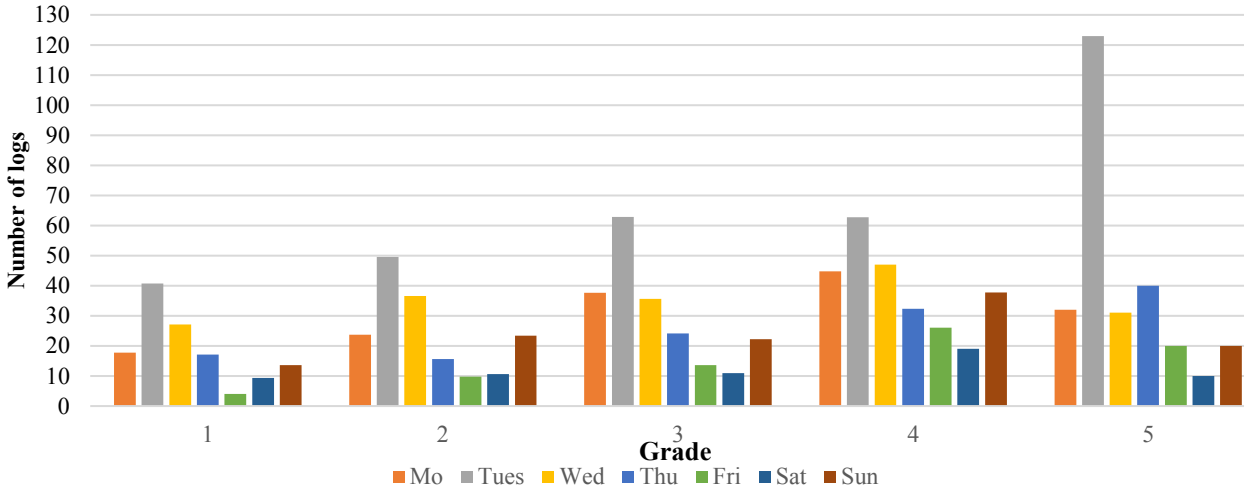

Figure 6. Distribution of logs per day in week with respect to achieved grade

Similarly, the time-focused analysis results for the whole course period level are presented in Fig. 5. It shows the hours of the day during which students were logged into the course, and the opening is concentrated from 11:00 on. During the afternoon, a number of logs persist, but this decreases in the evening. In the period after the midnight, there is no activity on the e-course. However, this does not mean that students were not active on the course—some may have performed an offline assignment after downloading it earlier.

Figure 6 presents an analysis of students' activities with respect to the grade they achieved and the day in the week. Surprisingly, for the students with the highest grade, most of the course activity was done on the day before lectures, seminars, and tests.

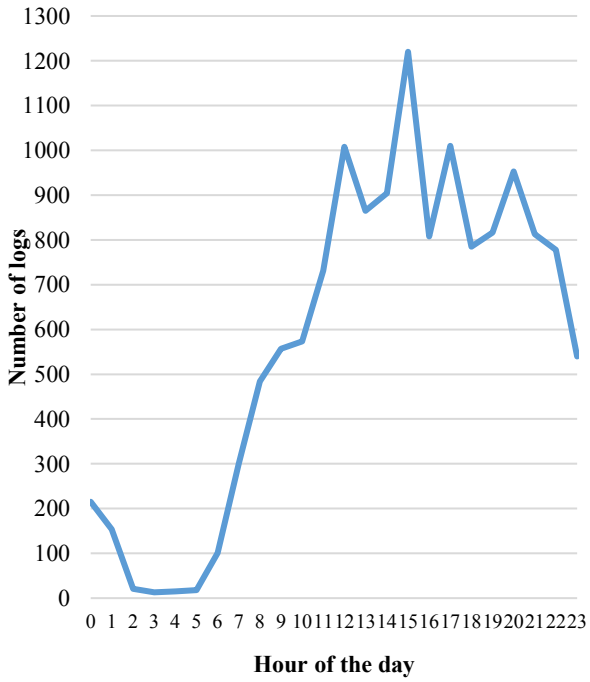

Figure 5. Distribution of logs per day hours

V. Conclusion

Our results are potentially beneficial in the early detection of students experiencing difficulties in a course. Both teachers and students benefit from this kind of research, as teachers can identify excellent students for collaboration and students find out how to give greater effort to obtain good results.

In the conducted research, the female students are more active and successful in the course than are the male students. There is a correlation between the number of logs in the e-course and the final grades. The students were most active in the test weeks and, specifically, on the day before the tests. Students can be characterized as "last-minute" students, as they perform their obligations as late as possible in terms of the deadline and are active in the late hours. However, this cannot be generalized because the research was conducted in only one course. Also, the research covered only informatics students. In future research, the analysis will be performed across several courses. Additionally, students from other disciplines, not only informatics, will be included in future research.

Acknowledgment

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Enhanced Access to Training Information in E-learning Systems

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***Abstract* - Various forms of training that use e-learning systems such as closed and opened educational portals were examined. Existing e-learning systems do not have the ability to find information quickly in all the training courses that have been downloaded, which limits access to the information provided. Several commonly used searching engines were researched to access the possibility of using them for efficient access to all materials presented in the e-learning system. For testing them, e-learning system EFront was chosen. The EFront system is based on the database with clustered indices. Use of an additional programming module connected to EFront system is proposed. This module would allow a full-text search of the information needed. During the research, several modules of full-text searching were considered. The Sphinx technology was selected as the most efficient one. Thus, the proposed solutions made it possible to expand the students' ability to access the necessary educational information.**

Keywords - e-learning systems; training courses; full-text search.

I. INTRODUCTION

Innovative forms of learning such as distance education, blended education, STEM - education, and peer-2-peer education are increasingly used in the learning process. Information technology is the main component of these forms. There are several educational forms exist.

A. Forms of training based on information technologies

Distance learning is a form of training that uses computer and telecommunication technologies that provide interactive communication between teachers and students at different stages of learning, and also support independent work with information network materials. To organize this process, e-learning systems are used that provide:

- educational materials for students;
- control of students' progress;
- interactive teacher - student collaboration ;
- teaching materials toolkit.

Blended education combines the use of traditional methods of education and information technology. This type of training uses electronic and mobile education systems. The educational systems that are used in blended education are open educational portals that are designed to create and maintain open training courses [1].

STEM education combines science, math, technology, and engineering. Its aim is to develop a creative thinking and the ability to solve problems. The educational process is organized by creating communities, coalitions, projects, and virtual laboratories [2] on the Internet; electronic and mobile learning systems can also be used in the learning process.

Teaching peer-2-peer is based on the principle of collaboration - students study by themselves and help each other. This includes repositories, thematic chats and blogs, as well as virtual educational communities that provide collaborative sites (such as the Google Educator Group) [3].

B. Reasons

- All new forms of education use different e-learning systems that help organizing the learning process by providing the interaction between its participants. E-learning systems include Moodle, eFront, ATutor, Blackboard, and others. There are two types of users: those who create training courses and those who get access to created courses. However, any course has a limited amount of information, and very often does not have enough answers for scientific or research students' activity. Also, some courses require an additional knowledge on other related subjects. Course developers can supplement their material with links to other resources, or students can independently search for the necessary information on the network. It is time consuming for both types of users, and does not always give the necessary result.
- The systems of e-learning and the system of open educational portals are constantly expanding and filled with knowledge, but do not have an internal search engine. Some systems would provide the opportunity to search for additional information within the system and, if necessary, expand this search beyond the system to other portals, including scientific metric databases.

II. RESULTS AND DISCUSSION

The aim of this work is to research the possibility of quick access to all the course materials presented in the e-

learning system using quick search on the specified set of keywords. Ensuring a search within one e-learning system can be accomplished by connecting an additional programming module that will enable creating a full-text search of information in the database system. Therefore, it was decided to explore systems used for the full text search.

At the Department of Computer Science and Higher Mathematics of the Kremenchug National University, an e-learning system [4] based on EFront for the introduction of blended learning is used. The database in this system uses clustered indices, which allows you to create clusters. The cluster is used to physically co-store one or more tables that are joined together in an SQL query [5]. Fig. 1 and 2 show how requests in tables that are linked to one-

Figure 1. Usual connection of users with the department and faculty "one to many"

to-many tables with clustered indices work.

In the database of the distance learning system the tables for departments and faculties users are not linked by clustered indices Fig. 1.

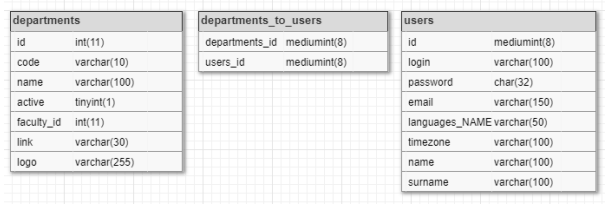

Figure 2. Cluster connection of users with a department and a faculty

The usual and cluster linking of the database tables with cluster connection of users and chairs is shown in Fig. 2.

Below are two SQL queries to display users of a particular department with usual link and cluster link.

SELECT users.name, users.surname FROM users, departments WHERE users.id_departments=departments.id AND departments.id=1

This query displays a list of users of a specific department for usual link. To search for student data, a query will go through each user table field and select users in which id_departments will be 1. The execution time for such a query is shown in Fig. 3.

The query for a cluster link:

SELECT users.name, users.surname FROM users INNER JOIN departments INNER JOIN departments_to_users WHERE

Query_ID	Duration	Query
4	0.00008000	SELECT DATABASE()
5	0.00011050	SELECT users.name, users.surname FROM users, depar...
6	0.00007725	SELECT SQL_CALC_FOUND_ROWS users.name, users.surna...
7	0.00011750	SELECT FOUND_ROWS()
8	0.00010625	SELECT @@lower_case_table_names
9	0.00035575	SHOW INDEXES FROM `sdnknu_efront`.`users`
10	0.00680175	SELECT TABLE_NAME FROM information_sch...
11	0.00017700	SHOW CREATE TABLE `sdnknu_efront`.`users`
12	0.01140950	SHOW FULL COLUMNS FROM `sdnknu_efront`.`users`
13	0.00777650	SHOW FULL COLUMNS FROM `sdnknu_efront`.`department...
14	0.00033550	SHOW INDEXES FROM `sdnknu_efront`.`departments`
15	0.00052150	SHOW SESSION VARIABLES LIKE 'FOREIGN_KEY_CHECKS'
16	0.00041625	SHOW SESSION VARIABLES LIKE 'FOREIGN_KEY_CHECKS'
17	0.00040150	SHOW SESSION VARIABLES LIKE 'FOREIGN_KEY_CHECKS'
18	0.00008675	SELECT DATABASE()

Figure 3. Query time of usual link

departments_to_users.departments_id=departments.id AND departments_to_users.users_id=users.id AND departments_to_users.departments_id=1

This query will scan all users that are listed in the departments_to_users table and have a department_id = 1. In this way, the query will only take the records that we need. The execution time for such a request is shown in Fig. 4.

Query_ID	Duration	Query
6	0.00007175	SELECT SQL_CALC_FOUND_ROWS users.name, users.surna...
7	0.00010675	SELECT FOUND_ROWS()
8	0.00008575	SELECT @@lower_case_table_names
9	0.00031650	SHOW INDEXES FROM `sdnknu_efront`.`users`
10	0.00606425	SELECT TABLE_NAME FROM information_sch...
11	0.00017675	SHOW CREATE TABLE `sdnknu_efront`.`users`
12	0.00590175	SELECT TABLE_NAME FROM information_sch...
13	0.00244600	SELECT TABLE_NAME FROM information_sch...
14	0.00260000	SELECT TABLE_NAME FROM information_sch...
15	0.00223000	SELECT *, `TABLE_SCHEMA` AS ...
16	0.01291875	SHOW FULL COLUMNS FROM `sdnknu_efront`.`users`
17	0.00050100	SHOW SESSION VARIABLES LIKE 'FOREIGN_KEY_CHECKS'
18	0.00037800	SHOW SESSION VARIABLES LIKE 'FOREIGN_KEY_CHECKS'
19	0.00035800	SHOW SESSION VARIABLES LIKE 'FOREIGN_KEY_CHECKS'
20	0.00007900	SELECT DATABASE()

Figure 4. Query time of cluster link

Thus, we can conclude that query for tables with cluster links are performed faster than query for tables with usual links.

In addition to the higher speed of database queries, these links can be used for tree-like structures. With time, cluster indices grow in the process of adding data, and the table start to branch. The data page is divided into two, and in that node (on that page) where previously the data was located, there is an index covering both of the new pages. The specific node of such a tree includes the indices of all child nodes or the final data if the node is the last. Nodes can be referred to each other only in one direction from the parent to the child. If the amount of data increases, the tree will become more complicated and branched, and the more complex data storage scheme provide greater advanteges .

The tables includes directions, courses and lessons of the database of distance learning systems are designed to store lecture materials. The directions table stores categories of subject, such as mathematics, programming, etc. The courses table stores subjects, and the lessons table stores lectures on the subject. The lessons_to_courses table forms a clustered index for linking the subject with lectures. The lecture material cluster is depicted in the Fig. 5.

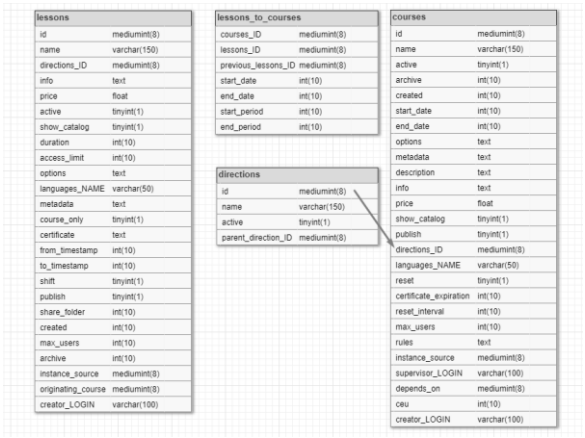

Figure 5. The lecture material cluster

There are two tables, users_to_lessons and users_to_courses, that have clustered indexing for link the courses and lectures with system users Fig. 6.

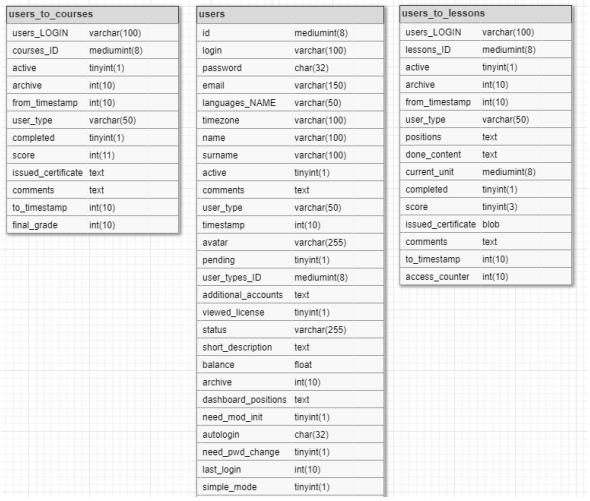

Figure 6. Cluster for link the lecture material and users

There are three tables, users_to_groups, courses_to_groups and lessons_to_groups that have clustered indexing for linking the user groups with lectures Fig. 7.

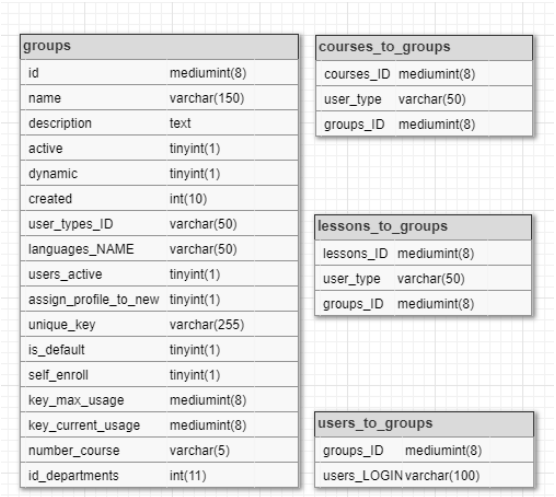

Figure 7. Cluster for link the user groups with lectures

For example, in a cluster of lecture material figure 5, each lecture material belongs to a particular subject; the subject in turn belongs to a certain subcategory belonging to a category belonging to some type of information, etc. For example, the lecture "Object-oriented thinking and analysis" belongs to the subject "Object-oriented analysis and design", the subject belongs to the category "OOP", which in turn belongs to the category of "Programming", this category belongs to the educational type of information, etc. So we have a tree-like structure where each branch is a higher level abstraction. Such a structure should be organized for convenient and accurate search of data according to the specified parameters and criteria. If you create such a structure with a usual link, then searching will be very complex and slow.

Most full-text search solutions work on the principle of index search. Index is built based on the text data and keeps all search results along with the information where this data was found in the document. This approach increases the search speed more than scanning the entire content of all (or multiple) database tables.

The search service consists of two components: a search engine and an indexer. The indexer receives the text on the input, does the processing of the text - cutting out the endings, insignificant words, etc., and stores everything in the index. The structure of the index allows you to conduct a very fast search on it. Search engine woks by searching interface by index - receives a query from the client, treats the phrase and searches it in the index.

Search technologies with a full-text index are used to create a full-text search on the site. These include built-in full-text search in the sub, Sphinx, Elastic Search, Apache Solr, etc. It was researched how these technologies work with the database of the distance learning system.

In the built-in MySQL search it is needed to create an index. To create an index, the "FULLTEXT" type is used. Unlike the LIKE operator, in this approach, a full-text index is a dictionary that stores the location of a search query. For example, in the code below two indices are created: index1 and index2 that can be used to search in the main and info fields – index1 or only in the info field – index2.

```
CREATE TABLE IF NOT EXISTS `lessons` (
    `id` mediumint(8) unsigned NOT NULL AUTO_INCREMENT,
    `name` varchar(150) NOT NULL,
    `directions_ID` mediumint(8) unsigned DEFAULT '0',
    `info` text,
    PRIMARY KEY (`id`),
    KEY `les_indx1` (`directions_ID`),
    KEY `les_indx2` (`active`),
    FULLTEXT KEY `index1` (`name`, `info`),
    FULLTEXT KEY `index2` (`info`)
) ENGINE=MyISAM DEFAULT CHARSET=utf8;
```

MATCH-AGAINST is used for full-text search. In the example below the word "programmer" was searched based on index1.

*SELECT * FROM ` lessons ` WHERE MATCH (name, info) AGAINST (' programmer');*

In the built-in full-text search, MySQL indices take up quite a lot of disk space. Changing tables with these indices, in contrast to other technologies, will perform much longer, and the search will be slow.

Sphinx technology [6] is a server for full-text search with open source. To work with it on the server a search daemon (server) Sphinx should be installed, which will index the search data in the database after a specified period of time.

For a full-text search on the content of lectures the content of lectures needs to be indexed figure 5. At first a configuration file would be created. In the configuration file, the source settings would be specified where the content is stored; a query that makes a selection of all records would be written, which must be indexed, and text attributes would be defined. Also, the index building settings, the settings for storing the values of the document attributes, the indexer settings, and the search daemon settings should be set. The query that makes a selection of all the records that should be indexed is as follows:

sql_query = SELECT content.id AS contid,content.name AS contname,content.data AS cdata, lessons.name AS lname, courses.name AS cousesname FROM `content` INNER JOIN lessons ON content.lessons_ID=lessons.id INNER JOIN courses INNER JOIN lessons_to_courses ON lessons.id = lessons_to_courses.lessons_ID AND courses.id=lessons_to_courses.courses_ID

After creating the configuration file, the data needs to be indexed and the configuration daemon (the server, Search Daemon) to be run. The results are shown in the Fig. 8.

After successful indexing, several search queries would be executed in the console. For example, for searching for all subjects and lectures that contain the word "zend", the following command should be executed:

```
using config file '/usr/local/sphinx/etc/sphinx.conf'...
indexing index 'mysqlbasename'...
collected 615 docs, 2.2 MB
sorted 0.1 Mhits, 100.0% done
total 615 docs, 2158832 bytes
total 0.129 sec, 16682884 bytes/sec, 4752.55 docs/sec
total 3 reads, 0.000 sec, 65.5 kb/call avg, 0.0 msec/call avg
total 10 writes, 0.000 sec, 52.8 kb/call avg, 0.0 msec/call avg
root@vps-26349:~# /usr/local/sphinx/bin/searchd
Sphinx 2.1.3-dev (r4319)
Copyright (c) 2001-2013, Andrew Aksyonoff
Copyright (c) 2008-2013, Sphinx Technologies Inc (http://sphinxsearch.com)

using config file '/usr/local/sphinx/etc/sphinx.conf'...
listening on all interfaces, port=9312
listening on all interfaces, port=9306
precaching index 'mysqlbasename'
precached 1 indexes in 0.001 sec
```

Figure 8. Indexing data and starting the search server

/usr/local/sphinx/bin/search --config /usr/local/sphinx/etc/sphinx.conf zend. The results of this command are shown in the Fig. 9.

The full-text search usies php. To do this, a class to the Sphinx API project is connected. The result of a full-text search using php for searching the subjects and lectures

```
using config file '/usr/local/sphinx/etc/sphinx.conf'...
index 'mysqlbasename': query 'zend ': returned 9 matches of 9 total in 0.000 sec

displaying matches:
1. document=1087, weight=2792, contname=Початкове завантаження, lname=Zend Frame
2. document=1094, weight=2785, contname=Веб-сайт, lname=Zend Framework, cousesna
3. document=1086, weight=2773, contname=Процес розробки і підтримки, lname=Zend
4. document=1301, weight=2704, contname=Zend Framework, lname=Zend Framework, co
5. document=1083, weight=1649, contname=Введення, lname=Zend Framework, cousesna
6. document=1084, weight=1649, contname=Відсутність перевірки коректності даних,
7. document=1085, weight=1649, contname=Фільтрація даних у полях форми відповіда
я
8. document=1095, weight=1649, contname=Загальний HTML-код, lname=Zend Framework
9. document=1300, weight=1649, contname=Презентація, lname=Zend Framework, couse

words:
1. 'zend': 9 documents, 31 hits
```

Figure 9. Indexing data and starting the search server

that contain the word "zend" is shown in the Fig. 10.

The Apache Solr technology [7], in contrast to the Sphinx technology, creates not only a search index, but it is also used as a data storage, that is, the data is stored entirely and does not need to be duplicated in the

zend

(zend | *zend*)

Course: Сучасні технології програмування
Lesson: Zend Framework
Content: Процес розробки і підтримки
id: 1086
content data: ... трохи видозмінений підхід, щоб пом'якшити ці вимоги і зробити Zend Framework більш зас
Course: Сучасні технології програмування
Lesson: Zend Framework
Content: Початкове завантаження
id: 1087
content data: ... include "Zend/Loader.php"; Zend Framework розрахований на те, ... Zend/Loader.phpсодержи Zend ...
Course: Сучасні технології програмування
Lesson: Zend Framework
Content: Веб-сайт
id: 1094
content data: ... А тепер настав час додати в наше додаток новий вигляд. Вид Клас Zend Framework, на базі
Course: Сучасні технології програмування
Lesson: Zend Framework
Content: Zend Framework
id: 1301
content data:
Course: Сучасні технології програмування
Lesson: Zend Framework
Content: Введення
id: 1083
content data: Використання вбудованих методів моделі, замість написання своїх Перше, що відразу кинуло
Course: Сучасні технології програмування
Lesson: Zend Framework

Figure 10. Indexing data and starting the search server

database.

The built-in Apache Solr functions support different types of data and rules for indexing documents. To extend the capabilities of Apache Solr, a new Java classes are created. In Apache Solr, a schema for typing data types and rules for managing indices and describing data is created. After that, the data is exported and loaded into Apache Solr according to the scheme.

Fragment of the Apache Solr schema:

```
<schema name="example" version="1.1">
  ...
  <fields>
  <field name="id" type="string"
indexed="true" stored="true" required="true" />
  <field name="name" type="text"
indexed="true" stored="true"/>
  <field name="nameSort" type="string"
indexed="true" stored="false"/>
  <field name="cat" type="text"
indexed="true" stored="true" 4ultivalued="true"/>
```

```
        ...
        </fields>

        <uniqueKey>id</uniqueKey>
        ...
        <copyField source="name"
dest="nameSort"/>
        ...
      </schema>
```

For indexing and searching both Solr and Elastic Search use Lucene. These technologies are most often used for searching in the cloud; they work with a cluster that connects several servers to one node [8].

The main logical data structure for Solr is called the collection. A collection is composed of shards that are really Lucene indices. A single collection can have multiple shards, and shards can live on different nodes.

In Elastic Search the top logical data structure is called an index. Similar to a collection in Solr, Elastic Search index can have multiple shards and replicas. Shards and replicas are small Lucene indices that can be spread across the cluster in order to create a distributed environment. In Elastic Search there are multiple types of documents in a single index. This means that we can index documents of different index structure (for example users and their documents) in a single index. ElasticSearch is able to distinguish those types during indexing as well as querying.

Apache Solr and Elastic Search expose an HTTP API.

To receive the search results from Solr it is needed to query one of the requests handlers and pass in the parameters that define the query criteria. Depending on which query parser used, these parameters will be different, but the method of obtaining search results is HTTP GET. The results can be obtained in XML, JSON, JavaBin, and several other formats. Solr API includes querying, some statistics about different search components or control Solr behavior, such as collection creation.

ElasticSearch exposes a REST API which can be accessed using HTTP GET, DELETE, POST and PUT methods. Its API allows not only querying or deleting documents but also creating indices, managing them, controlling analysis, and getting all the metrics describing current state and configuration of Elastic Search. Elastic Search only produces results in JSON format. In Solr all query parameters are passed as URL parameters, and in Elastic Search queries are structured in JSON representation. Queries structured in JSON format control the Elastic Search results output.

Below is an example of adding an index in Elastic Search:

```
        curl –XPUT
"http://127.0.0.1:9200/lessons/material/1?program" –d'
        {
        «title»: «Программирование»,
        «content»: «<p> Теория
программирования…<p>»,
        "tags": [ "программирование", " Теория
программирования" ],
        "published_at": "2018-01-
26T20:44:42+00:00"
        }'
```

As a result, there is a server response that the data has been successfully indexed:

```
        {
         "_index" : "lessons",
         "_type" : "post", "_id" : "1",
         "_version" : 1,
         "_shards" : { "total" : 2, "successful" : 1,
"failed" : 0 },
         "created" : false
        }
```

This will display all id documents that contain the word "*программирование* ":

```
curl –XGET "http://127.0.0.1:9200/lessons
/material/_search? program" –d'
        { "_
                source": [ "title", "tags" ],
                "filter":
                { "term":
                        { "tags":
                         " программирование"
                         }
                }
        }'
```

All the researched technologies allow solving the task of the full-text search in the e-learning system with the exception of the built-in full-text search MySQL. Based on the research it is advisable to use Sphinx technology for e-learning system since Apache Solr and Elastic Search are designed for complex data structures.

III. CONLUSION

The innovative forms of training that are based on the use of information technologies were researched. The main component of such forms of education is e-learning system. These systems are, in turn, divided into open training courses and closed distance or blended learning within an educational institution. The results show that these systems do not have the ability to quickly find information in all the training courses loaded into the system. This limits an access to knowledge and the possibility of obtaining more complete information. Thus, an effective training is very important in increased pace of modern life.

The aim of the work was to study the possibility of quick access to all the materials presented in the e-learning system through quick search in any course on the specified set of keywords. EFront was chosen as the system that is built on the basis of a database with clustered indices. It was suggested to create cluster indices taking into account thematic similarity in dynamics, i.e. during the process of addition of the new data. This allows the tables to branch out. In order to search for information within the same e-learning system, it was suggested to connect an additional programming module that will allow organizing a full-text search in the system's database.

During the research, several modules of full-text search were considered, and for the selected e-learning system, it was suggested to use the Sphinx technology. Thus, the proposed solutions made it possible to expand the students' ability to access the necessary educational information through the use of full-text search.

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Applications and software for teaching logistics and logistics management

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***Abstract* - Overall development of technology in recent years has had a great impact on the business itself, including logistics and logistics management as examples of business sectors which extensively use information and communications technologies (ICT). Teaching methods have been changing during this period to keep track with the demand of business sector for seeking and employing more skilled workforce. This paper will sum up some of the software and applications used in teaching and learning logistics, but will also give a brief comparison of students' desires and current state of the methodology used at University of Rijeka, Faculty of Maritime Studies. E-learning is commonly used in higher level education, combining traditional methods with modern methods. On the other hand, game-based learning and m-learning are newer approaches, and have a large potential in teaching logistics and logistics management.**

Keywords - teaching and learning logistics; e-learning; m-learning; game-based learning; simulations

I. INTRODUCTION

The evolution of ICT has led to the increasing use of ICT in teaching, too. Methods used in education have over the years developed and adapted to newer generations that are more demanding and involved with the technology of any kind. Therefore, it is no wonder that teaching and learning has modernized and digitalized so much. Parallel with this, new terms have emerged that describe such learning methods, and are described in this article.

A. e-learning and m-learning

E-learning is more than transforming existing teaching material into multimedia content for distribution over the Internet or intranet. The implementation of the electronic learning model does not necessarily include the conversion of the entire teaching content and can greatly improve the value of the educational content of the educational institution [1]. E-learning is something that is still developing, and the most recent progress is its development into mobile learning (m-learning). Smartphones have become a crucial tool for getting online and accessing e-content, and it was logical that e-learning would evolve into m-learning.

B. Gamification and game-based learning

Having considered that games have become a part of daily life for most students, it is no wonder that this type of learning and teaching developed. The benefits of games used for encouraging students to be more active seem to give a positive outcome. Gamification is the craft of identifying the fun and addicting elements found in games and applying them to productive activities. Gamification does not involve actual games, it absorbs the fun elements in a game (Game Mechanics or Game Design Techniques) into real-world applications [2]. Unlike gamification, game-based learning relates to the use of games to enhance the learning experience [3]. Gamification only uses traditional techniques or e-learning material without using games at all, while on the other hand, game-based learning actually uses games as tools for learning

C. Blended learning

Blended learning is both simple and complex. At its simplest, blended learning is the thoughtful integration of classroom face-to-face learning experiences with online learning experiences. There is a considerable intuitive appeal to the concept of integrating the strengths of synchronous (face-to-face) and asynchronous (text-based Internet) learning activities [4]. The term blended learning can be summed up as a successful combination of contemporary and traditional learning methods.

D. Simulations

Simulations used as teaching methods mean actually imitating or copying some events or processes or relations to analyse the results. The main advantage of this sort of learning is that users can change various conditions and compare results in order to make the best decision. This can be achieved without risking and without creating unnecessary costs. In simulations, users are often given roles in those processes.

Using all these methods is associated with the generations that have grown up playing various games. In higher education, this means implementing applications and software that solve problems and situations copied from real cases, but in a way that is no longer boring and unappealing.

II. APPLICATIONS AND SOFTWARE USED FOR TEACHING AND LEARNING

The following review presents some of the applications and software used for learning logistics and

logistics management. Modern logistics companies regularly use some of them.

A. ARENA

Arena logistics simulation software has a proven track record of enabling companies to model and evaluate virtually every aspect of their logistics network. Arena's flowchart modelling methodology makes it easy to define and communicate the intricacies of complex logistics. It can be used for plant simulations, supply chain optimization, warehouse simulation and logistics optimization [5].

Arena Simulation Software is the most widely-used Discrete Event Simulation software in the world. Companies consider experience with Arena simulation to be a differentiator and a competitive advantage when making hiring decisions [6]. Common capabilities of this software are [7]:

- JIT operations
- Evaluating shipping and transportation alternatives
- Determining the best location for warehousing or other facilities
- Evaluating dispatching rules
- Determining facility size requirements
- Identifying bottlenecks in the logistics network
- Quantifying risks
- Determining warehouse capacity requirements
- Evaluating warehouse picking strategies
- Determining labour requirements.

B. IBM ILOG CPLEX

Leading organisations from various industries across the world use IBM ILOG CPLEX Optimization Studio (COS) to achieve better outcomes. Here are some examples [8]:

- A global logistics provider creates its next-generation logistics management platform
- An arc welding systems and power source manufacturer in Italy reduces inventory by 15 percent, and cuts lost orders by 70 percent
- A financial services company helps banks reduce cross-shipping fees by 63 percent

IBM ILOG COS enables rapid development and deployment of decision optimization models using mathematical and constraint programming. IBM COS combines a fully featured integrated development environment that supports Optimization Programming Language (OPL) and the high-performance CPLEX and CP Optimizer solvers [9].

C. ANYLOGIC

AnyLogic is the leading simulation software for business applications, utilised worldwide by over 40% of Fortune 100 companies. AnyLogic models enable analysts, engineers, and managers to gain deeper insights and optimise complex systems and processes across a wide range of industries [10]. AnyLogic is used in the following industries:

- Supply Chains
- Transportation
- Warehouse Operations
- Rail Logistics
- Mining
- Oil & Gas
- Road Traffic
- Passenger Terminals
- Manufacturing
- Healthcare
- Business Processes
- Asset Management
- Marketing
- Social Processes
- Defence

The three models pictured in Fig 1 can be used in any combination, with one software, to simulate business systems of any complexity. In AnyLogic, various visual modelling languages can be used, for example process flowcharts, statecharts, action charts, and stock & flow diagrams [11].

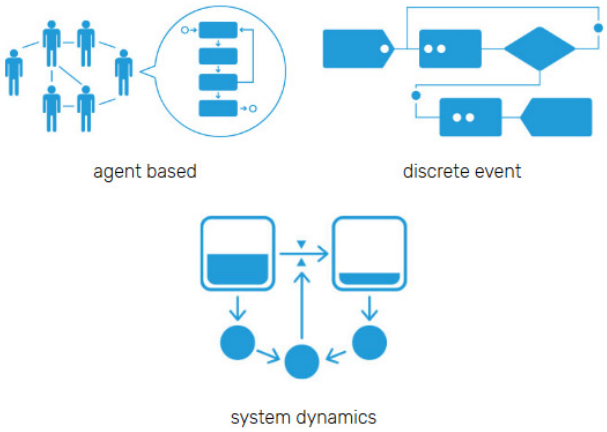

Figure 1. Three simulation models

D. ANYLOGISTIX

AnyLogistix simulation is powered by AnyLogic, the industry-leading simulation software tool, combined with the renowned optimisation abilities of IBM ILOG CPLEX. It investigates how a model comes to its results. By changing model parameters when it is running, the user can discover cause-and-effect dependencies – for example, how will changing inventory policies influence the bullwhip effect [12]. AnyLogistix is used for business challenges such as [13]:

- Supply Chain Design
- Supply Chain Risk Assessment
- Transportation Planning
- Inventory Optimization
- Sourcing Optimization
- Production Capacity Planning
- Supply Chain Optimization
- Bullwhip Effect Quantification

E. SIMUL8

SIMUL8 creates a visual mock-up of processes, which is similar to drawing a flowchart. By adding timings and rules to different tasks, resources and constraints that make up the system, the simulation will accurately represent the real business process [14]. It is used to improve processes across a wide range of industries such as [15]:

- Healthcare
- Manufacturing
- Automotive
- Call centres
- Pharmaceutical and medical devices
- Supply chain & logistics
- Business
- Public sector & justice

AUT Auckland University (New Zealand), UMass Amherst Massachusetts (USA), Reykjavik University (Iceland), Brunel University London (UK) and NUS National University of Singapore (Singapore) are currently teaching simulations using the SIMUL8 software [16].

F. FLEXSIM

FlexSim is a three-dimensional simulation software that is able to model, simulate, predict and visualise various systems (manufacturing, material handling, warehousing, healthcare, packaging, logistics, etc.). It helps in optimising current and planned processes, identifying and decreasing waste, reducing costs, and increasing revenue [17].

FlexSim simulation software is especially effective at improving logistics systems. The pre-built objects make it easy to quickly build models. With the model, problem can be identified and solutions can be tested. Simulation software can help to increase service reliability, optimise truck utilisation, or complete more shipments [18].

G. FLEXSIM CT / FLEXTERM

FlexSim CT is a powerful tool for planning and analysis of container terminal and intermodal rail yard projects and operations. It has been renamed FlexTerm [19]. FlexTerm is a software package solution that provides powerful 3D simulation for the analysis of terminals involved with the movement of freight. FlexTerm strengthens capabilities in planning, analysing, and optimizing terminal layout, as well as the simulation and emulation of nearly every other type of marine and freight movement facility [20]. It can be used for simulating:

- Marine terminals [21]
  - Container terminals
  - Bulk terminals
  - Energy and power facilities
- Transportation [22]
  - Rail modules
  - Intermodal rail facilities

The Simulation Library has numerous spreadsheets and simulation models for simulation, analysis and planning [23]:

- Yard stacking strategies
- Yard layout and dispatching
- Wheeled vs grounded operations
- Gate logistics and capacity
- Rail logistics and capacity
- Quay crane allocation

H. BEER GAME

The Beer game (or Beer distribution game) was originally developed in the 1960s by Jay Forrester at MIT as a result of his work on system dynamics. While the original goal of the simulation game was to research the effect of systems structures on the behaviour of people ("structure creates behaviour"), the game can be used to demonstrate the benefits of information sharing, supply chain management, and e-collaboration in the supply chain [24].

Suppliers, manufacturers, salespeople, and customers have their own (often incomplete) understanding of what real demand is. Each group has control over only a part of the supply chain, but each group can influence the entire chain by ordering too much or too little. Further, each group is influenced by decisions that others are making. This lack of coordination coupled with the ability to

influence while being influenced by others leads to the Bullwhip Effect (shortages and overstocks across the supply chain) [25].

There are several different versions of the Beer game. Some versions can only be played with certain downloaded software, but there is also a completely free and easily accessible online version. Players can play online and access any of the existing games, or start a new game [26].

III. PRELIMINARY RESEARCH

Students from the University of Rijeka, Faculty of Maritime Studies participated in a survey aimed at researching what the students want from the lectures. The anonymous survey was conducted through an online form and was aimed at former and current students of Logistics and Management and Transport technology at all levels of the study [27]. At the time of data processing, a total of 151 students participated in the survey through questionnaires. 49.3% of those were undergraduate bachelor students, 61.3% were master students and 1.3% were PhD students.

Regarding the question whether the students want (or wanted at some point) more practice or practical examples, the majority (88.1%) said that they really wanted practice included in lectures. They rated their desire with the grade 5 which expressed the largest desire (5 - I really want it 1 – I certainly do not want it). The relationship between the answers is visible in Fig 2. „Do you (or did you) want more practical knowledge or examples from real business" (from the options given in the list) [28].

Following the previous question, the next multiple choice question was devised with the intention to find out what would encourage the students to take a more active part in lectures (Fig 3: What would encourage you to be more active in the class (from the options given in the list) [29].

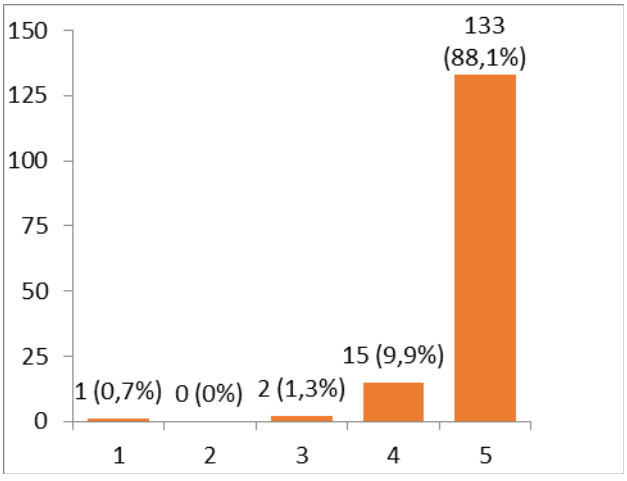

Figure 2. Question: Do you (or did you) want more practical knowledge or real business examples?

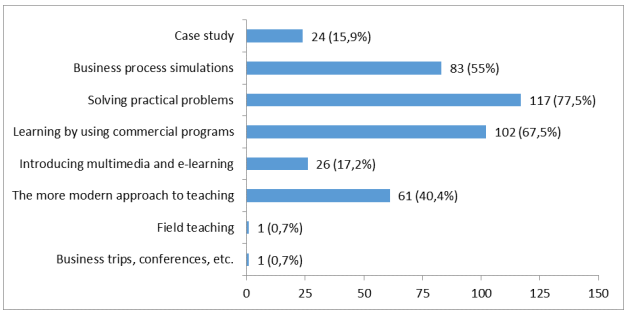

Figure 3. Question: What would encourage you to be more active in the class?

The highest percentage refers to the answers 'Solving Practical Problems' (77.5%), 'Learning by using commercial programs used in business' (67.5%) and 'Business process simulations' (55%).

In the fourth place, with 40.4% was the answer 'The more modern approach to teaching'. The answer 'Introducing multimedia and e-learning in the curriculum' follows with 17.2% and 'Case Study' follows with 15.9%. The answers "learning through field teaching" and "learning through business trips and conferences" are under 1%.

IV. CONCLUSION

After the analyses have shown that the students of the target groups want to change and modernise the teaching and learning methods in logistics, and want to learn from real business examples, it is logical to conclude that the introduction of the mentioned and similar curriculum programs would have positive effects on the class activity and student knowledge.

E-learning, m-learning, game-based learning, simulation and implementation of similar, or using the same software as used in the business sector, are the future of teaching and learning of logistics. Although some universities use the above mentioned methods, there is still room for further development of such tools and their better implementation, especially in the field of m-learning.

The use of traditional methods and blended learning would result in students who are more active in studying, and would therefore positively affect the overall teaching and learning atmosphere. Furthermore, by using the software from the real business sector, young logisticians would be more competitive and more prepared after graduation (faster adaptation to the workplace). Such knowledge and skills are something that the future employers would surely appreciate in a new worker or intern.

Given that there is a whole range of programs that offer a variety of opportunities for individuals, students and universities, there should be no barriers to using modern logistical training methods, apart from costs. The goal of each university should be to provide their students with theoretical knowledge supported by practical examples, and backed by modern teaching methods.

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Assessing the Digital Maturity Level of Higher Education Institutions

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Abstract - **The primary focus of this paper is to propose a methodology for prioritizing the elements in the Digital Maturity Framework for Higher Education Institutions (DMFHEI) and assessing the digital maturity level (ML) of HEIs in Croatia. Developing the DMFHEI requires the application of a sophisticated methodology, which includes a set of methods, techniques, and instruments. Some of the analyses performed are qualitative, such as the comparison of similar frameworks and strategic documents, while others are quantitative, such as the Q-sorting method, focus groups, and multi-criteria decision-making methods. In the framework development phase, the well-known multi-criteria decision-making method the analytic hierarchy process/analytic network process (AHP/ANP) was implemented to prioritize the main areas and elements identified in the framework. The results of prioritization are shown in this paper, as well as the influence of the area and element priorities on the general digital ML of the institution.**

Keywords - digital maturity, framework, prioritization, higher education, AHP, ANP, areas, elements

I. INTRODUCTION

Digital technologies in educational institutions have the potential to be one of the leading means of delivering quality education in line with institutions' mission and vision. Using the Digital Maturity Framework for Higher Education Institutions (DMFHEI) makes it possible to estimate the maturity level (ML) of the higher education institutions (HEI), to identify all areas that need to be improved, and to give recommendations about how to achieve the required improvements. This paper aims to propose a methodology for prioritizing elements within the DMFHEI and assessing the digital MLs of HEI in the Republic of Croatia. This paper is divided into the several sections. Section 2 introduces the areas and elements of the DMFHEI. In Section 3, the methodology for prioritizing the elements in the DMFHEI is proposed and the methods used to develop the methodology are described. In Section 4, the application of the methodology for prioritizing the elements in the DMFHEI and for calculating HEI digital maturity is presented.

II. AREAS AND ELEMENTS OF THE DMFHEI

The DMFHEI has been in development since July 2015. The methodological approach used throughout the development process was mostly qualitative. We have modified methodology used in development of Digitally Mature Framework for primary and secondary schools in Croatia [1]. In the first phase, we completed a qualitative analysis of 15 frameworks for digital maturity [2]–[16], with a particular focus on information and communication technologies (ICT). After conducting qualitative analyses of the e-readiness assessment tools [17] and of the digital maturity assessment frameworks, in the second phase of the framework development process, two focus group studies were conducted to obtain input from experts on defining new framework areas and their elements. The results of the qualitative analyses of 15 digital maturity frameworks and the results of the two focus groups led to the proposal of seven areas and 53 elements for the DMFHEI [18].

In the second phase of the framework development process, the sorting cards (Q-sorting) method was applied [19]. During the Q-sorting process, experts were asked to sort 53 element cards into the seven proposed areas. After this was complete, we calculated a content validity ratio (CVR) [20], which decreased the number of elements by 10, from 53 to 43. In the third development phase, the results obtained by qualitative analysis, the research from the two focus groups, the Q-sorting process, and the calculation of the CVR ratio were analyzed by two external experts to yield a proposal for the DMFHEI. The developed DMFHEI contains areas and elements that are not mutually exclusive or disjointed. The DMFHEI identifies seven areas, within which there are 43 elements. These areas are as follows: 1) Leadership, Planning, and Management; 2) Quality Assurance; 3) Scientific Research Work; 4) Technology Transfer and Service to Society; 5) Learning and Teaching; 6) ICT Culture; and 7) ICT Resources and Infrastructure. After determining the DMFHEI area and elements, the next step was to determine the descriptions of each element. Due to space limitations, we are not able to show the descriptors of all 43 elements; however, we do highlight a few below.

The Leadership, Planning, and Management area [2]–[4], [16] consists of eight elements: financial investment in the use of ICT in learning and teaching, research and development, and the business of the institution; strategic planning of ICT integration in HEI; managing the integration of ICT in learning and teaching at HEI; managing the integration of ICT in scientific research at HEI; the information system for supporting the business

processes of HEI; the planning and implementation of training for HEI employees in the field of digital competencies and ICT application; the relationship between HEI and state from the aspect of ICT integration; and HEI policy in ICT integration and monitoring global trends.

The Quality Assurance area [21] consists of six elements: ICT quality assurance policies; the monitoring and periodic review of study programs, from the aspect of ICT application; work evaluation of teaching, research, administrative, and technical staff; the continuous monitoring of the results of scientific-teaching work and progress; procedures for determining the needs, development, or acquisition of ICT resources and their application; approved procedures and follow-up of student enrolment, progress through study, and completion of studies supported by ICT.

The Scientific Research Work area [22] consists of six elements: the use of ICT in the preparation and publication of scientific papers; ICT support in the preparation and management of scientific research work and projects; ICT research (collaborative ICT research on HEI); a system of support for researchers at the beginning of their careers in applying ICT in scientific research; continuous training of researchers in ICT application in scientific research; and the networking and collaboration of researchers with ICT support.

The Technology Transfer and Service to Society area [3], [5], [16] consists of three elements: collaboration with stakeholders (i.e., employers, the local community, and pre-tertiary education) supported by ICT; applied research and professional projects supported by ICT and/or for ICT; and the networking of researchers and users of research (stakeholders) supported by ICT.

The Learning and Teaching area [2]–[4], [12], [16] consists of seven elements: preparation, storage, and use of digital content in learning and teaching; innovative learning and teaching methods with ICT; the development of teachers' digital competence; the development of students' digital competence; the use of learning analytics to improve learning and teaching; ubiquitous learning and open curricula; and personalization and support for under-represented groups by using ICT in learning and teaching.

The ICT Culture area [2], [3], [12], [16] consists of six elements: the network presence of HEI; using ICT in HEI promotion; the development of digital literacy and the promotion of innovativeness in ICT application with HEI employees; the self-confidence and motivation of employees in terms of the importance of ICT application; providing access to and support in the application of ICT infrastructure; and the application of ethical standards, copyrights, and intellectual property in the ICT field.

The ICT Resources and Infrastructure area [3]–[5], [12], [16] consists of seven elements: the availability of ICT resources (hardware and software) for learning and teaching; the availability of ICT resources for scientific research; network infrastructures at HEI; access to ICT resources for students (both in and out of the classroom); the digital environment and information systems available to employees and students; the technical support and maintenance of ICT resources at HEI; and the information security system.

III. METHODOLOGY

The main idea of the DMFHEI is to measure the digital maturity of HEI using the criteria (areas and elements) described in Section 2. These criteria are not equally important, so we calculated their weights using the multi-criteria decision making method called the analytic hierarchy process/analytic network process (AHP/ANP). However, to calculate how digitally mature a certain HEI is, it is important to use the appropriate instrument for collecting judgments from examiners. Based on the characteristics of answers (judgments) that must be collected for assessing the digital maturity level of HEI, we decided to use instrument based on rubrics and ratings.

The proposed methodology for prioritizing the areas and elements in the DMFHEI and calculating the digital ML of HEI in Croatia consists of several phases (Fig. 1):

1. Establishing the starting point, which is the hierarchical structure of the DMFHEI's elements
2. Prioritizing the main areas
3. Prioritizing the elements
4. Calculating the total elements' weight
5. Establishing rubrics and evaluating the HEI using the rubrics
6. Transforming the levels to level priorities
7. Calculating the HEI's element priorities
8. Calculating the final ML of the HEI

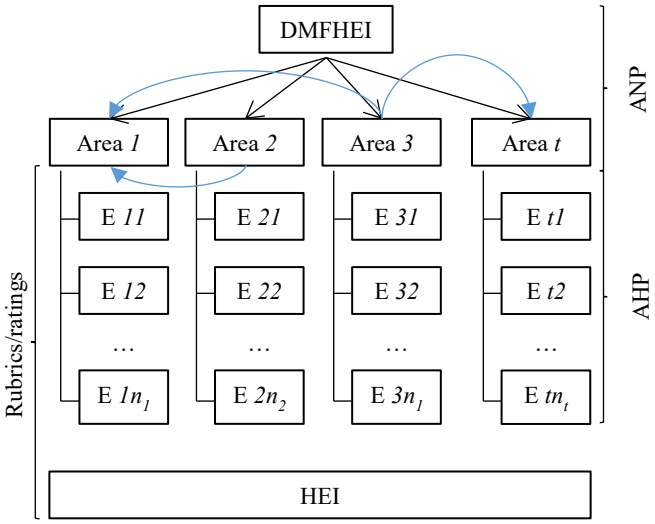

Figure 1. Methodology for prioritizing elements in the DMFHEI and calculating the digital ML of HEI in Croatia.

In next part of the paper, the methods used in the proposed methodology are shortly presented.

A. AHP and ANP

In the previous section, an initial hierarchical structure of the DMFHEI was presented. However, in previous researches the authors of the paper have characterized

problems in HE field as complex problems with influences, dependencies, and feedback between elements [23]–[26]. So conclusion is that the network structure is more appropriate for modelling strategic problems in HE then hierarchical structure. That means that some areas in the framework can influence other areas. Similarly, some elements can influence other elements, even those that are from different areas. Establishing the network structure by using the ANP on both levels – areas and elements is a very complicated task in terms of implementation because it is very difficult to consistently perform this kind of decision making and it is time-consuming to correctly identify the intensity of the influence of each element upon each of the other 42 elements. So in this paper we are proposing a hybrid approach: the weights of the areas will be determined using the ANP, and the weights of the elements will be determined using the AHP. This will decrease the complexity of implementation (when compared to applying the ANP to determine both the weights areas and elements).

The AHP is the most-used multi-criteria decision-making method in HE [27]. It is based on pairwise comparisons of decision-making elements. In pairwise comparisons, the Saaty scale is used. The scale consists of nine degrees (1–9). Value 1 means that two elements in the pair are equally important. Other values represent the domination of one element over others (weak, strong, very strong, and absolute) [28]. When pairwise comparisons are completed, the inconsistency ratio is calculated. There are four steps in the AHP [29], [30]:

1. Creating the hierarchy structure
2. Completing pairwise comparisons of elements from the same level in the structure with respect to superior elements in the hierarchy
3. Calculating priorities
4. Performing sensitivity analysis

The ANP is a generalization of the AHP. This method supports modeling dependencies and feedback between elements in the problem structure [31]. There are several steps in the ANP (adapted from [26], [32], [33]):

1. Creating the network structure of the problem
2. Completing pairwise comparisons on the node level and calculating the unweighted supermatrix
3. Completing pairwise comparisons on the cluster level and calculating the weighted supermatrix
4. Calculating the limit matrix
5. Performing sensitivity analysis

The ANP has some weaknesses in terms of its implementation, such as the high number of pairwise comparisons, the long duration of the implementation process, and the ease of misunderstanding some of the pairwise comparisons that have to be done (e.g., comparing the cluster of alternatives and the cluster of criteria with respect to the other cluster of criteria). If only ANP were to be applied to the presented case, 826 consistent pairwise comparisons of the criteria and 147 consistent pairwise comparisons of the cluster levels would need to be done. Because of this large number of comparisons that would have to be made by experts in the field, the implementation process becomes almost impossible. In a hybrid approach, 118 pairwise comparisons on the criteria level and 147 pairwise comparisons on the cluster level have to be done. The complexity of the pairwise comparisons on the cluster level will also be decreased when integrating the ANP with the Decision-Making Trial and Evaluation Laboratory (DEMATEL), as suggested in [26].

B. Rubrics and Ratings

The weights of the areas in the DMFHEI will therefore be calculated using the ANP integrated with the DEMATEL. In DEMATEL it is possible to structure the problem and transform it from graphs with influences onto the graph of dependencies, keeping the intensities of dependencies the same. In DEMATEL, the intensities of the influences between criteria are measured on a scale of 5 degrees: 0 means no influence, and 4 means very high influence [34]. Using the AHP, the local priorities of the elements in the DMFHEI will be calculated. By multiplying the local priorities of elements by the associated area weights, the total weights of the elements (TW) are calculated. To calculate the digital ML of certain HEI in some elements (HEI SP), the total weight of each element (TW) must be multiplied by the HEI's element priority (i.e., the HEI's ML per some element), which can achieve values from 0 to 1. The easiest way of determining the ML per some element is through the concept of direct assessment. Considering that local, direct assessment means evaluating the ML of HEI per some element and assigning a concrete value between 0 and 1 based on the HEI's real state, this approach is efficient but potentially dangerous, as it can bring a researcher to the wrong results. A more objective approach is to use rubrics combined with ratings, as "rubrics offer a process for making explicit the judgements in the evaluation and are used to judge the quality, the value, or the importance of the service provided" [35]. There are two basic elements, or dimensions, of rubrics:

- Criteria (in our case, element)
- Levels of how a specific criterion (element) is satisfied (e.g., poor, adequate, good, and excellent [36]). It is possible that all criteria are defined at the same level, but they can also differ within one area.

For each criterion (element) and level, an evaluation question or statement is defined, and the expert can more easily determine the local ML of HEI for certain element. Rubrics reduce assessment subjectivity. The instrument for the measurement of DMFHEI in this paper is based on the rubrics, and it was validated by several experts. There are several methods available for converting a qualitative rubric (level) to a quantitative priority (local ML):

- Direct assessment (e.g., we define that the level *poor* is the same as priority 0, *adequate* is 0.2, *good* is 0.5, and *excellent* is 1)
- Pairwise comparison (i.e., make pairwise comparisons of the levels and calculate the priorities, which have to be normalized)

Applying either of these two methods will assign a quantitative value to each level. We notice here that some values from the 0–1 scale will not be used.

IV. RESULTS: DMFHEI

We developed an Excel-based application in which the whole DMFHEI calculation is implemented. When the HEI digital ML is to be determined, the user must evaluate the HEI with respect to each criterion. The rest of the calculation is automated. The procedures will be demonstrated in an example HEI. The focus of this paper is to propose a methodology for prioritizing the elements in the DMFHEI and calculating the digital ML of HEIs in Croatia, but not to come up with final priorities (weights and ML priorities). These can be determined after comprehensive data collection.

A. Priorities of the Areas

The areas (and elements) of the DMFHEI were previously identified using different techniques, as explained in [18]. To determine the priorities of areas, the integrated DEMATEL-ANP approach was used. Data were collected in the workshops, seminars, and meetings in the scope of the project Higher Decisions (higherdecision.foi.hr). The respondents were HE employees with experience in managing HEI. First, respondents evaluated the intensities of the influence between areas using the DEMATEL scale (0 = no influence, 1= weak influence, 2 = medium influence, 3 = strong influence, and 4 = very strong influence). The averaged results are given in Table 2. Second, the matrix has been converted to an unweighted and weighted supermatrix using the normalization procedure explained in [26].

TABLE 2. MATRIX OF INFLUENCES

	M	QI	SC	S	T	Cul	Infra
Management	0.00	3.50	2.17	2.83	2.67	2.83	3.33
QI	2.50	0.00	2.17	2.00	3.17	1.83	1.17
Science	1.67	1.67	0.00	3.33	2.67	1.50	1.50
Society	2.17	1.50	2.67	0.00	2.17	2.33	2.00
Teaching	1.17	2.33	2.67	2.17	0.00	2.67	2.33
ICT Culture	1.67	1.83	1.50	2.33	2.67	0.00	3.50
ICT Infra.	2.50	1.33	2.33	2.33	3.00	3.33	0.00

Last, the area weights were obtained from the limit matrix: Leadership, Planning, and Management (0.171), Quality Assurance (0.133), Scientific Research Work (0.127), Technology Transfer and Service to Society (0.136), Learning and Teaching (0.139), ICT Culture (0.141), and ICT Resources and Infrastructure (0.152). The area weights were inserted into the Excel-based application (see Table 3, column ANP).

B. Priorities of the Elements

The priorities of the elements were identified by applying the AHP procedure directly and, after obtaining the priorities from the AHP, by multiplying those priorities with the associated area weights. The local priorities of the elements were inserted into Table 3 (column AHP). The final element priorities were also inserted into Table 3 (column TW).

TABLE 4. RUBRIC OF AREA TECHNOLOGY TRANSFER AND SERVICE TO SOCIETY

Elements	Basic	Initial	e-Enabled	e-Confident	e-Mature
Collaboration with stakeholders (i.e., employers, the local community, and pre-tertiary education) supported by ICT	The HEI does not advocate cooperation with stakeholders (i.e., employers, the local community, or pre-tertiary education) with ICT support.	The HEI partly encourages but does not direct employees and students to cooperation with stakeholders (i.e., employers, local community, or pre-tertiary education) with ICT support.	The HEI is partially committed to cooperating with stakeholders (i.e., employers, local community, or pre-tertiary education) with ICT support.	The HEI encourages and directs employees and students to cooperate with the support of ICT with employers, businessmen, and the local community for the purpose of counselling.	The HEI encourages and directs employees and students to cooperate with the support of ICTs with employers, businessmen, and the local community (face to face, online, or in combination with one another) for the purpose of counselling or future cooperation.
Applied research and professional projects supported by ICT and/or for ICT	The HEI does not encourage or direct employees and students to conduct applied research and professional projects supported by ICT and/or for ICT.	The HEI partly encourages but does not direct employees and students to conduct applied research and professional projects supported by ICT and/or for ICT.	The HEI partly encourages and directs employees and students to conduct applied research and professional projects supported by ICT and/or for ICT.	The HEI encourages and directs staff and students to conduct applied research and professional projects supported by ICT and/or for ICT in order to promote development, innovation, and collaboration between the economy and the scientific research sector.	Applied research is a theoretical or experimental work undertaken to achieve new knowledge and primarily aimed at achieving a practical goal such as developing a new technology or product. The HEI encourages and directs employees and students to conduct applied research and professional projects supported by ICT and/or for ICT in order to improve development, innovation, and cooperation between the economy and the scientific research sector and to promote the development and transfer of technology activities.
The networking of researchers and users of research (stakeholders) supported by ICT	The HEI is not committed to the cooperation and exchange of the knowledge of researchers and users of research and employers.	The HEI is partially committed to cooperating but not to the exchange of the knowledge of researchers and users of research and employers with the support of ICT.	The HEI is partially committed to the cooperation and exchange of the knowledge of researchers and users of research with the support of ICT.	The HEI is committed to cooperating and exchanging researchers' knowledge through the networking of researchers and users of research (stakeholders) and employers with the support of ICT through partnerships with other educational institutions.	The HEI is committed to the cooperation and exchange of knowledge with the support of ICT through partnerships with other educational institutions, the private and public sectors, and the whole community as users of research.

TABLE 3. CALCULATING DIGITAL ML FOR HEI EXAMPLE

Areas	Elements	ANP	AHP	TW	LEVEL	LP	HEI SP
Leadership, Planning and Management	1. Financial investment in the use of ICT in learning and teaching; research and development; and the business of the institution	0,17	0,18	0,031	1	0,00	0,0000
	2. Strategic planning of ICT integration in HEI	0,17	0,20	0,034	2	0,20	0,0069
	3. Managing the integration of ICT in learning and teaching at HEI	0,17	0,11	0,019	3	0,40	0,0075
	4. Managing the integration of ICT in scientific research at HEI	0,17	0,11	0,019	4	0,60	0,0113
	5. The information system for supporting the business processes of HEI	0,17	0,10	0,017	5	1,00	0,0171
	6. The planning and implementation of training for HEI employees in the field of digital competencies and ICT application	0,17	0,10	0,017	3	0,40	0,0069
	7. The relationship between HEI and state from the aspect of ICT integration	0,17	0,11	0,019	2	0,20	0,0038
	8. HEI policy in ICT integration and monitoring global trends	0,17	0,09	0,015	1	0,00	0,0000
Quality Assurance	1. ICT quality assurance policies	0,13	0,21	0,028	1	0,00	0,0000
	2. The monitoring and periodic review of study programs from the aspect of ICT application	0,13	0,16	0,021	1	0,00	0,0000
	3. Work evaluation of teaching, research, administrative, and technical staff	0,13	0,15	0,020	2	0,20	0,0040
	4. The continuous monitoring of the results of scientific-teaching work and progress	0,13	0,14	0,019	3	0,40	0,0074
	5. Procedures for determining the needs, development, or acquisition of ICT resources and their application	0,13	0,16	0,021	5	1,00	0,0213
	6. Approved procedures and follow-up of student enrolment, progress through study, and completion of studies supported by ICT	0,13	0,18	0,024	3	0,40	0,0096
Scientific Research Work	1. The use of ICT in the preparation and publication of scientific papers	0,13	0,11	0,014	1	0,00	0,0000
	2. ICT support in the preparation and management of scientific research work and projects	0,13	0,08	0,010	2	0,20	0,0020
	3. ICT research (collaborative ICT research on HEI)	0,13	0,25	0,032	3	0,40	0,0127
	4. A system of support for researchers at the beginning of their careers in applying ICT in scientific research	0,13	0,11	0,014	5	1,00	0,0140
	5. Continuous training of researchers in applying ICT in scientific research	0,13	0,16	0,020	3	0,40	0,0081
	6. The networking and collaboration of researchers with ICT support	0,13	0,29	0,037	2	0,20	0,0074
Technology Transfer and Service to Society	1. Collaboration with stakeholders (i.e., employers, the local community, and pre-tertiary education) supported by ICT	0,14	0,40	0,055	5	1,00	0,0546
	2. Applied research and professional projects supported by ICT and/or for ICT	0,14	0,30	0,041	5	1,00	0,0409
	3. The networking of researchers and users of research (stakeholders) supported by ICT	0,14	0,40	0,055	5	1,00	0,0546
Learning and Teaching	1. Preparation, storage, and use of digital content in learning and teaching	0,14	0,12	0,017	1	0,00	0,0000
	2. Innovative learning and teaching methods with ICT	0,14	0,19	0,026	2	0,20	0,0053
	3. The development of teachers' digital competence	0,14	0,16	0,022	3	0,40	0,0089
	4. The development of students' digital competences	0,14	0,17	0,024	2	0,20	0,0047
	5. The use learning analytics to improve learning and teaching	0,14	0,18	0,025	1	0,00	0,0000
	6. Ubiquitous learning and open curricula	0,14	0,08	0,011	2	0,20	0,0022
	7. Personalization and support for under-represented groups by using ICT in learning and teaching	0,14	0,10	0,014	1	0,00	0,0000
ICT Culture	1. The network presence of HEI	0,14	0,20	0,028	1	0,00	0,0000
	2. Using ICT in HEI promotion	0,14	0,11	0,016	2	0,20	0,0031
	3. The development of digital literacy and the promotion of innovativeness in ICT application with HEI employees	0,14	0,26	0,037	4	0,60	0,0220
	4. The self-confidence and motivation of employees in terms of the importance of ICT application	0,14	0,15	0,021	5	1,00	0,0212
	5. Providing access to and support in the application of ICT infrastructure	0,14	0,10	0,014	4	0,60	0,0085
	6. The application of ethical standards, copyright, and intellectual property in the ICT field	0,14	0,18	0,025	3	0,40	0,0102
ICT Resources and Infrastructure	1. The availability of ICT resources (hardware and software) for learning and teaching	0,15	0,15	0,023	5	1,00	0,0229
	2. The availability of ICT resources for scientific research	0,15	0,15	0,023	4	0,60	0,0137
	3. Network infrastructures at HEI	0,15	0,13	0,020	3	0,40	0,0079
	4. Access to ICT resources for students (both in and out of the classroom)	0,15	0,18	0,027	2	0,20	0,0055
	5. The digital environment and information systems available to employees and students	0,15	0,12	0,018	1	0,00	0,0000
	6. The technical support and maintenance of ICT resources at HEI	0,15	0,12	0,018	2	0,20	0,0037
	7. The information security system	0,15	0,14	0,022	1	0,00	0,0000
						ML	**0,4296**

*ANP = area weight, AHP = element local weight, TW = total element weight, LEVEL = maturity achievement of HEI per each element (expert evaluation using rubrics), LP = priority of certain level, HEI SP = achieved priority of HEI per each element, ML = HEI ML

C. Digital MLs of HEI

A rubric was designed for each area. Each rubric consists of five levels, and each element is described through an appropriate statement. To each level, a local maturity priority (level priority, LP) is assigned. The application supports both direct assessment and pairwise comparisons for determining the LP. After the ML for each HEI is determined using the rubrics (Table 3, column LEVEL), the HEI's element priority is automatically calculated (Table 3, column HEI SP); then, the level is transformed to LP and multiplied by the total weight of the element (TW). Finally, the HEI ML is calculated by summing all the HEI SPs. The instrument used for the measurement of the DMFHEI created to assess digital maturity is very big, so it does not fit the paper limit. Therefore, we bring only a part of the rubric in Table 4, which presents the evaluation elements related to the Technology Transfer and Service to Society area. The whole rubric is available at the webpage of the Higher Decision project (http://higherdecision.foi.hr/).

V. CONCLUSION

In this paper, we proposed and demonstrated the methodology for evaluating and quantifying the digital ML of HEI based on the created DMFHEI. Still, there are some limitations to the proposed approach, which must be resolved before applying the methodology more broadly. The first limitation is related to data collection in terms of calculating the areas and elements priorities, as more field experts must be included in the process. The second limitation is related to the evaluation of the rubric instrument, which must also be evaluated by more field experts. Those are two main prerequisites for DMFHEI acceptance and its application to HEI in the Republic of Croatia. As a proposal for future work, calculating the elements' weights using the ANP (not AHP) must be examined, as there are also influences between the elements.

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Teaching Future Teachers to Code – Programming and Computational Thinking for Teacher Students

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***Abstract* - Programming is one of the key assets in the modern society. In addition to teaching programming to future programmers, it has become more and more important to teach it alongside computational thinking to all students. We designed and implemented a programming course aimed for teacher students at our university. The goal of the course was to teach programming, computational thinking and the methods and tools used in programming education. The course was divided into two parts: first, the students were taught basic programming skills by utilizing tutorial-based learning with automatically assessed electronic exercises and play-based programming tasks. In the second part, the students utilized the acquired skills by teaching programming integrated into mathematics to children at elementary school level. The students worked really hard throughout the course, completing more than 90 % of all tasks in average. Moreover, the feedback from the tutorial sessions and the practice lessons at schools was mainly positive.**

Keywords - programming; computational thinking; teacher education; teacher students

I. INTRODUCTION

In the modern society, a knowledge of programming and computational thinking is quickly becoming skill deemed necessary for all people, not just programmers. Hence, the educators at all school levels need to have adequate knowledge about programming and the tools and the methods for teaching it. The obvious way to ensure this is include programming into curriculum of future teachers at teacher education institutes. With this in mind, we designed and implemented a programming course aimed for teacher students at University of Turku. It was designed to give students sufficient knowledge about programming and computational thinking with tutorial-based, automatically assessed exercises. The course was concluded with three practice lessons, where the students collaboratively taught programming (integrated into mathematics) to children at elementary school level. In this paper, the course design and implementation are described along with results and students' perceptions about the course.

The article is structured as follows: in the following Section, related research is presented. In the third section, we present the course design principles including the learning goals and the methodology designed for the course. In the fourth section, the data collection and research setup are presented followed with results and students' perceptions. In the final section, the results are discussed and interpreted.

II. RELATED WORK

Programming is a difficult skill to master (see for example [1]). It requires both technical skills and problem solving skills [2], usually addressed as computational thinking nowadays. Several methodologies to teach programming better have been developed or adapted over the years. Such methodologies include for example flipped learning [3] and pair-programming [4]. Vihavainen et al. [5] conducted a systematical review on programming education methodologies, and found out, that the most successful methods were utilization of media computing and group work, to name a few. Automatic assessment [6] is extremely useful in programming education, as programming is a skill that requires continuous training with adequate feedback.

Woodrow [7] presents a study where preservice teachers were taught programming and found out, that their overall attitudes towards computers and computing became more positive. Similarly, Fesakis and Serafeim [8] found out that teaching introductory programming to future teachers by using the Scratch programming environment [8] gained a positive change in attitudes towards programming. Mentz et al. [10] utilized pair-programming to teach programming to teacher students, and found out, that pair-programming can be made more effective if applied with principles of cooperative learning. Bell and Frey [11] included teacher students into their programming camp and also found out, that teaching programming had a positive effect on students' attitudes towards programming.

III. COURSE DESIGN

The course design started by listing the programming-related skills necessary for the future teachers. The skills were then mapped to three learning goals:

1. *Programming skills*: although the teachers don't need to become programmers, basic understanding of programming is still fundamental to teach the topic. The group designing the course has years of experience in developing methodologies for teaching programming to computer science majors (see for example [12][13]). However, the focus, learning goals and the target group in the designed course were a little different. Hence, the

course was designed to only contain the fundamental programming concepts (such as conditional statements, repetition and functions). Python [14] was decided to be the primary programming language, since it is widely considered as easy to learn but still powerful choice for the first language see for example Grandell et al. [15][12].

2. *Methodology and tools for teaching programming*: one of the main goals of the course designed was to offer concrete tools and methods that can be directly applied to teaching programming in elementary school. Hence, a methodology combining educational technology and hands-on exercises was decided to be designed and applied throughout the course. It was also decided, that the teacher students needed to experiment teaching with the methodology in an authentic setup.

3. *Computational thinking*: according to Wing [16], computational thinking "will be a fundamental skill used by everyone in the world by the middle of the 21st century". Computational thinking can be seen as expressing a problem and its solution so that it can be executed, often algorithmically step by step. To illustrate computational thinking as a skill that extends beyond programming, play-based exercises (see for example Leskelä et al. [17]) were decided to be designed.

After the learning goals were established, the course methodology and the tools and materials needed were designed and implemented.

A. Tutorial-Based Learning

Teaching programming in the course was based on the tutorial-based learning methodology. In the methodology, a relatively short lecture is accompanied with a tutorial, where students solve automatically assessed programming exercises collaboratively. The tutorials are answered in a computer lab with course staff present to assist students with their problems. Tutorials were built using educational tool called ViLLE. It is an exercise-based learning tool with focus on automatically assessed exercises with immediate feedback. In ViLLE's tutorials, the exercises are accompanied with learning material (such as text, code examples, images or videos). An example of ViLLE tutorial is displayed in Figure 1.

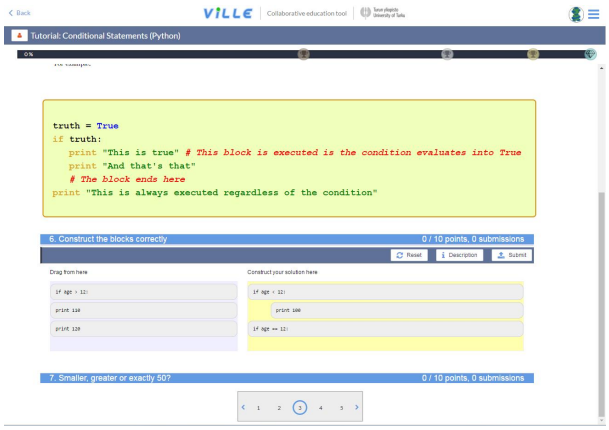

Figure 1. An example of a ViLLE Tutorial teaching conditional statement, translated into English.

The tutorials were based on the programming material designed earlier to be used at junior high school level [18]. However, the materials and the exercises were modified to suit the target group better. A total of seven programming tutorials were prepared with following topics:

1. Introduction to computational thinking and algorithms
2. Introduction to programming concepts (such as succession, variables and expressions)
3. String operations
4. Conditional statements
5. Repetition
6. Procedures and functions
7. Lists (voluntary tutorial)

The tutorial sessions were mandatory (excluding the final one) for completing the course. In addition to tutorials, ViLLE was used for other tasks in the course. The attendances to sessions were recorded with ViLLE using RFID tags delivered to each student. An attendance was automatically registered into ViLLE when the tag was used in the reader. Moreover, feedback was collected from the students after each session. Each feedback survey consisted of the same four questions: "What did you learn?", "What remains unclear after the session?", "How would you improve the lecture or tutorial?" and "How could you utilize this week's topics in your own teaching?". Additionally, the students were asked to give a grade of 1 to 5 to the session. The feedback was analyzed after each session, and subsequent lecture material or tutorials modified based on the analysis.

One of the reasons for using ViLLE and the tutorial-based learning throughout the course was to make the students' progress visible for both, teachers and students themselves. The score limits for different grades were announced at the beginning of the course, and students' current status was visible for them in ViLLE in real time. In addition, elements utilizing the principles of gamification (see for example Huang et al. [16]), such as virtual trophies, were used.

B. Play-based Exercises

Since computational thinking was one of the key topics in the course, exercises were designed to underline the topic outside of traditional programming. In Leskelä et al. [17] the authors found out, that kinesthetic, play-based exercises can be more useful than graphic programming when illustrating the basic concepts of programming (such as repetition or selection). With this in mind, a set of play-based exercises was designed for the course. Hence, the structure of each three hour session followed the same pattern, illustrated in TABLE 1.

TABLE 1. THE STRUCTURE OF EACH SESSION IN THE COURSE

Section	Duration	Purpose
Feedback review	5 minutes	Reviewing the feedback from the previous session and answering questions that arose
Lecture	30 to 45 min.	Providing theoretical basis and various code examples about the topic at hand
Play-based exercises	15 to 25 min.	Demonstrating exercises to be used for teaching computational thinking and programming logic
Tutorial	~ 2 hours	Practicing programming skills

The play-based exercises were done in groups of 2 to 20 students, depending on the nature of the exercise. The exercises were designed for both, teaching programming logic and computational thinking for students, and to provide examples and ideas for their own lessons in the future. Some examples of the exercises used are given below.

1. *Drawing exercise:* one of the students acts as a drawer and the other as an instructor. The drawer's eyes may be closed. The idea is, that first freely, and then with a limited set of instructions available (such as "pen down" or "turn 90 degrees left"), the pair tries to duplicate the figure given to the instructor. The purpose of the task is to illustrate for example the sequential nature and the limited instruction set of computer programs and the solving of problem algorithmically.

2. *Classification exercise:* the students work in a group of 10 to 20. One of the students comes up with (or is given) basis for classifying the students into two groups. Such criteria could be something like "if person has jeans, (s)he goes to the left group, and if not, (s)he goes to the right group". The persons classified try to guess the criteria used in classification. There can be rules on how the criteria needs to be expressed (for example by using Python's if-elif-else conditional structure). The goal of the exercise is to teach selection as a structure and expressing conditional statements validly.

3. *Sorting exercise:* the students are again divided into groups of 10 to 20. The task is to select a sorting criteria (such as age, height or shoe size) and sort the group into ascending or descending natural order based on the criteria. The task can be varied by giving a sorting algorithm which to follow (for example quick sort or merge sort, see [22]) or let the students come up with an algorithm themselves. The goal of the task is to again learn how to solve a problem algorithmically and how to utilize computational thinking in problem solving.

The course staff supervised the exercises and offered hints and tips when necessary. After the exercises, they were shortly discussed with the whole group before advancing to tutorial.

C. Practice Lessons in Schools

The main goal of the course was to provide students concrete skills, tools and methods for teaching programming and computational thinking in schools. Because of this, it was seen essential to provide the students a possibility to practice the concepts in an authentic environment. Hence, each student participated into three actual lessons held in the elementary schools in the area. The pupils in the participating classes were from grades four to six (in Finnish elementary school 10 to 12 year olds). The students in the course were divided into pairs. Each pair was responsible for one lesson and acted as observer and assistant in two others hosted by another pairs.

In the Finnish curriculum, programming is integrated into other topics. Most often integration is done with mathematics. ViLLE provides an electronic learning path for mathematics (see for example [19][20]), where one lesson a week is transformed into electronic one with automatically assessed math exercises and games. Examples of exercises for math are displayed in Figure 2.

Figure 2. Examples of math exercises in ViLLE

For the lessons, more programming exercises were integrated within the math exercises. Each lesson started with a play-based exercise, planned by students responsible. The time reserved for the exercise was around 10 to 20 minutes. The rest of the lesson was dedicated to programming and math exercises in ViLLE, and the role of the students (the pair responsible and the observers) was to assist students with problems and questions.

IV. RESEARCH SETUP AND DATA COLLECTION

The course was arranged for the first time in the spring of 2017. The course was mainly targeted for teacher education students in the university, but slots were opened for computer science majors as well. The hope was to create multidisciplinary teaching teams with previous experience from teaching and from programming. A total of 41 students enrolled into the course. Two students did not attend the course despite enrolling, so the final number of students was 39 (30 students from the teacher education department and 9 computer science majors). 22 (56 %) of all students were female.

The course lasted a total of 11 weeks. The first seven weeks were reserved for learning programming and computational thinking using tutorial-based learning and play-based exercises. There was one three-hour session a week with possibility to continue working on the tutorial exercises at home if they were not completed in the session. Weeks 8 to 10 were reserved for the practice lessons in schools and the final week was used for a wrap-up session, where both students and the course staff gave feedback and discussed the course implementation and possibilities for improvements together.

ViLLE collects automatically data from all submissions. In addition to score obtained, it automatically records for example the time used and a

total number of submissions to the exercise. ViLLE was also used to collect the attendance data in all course sessions, including the practice lessons in schools. The students answered to a short survey after each tutorial-based session (see Section 3.1 for details). In addition, the students evaluated all practice lessons via another survey.

V. RESULTS

The attendance to at least five of the seven tutorials and to all three practice lessons was mandatory. The average number of attendances per student was 9.36 out of 11 total. The average number of points collected from each of the tutorials is displayed in Figure 3.

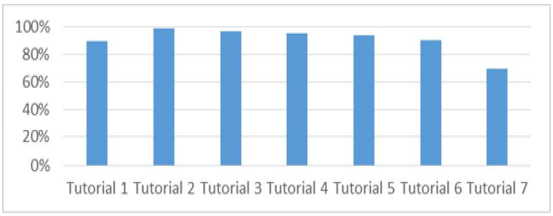

Figure 3. The average points collected in seven tutorials of the course

As seen in the figure, the average number of points collected was quite high in the first six tutorials, but dropped a little in the final tutorial (69.7 %). This is very likely due to attendance into final tutorial being voluntary. The total average for all tutorials combined was 91.1 %. If the final, voluntary tutorial is omitted, the average is as high as 94.6 %. Hence, it seems that in average the students completed a very high number of all exercises in all tutorials.

In addition to tutorials, the students could collect a minor amount of points from attendances, answering surveys (although the final survey was answered as anonymous, and did not hence add to total points) and by trying out a small set of math exercises in ViLLE before the practice lessons started. The average number of points collected from each section of the course is shown in Table 2.

TABLE 2. Points Collected from different sections of the course

	Max	Mean	% of max.
Attendances	110	93.6	85%
Tutorials	1380	1277.6	93%
Surveys	100	84.8	85%
Additional ViLLE Exercises	60	53.6	89%
Total	1650	1509.6	91%

As seen in the table, the students collected the points throughout all sections quite well. This can be seen in the course's final results, where 47 % of the students earned at least 95 % of all points available, and got the highest grade (5). The lowest grade given was 3 (17.5 % of all students) on a scale of 1 to 5; for a grade 3, a minimum of 70 % of all points needed to be achieved.

A. *Students' Perceptions*

The students were surveyed throughout the course to both, collect data about the course and to make small improvements and fix mistakes during the course. The weekly feedback surveys contained four open questions (see Section 3.1) about the session and it's adaptability into teaching. In addition, the students graded each session in scale of 1 to 5 (5 being the best). The grade averages for sessions are displayed in Table 3.

TABLE 3. STUDENTS' GRADE AVERAGES TO SESSIONS 1 TO 7.

Week #	N	Mean (Scale of 1 to 5)
1	36	3.97
2	33	4.09
3	36	3.69
4	33	4.00
5	32	3.53
6	29	3.86
7	21	3.57

As seen in the table, the grade average was highest on weeks 2 and 4. The lowest average was given to session 5, where the topic was repetition. Although important topic, it was probably more difficult than the previous ones. There were only 21 answers to the seventh weekly survey. This can be explained by the fact that unlike the previous sessions, the seventh session was voluntary. All in all, the grade for all sessions was still towards positive (>3.50).

The answers to open questions were very useful for fine-tuning the course while it was going on. The answers to the first question, "What did you learn in this session?" mostly list out the topics covered and Python keywords (such as "the difference between operator and operand", "str, len and substring" and "using the while statement"). Although there were references to play-based exercises and lecture in the answers, most of them were about the tutorials. Weekly surveying and reacting to the answers seemed to please students, for example one student answered that "[Today] I learned to use subprograms. Tutorial was a lot easier to comprehend than last week's tutorial. It is great that you read the feedback and modify the teaching accordingly".

The answers to the second question, "What remains unclear after this session?" were more diverse. Naturally, there were again direct references to topics, concepts and keywords (such as "find and replace" or "indentation"), but many answers gave more detailed and/or general feedback ("Writing code still feels complicated, since I seem to have forgotten the previous concepts every time" or "The course feels a little short for a newcomer like me to learn these things"). There were also some questions about the practical arrangements ("When are the practice lesson schedules announced?"). Still, there were also positive comments, such as "Nothing [remained unclear] – the tutorial was good".

With the third question ("How would you improve this session?"), a lot of useful feedback on course design and the tools used was collected. The students suggested, for example, that "Pairs in tutorials could be randomly selected" and "It would be more useful if the theory and the exercises were given in shorter segments"). The course staff tried to react to all suggestions, when possible, but naturally all the issues could not be fixed during the course. The final question ("How would you adapt these concepts into your own teaching?") was mostly answered by listing either the play-based exercises or ViLLE

material the students found suitable for teaching programming at elementary school level.

The students also evaluated all three practice lessons at elementary schools. The students gave grade to seven individual fields of the session. Additionally, they gave an overall grade to the whole session. All answers were given in scale of 1 to 5. For the difficulty level, the scale translated into 1 being too easy, 5 too difficult and 3 a perfect level. For other questions, the scale was translated as 1 being the worst grade and 5 the best. The results are displayed in Table 4.

TABLE 4. STUDENTS' PERCEPTIONS ABOUT THE PRACTICE LESSONS IN SCHOOLS (L = LESSON)

Question	L 1	L 2	L 3	Mean
Concept difficulty level (1: too easy, 5: too hard)	2.71	2.56	2.70	2.66
Pedagogical value for programming (5 best)	3.91	3.59	4.00	3.83
Pedagogical value for mathematics (5 best)	3.22	3.15	3.65	3.34
Value of play-based exercises (5 best)	4.06	3.59	4.26	3.97
Programming difficulty level (1:too easy, 5: too hard)	2.81	2.83	3.13	2.96
Math difficulty level (1: too easy, 5: too hard)	3.16	2.96	2.96	3.03
Students' ViLLE fluency (5 best)	3.75	3.85	4.04	3.88
Overall grade	4.06	4.00	4.17	3.08

VI. DISCUSSION

All in all, the course was successful. The students worked hard throughout the course, completing a clear majority (91 %) of all exercises throughout the course. The feedback was also mainly positive, the average grades given to sessions were all over 3.50 in scale of 1 to 5. Naturally, there was some variation between the sessions. The lower grade given to some sessions was mainly due to exercises being considered as too difficult. The course staff reacted to all feedback quickly, which can be clearly seen in the subsequent grades. The practice lessons were also well conceived. The average grades given for difficulty level of programming and mathematic concepts taught were very close to perfect 3 (2.96 and 3.03, respectively). There is also a desirable progress in the grade given to students' ViLLE fluency, as there is a trend towards higher average in the latter sessions. One hidden objective of the lessons was to demonstrate the difficulties in adapting an educational tool in the classroom, and it seems, that the difficulties in the first lesson were overcome in the latter lessons. The feedback from the students seems to confirm this observation.

Teaching programming to teacher students is naturally different than teaching the same topic to computer science majors or engineering students. The students had different attitudes towards programming, teaching and course practicalities than CS majors in general. Most of the difficulties were overcome during the course. Moreover, a joint discussion session with the course staff and students organized at the end of the course was really useful for the future instances, as a lot of very useful feedback was collected. In the course closing survey, the average grade given for course difficulty (1: too easy, 5: too difficult) was 3.11, which can be seen as a very good result. The comments from the students were also mainly positive: students found the course useful, felt that they were given an adequate knowledge about programming and liked the hands-on lessons with actual pupils in elementary schools. The negative comments mainly concerned the difficulty of programming, which is a well-known problem among programming educators.

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Technology-Enhanced Programming Courses for Upper Secondary School Students

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Abstract - **Nowadays, it is typical to integrate programming into curriculum in upper secondary school level. However, there are rarely existing models or materials offered to teachers for teaching the courses. With this in mind, we have designed and developed two upper secondary school level programming courses which utilize educational technology in all areas extensively. The first course is about introductory programming concepts in Python, and the second course about object-oriented programming in Java. The courses emphasize gamification and active learning via tutorial-based educational model. In this model, each lecture is accompanied with a tutorial which combines learning materials with automatically assessed programming exercises. The teachers are provided with ready-to-use materials for all other areas of the course as well, including e.g. lecture slides, weekly exercises, course projects with model answers, and electronic exam. All materials are customizable to suit different students and learning styles. In this paper, we describe the design and implementation of the courses, and provide results and experiences from three instances where the courses were utilized in upper secondary schools. Based on the results, it seems that the courses are both effective and motivating to students, and have received excellent feedback from the teachers utilizing them.**

Keywords – Programming education; Learning technology; Learner collaboration; Upper secondary education

I. INTRODUCTION

The field of information and communication technology has increasingly more computing power to utilize, but the major problem lies on how to harness the power to provide end-users solutions that actually serve some purpose and hopefully bring out some benefits. Computer science experts and technical engineers research on how to get the actual computer and networking infrastructure to work and give the machines the orders to do the required tasks by writing the instructions with a programming language the machines are built to understand. Information systems science on the other hand includes the human element to the mix: how the computers could be utilized most efficiently by the users.

Thus, to provide end-users an efficient information and communication technology solution, one needs to think of the different types of machinery required, the programs that need to be written and how the humans will use the solution. This is the main topic of study in this article as well. How to introduce a new technology to an introductory programming course. However, here we for the most part deal with the software and human part of the problem. The technology discussed in this paper is a collaborative learning environment developed by the authors, the end-users are upper secondary school teachers and students, the learning space for the most part is computer class and the tasks are mostly solved in collaboration with another student.

The paper is structured as follows: first, related work by other researchers is presented. After that, the design principles behind the utilized course methodology are discussed along with course design, materials and used technology. In section IV a pilot study about adapting the course in a high school is presented followed with discussion of the results. Finally, the article is concluded and some possibilities for future research are presented.

II. RELATED WORK

Learning to program is not a trivial task [1]. Based on the earlier research students have problems in reading and writing programs after the introductory courses. Thus, various tools have been developed and introduced and their effect on learning algorithmic thinking and programming have been studied [2][3]. Most of the tools are usually quite short lived and mainly used to collect data for a set of research papers. There are however some exceptions [4][5][6]. Additionally, educational technology is a large and fast-growing field of business. Thus, there are increasingly more commercial learning solutions on the market. Unfortunately, most of them aren't usually based on rigorous scientific research.

In addition to the technology or software one should think of different ways on using the software in a learning situation. One method tried and tested in programming education is pair-programming [7], which was first introduced as a part of extreme programming, an agile method used in commercial software development. Several studies report on the benefits of pair-programming and more generally on the positive effect of student collaboration in learning to program [8][9]. However, although many studies show that active and collaborative learning methods are useful, the usefulness of collaboration vs. individual learning depends on many factors of which the learner type is really significant [10]. Thus, all learning should not be team-based. The sense of personal achievement can be stronger when certain topic is learned and understood individually.

Figure 1. Student progress visualized with a progress bar and virtual trophies. There are seven exercises in the round. The content is translated into English for this article.

III. Designing and Implementing the Courses

In this section, the design and implementation process of the programming courses aimed for upper secondary school students is described. Two separate courses were designed: the first one was decided to be an introductory course about fundamental procedural programming, utilizing Python as programming language. The second course was decided to be about object-oriented programming with Java.

A. Design Principles

The design of the courses was based on the existing research and on the excellent results gathered from earlier use of similar methodology in university level programming courses [11][12]. There were four design principles utilized: active learning, automatic assessment and immediate feedback, gamification and continuous feedback cycle. The principles are described below.

Active learning is essential in programming. Most researchers agree that the only effective way to learn how to program is to actively practice programming (and programming-related topics, such as computational thinking). With this in mind, the courses were designed to include as much activating and engaging tasks and exercises as possible. In addition to coding exercises, several other types of exercises were designed and implemented to strengthen the theoretical knowledge as well.

However, when active learning is emphasized, the workload for assessing exercises and other tasks may become too big for course staff. Because of this, *automatic assessment* was selected as the second design principle. Automatic assessment, especially when combined with *immediate feedback* [13], enables several benefits for both, students and teachers. For students, the feedback received right after the submission and the possibility to immediately fix, test and re-submit the solution are important steps in the learning process. For teachers, automatic assessment can save a huge amount of time and (if properly implemented) can reduce the number of errors in the assessment process. Automatic assessment is often limited to "simpler" tasks such as multiple-choice questions. However, for full benefits the tools utilized should be able to assess more complicated tasks automatically as well.

Gamification [14] is a process of introducing game-like elements into other (or, "serious") activities. Since gamification can enhance motivation, we decided to gamify some elements of the course. The important part of the process is to make the student progress in the courses transparent to students as well. This was enabled by virtual trophies and with a progress bar displaying students' score (in whole course and in individual rounds and assignments). Figure 1 displays an example of virtual trophies.

Collecting feedback from students can be a valuable tool for enhancing course design, fixing mistakes in the materials and exercises and for collecting knowledge about students' learning process. However, it is quite typical to gather such feedback only at the end of the course. Based on our earlier results [15], short surveys utilized throughout the course can be an excellent tool for collecting feedback. When the number of questions is kept relatively short, it is possible to evaluate feedback every week and make changes according to it in real time. Hence, it was decided to include three questions to each feedback survey: "What did you learn in this session?", "What things remain unclear after this session?" and "How would you improve this session?"

B. ViLLE – Collaborative Education Tool

For automatically assessed tasks, a suitable education tool was needed. The earlier experiments utilizing the methodology in the university level used a collaborative education tool called ViLLE. Hence, the natural choice was to use the same tool in the upper secondary school level courses as well. ViLLE is an exercise-based learning tool with support for more than one hundred automatically assessed exercise types, several programming languages and student collaboration. As of 2018, there are more than 50,000 public exercises in the tool, freely utilizable by any teacher registered to ViLLE. ViLLE is currently utilized by 5,000 teachers and more than 100,000 students for mathematics, programming and other topics. A complete description of the tool can be found in **Laakso et al. 2018.**

C. Materials and Assignments

The courses were designed to contain all materials, exercises and other tasks needed to teach them in upper secondary schools. Hence, for both courses, the following resources were prepared:

- *Teacher's manual*: a detailed handbook describing the technical details and the pedagogic approach of the whole course and the individual assignments and materials. The manual also provides instructions about using ViLLE and about typical mistakes usually associated with different exercises. Although the structure of the course is given in the manual, the teacher can modify the course to suit his/her own schedule and teaching style.
- *Lecture slides*: a set of slides with theory and examples was provided for each lecture in both courses. Since there was no separate book provided for students, the slides were prepared to be "readable" – i.e. to provide students the necessary information about the topics taught even if they missed the corresponding lecture. Moreover, a number of program code examples were included in the each slide set.
- *ViLLE Tutorials*: An important part of the methodology utilized is the tutorial-based learning. Tutorial, in this concept, is a combination of learning materials (such as text, images, code examples) and automatically assessed exercises. A total of eight ViLLE tutorials (last one being a summary of all topics) were prepared for both courses, respectively. Tutorials are meant to be answered in pairs (or in small groups) with emphasis on collaboration and active learning. Typically, a tutorial contains around ten exercises. The faster students can complete these exercises during a 75 minute lesson, and the rest can answer the remaining exercises at home.
- *Weekly exercises*: In addition to tutorials, a set of simple ViLLE exercises were prepared for each week. These exercises (typically 3 to 5 exercises each week) are meant to be answered right after the lecture has ended. The weekly exercises are also fully automatically assessed.
- *Course assignments*: It was also deemed important to provide students experience about writing programs outside ViLLE, in a "real" programming environment. Hence, a number of course assignments was prepared to be completed each week. Originally, one assignment a week was prepared. However, when the course was piloted, it was quickly revealed that the faster students required more assignments. Hence, a number of Extra assignments was created for each week.
- *Electronic exam*: Although we did not want to provide strict rules for assessing the course (and although the course model supports continuous assessment quite well), an optional final exam was provided. An electronic exam provided several possible benefits over traditional pen and paper exam. First, the students can test, debug and execute their solutions a number of times which makes the whole process more authentic. Second, utilizing automatic assessment results to faster and more reliable assessment process. Third, if all tasks in the exam are automatically assessed, the results can be published immediately after the exam ends.

All resources can be accessed and utilized by all interested teachers in Finland, although utilizing ViLLE requires participation to short ViLLE training session before the account is created.

D. Course Structures

Both courses were separated into eight one week modules with three 75 minutes sessions each week. This decision was made because typical lesson in a Finnish upper secondary school lasts for 75 minutes. Hence, each module consists of the following three sessions:

1. A lecture, accompanied with additional ViLLE exercises and a feedback survey about the lecture.
2. ViLLE tutorial, answered in small groups.
3. Course assignments done outside ViLLE with an IDE (or with separate text editor and compiler).

The final module in both courses was dedicated to summary tutorial and the final exam. The structure of the first course is displayed in Table 1.

TABLE 1. THE STRUCTURE OF THE FIRST COURSE

Week #	Topic
1	Introduction to programming and algorithms, types, variables, output
2	String operations, input
3	Conditional statements
4	Repetition
5	Functions and procedures
6	Lists
7	Using external libraries, other data structures
8	Summary, final exam

As seen in the table, content-wise the course is quite typical introductory programming course (often referred as CS1) with procedural paradigm. The second course, with

focus on object-oriented programming, is meant to be taken after the first course. The structure of the second course is displayed in Table 2.

TABLE 2. THE STRUCTURE OF THE SECOND COURSE

Week #	Topic
1	Transition from Python to Java
2	Conditional statements and repetition in Java
3	Methods
4	Introduction to objects, utilizing existing classes
5	Writing own classes
6	Encapsulation, member visibility
7	Inheritance, class hierarchies
8	Summary, final exam

As seen in the table, the first three weeks are dedicated to transferring the programming knowledge in Python to Java, and the following weeks to learning the basics of object-oriented programming.

IV. PILOT STUDY: ADAPTING THE FIRST COURSE

The first course was adapted in a Finnish upper secondary school in 2016 as a pilot study. The course was taught by a local teacher in school, but some additional mentoring help for teacher was provided by our research team. The course was optional, and a total of 10 students, aged 16 to 17, participated (N=10). Although the course has later been adapted in other high schools as well, at the moment no research permits were available for other instances. Hence, the pilot study is concluded with a rather small group of students. Students' performance in all exercises, tutorials and final exam was recorded automatically in ViLLE, including the scores obtained, the number of submissions made and the time used in individual exercises. Since the second course organized after the first one only attracted a few students, the comprehensive results are presented from the first course only.

A. Results

The total maximum score obtainable from tutorials, ViLLE exercises and answering the feedback was 1280. The score structure is displayed in Table 3.

TABLE 3. MAXIMUM SCORE FROM COURSE TASKS

Section	Max score
ViLLE Exercises	295
Tutorials	880
Feedback rounds	105
Total	1280

Students were awarded 5 points for answering each feedback (one for tutorial, one for lecture and one for course assignments each week). Students' total scores are displayed in Figure 2.

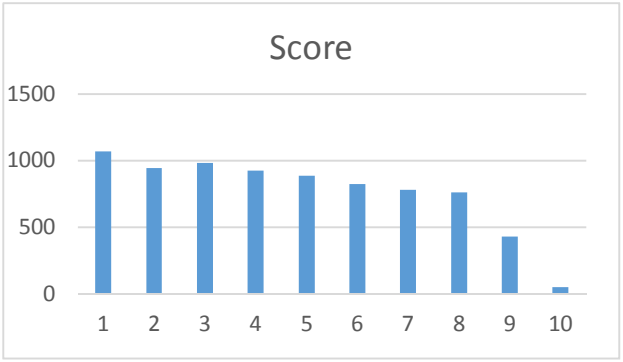

Figure 2. Students' total scores in tutorials, ViLLE exercises and feedback rounds combined

As seen in the figure, student number 10 dropped out of the course early. Hence, the statistics of that student are excluded from the rest of this section. The average of the remaining nine students is 842.0 points (out of maximum 1280), which indicates that the students worked quite hard during the course. The course assignments were not assessed automatically, and since the teacher did not score all submissions, the scores are not included in these statistics.

Students' scores in individual sections (tutorials, ViLLE exercises and feedback rounds) are displayed in Figure 3.

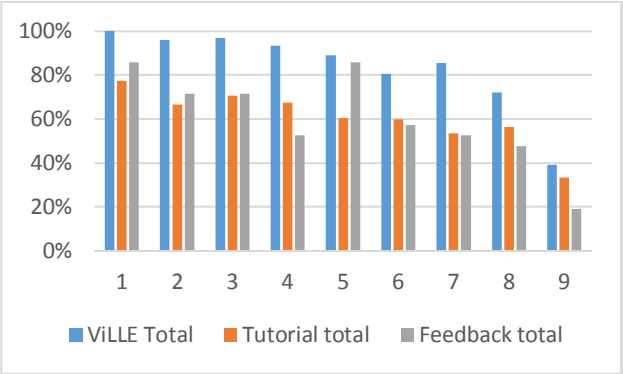

Figure 3. Students' scores in tutorials, ViLLE exercises and feedback round scaled

As seen in the figure, relatively, the students collected more points from ViLLE exercises than from tutorials or feedback rounds. However, there were a lot more exercises in the tutorials (and hence, a lot more points to collect) than in the other rounds. In average, students collected 83 % of ViLLE exercise points available, 61 % of tutorial points and 60 % of feedback points. One should note, that the final summary tutorial contained more exercises than the weekly tutorials, and the students were instructed to answer the questions they felt they needed the most practice with. If the summary tutorial is excluded, the average amount of points collected from the tutorials becomes 68 %.

Students' total points collected and the final exam score in the same scale are displayed in Figure 4.

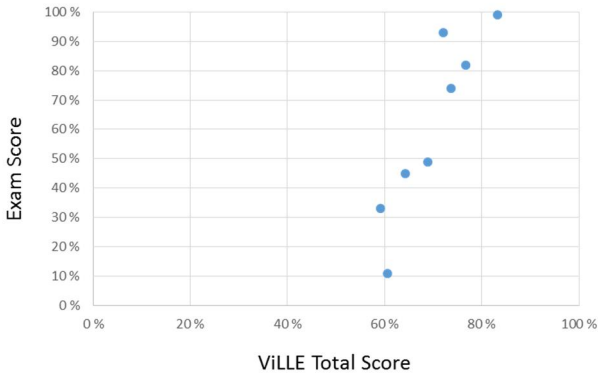

Figure 4. Students plotted according to their total score in ViLLE and the final exam score

As seen in the figure, there seems to be a correlation between the total score obtained during the course and the final exam points. Using formula

$$\frac{\sum(x-\overline{x})(y-\overline{y})}{\sqrt{\sum(x-\overline{x})^2\sum(y-\overline{y})^2}}$$

gives us a result of 0.910, which indicates a strong correlation (although it should be noted, that the sample size is quite small). Still, it seems that the students who worked the hardest during the course also got the best results in the final exam. There are some individual students that show interesting behavior in the figure: it is possible, that the collaborative work done during the course allowed some students to collect points without gaining enough knowledge. Also, one of the students who did rather well during the course, made a simple error in the final exam, which significantly reduced the final exam score.

Finally, students' feedback from all modules was analyzed. All feedback was categorized as positive or negative. The amount of positive feedback each week is displayed in Figure 5.

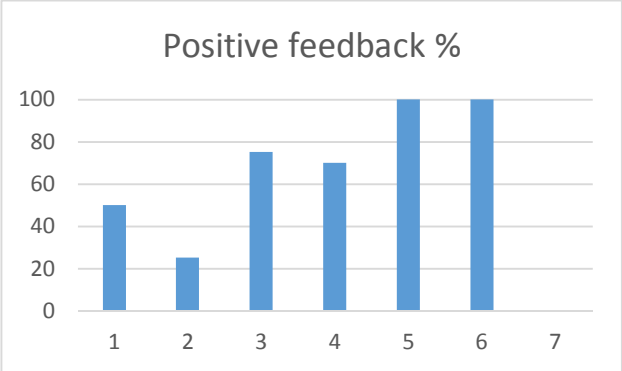

Figure 5. The amount of positive feedback given at first seven weeks of the course. Feedback was categorized as positive or non-positive, meaning that only the feedback that was clearly positive is included in these numbers.

As seen in the figure, the amount of positive feedback raised after the beginning of the course. In the seventh week, only one student provided feedback, and the feedback was categorized as non-positive.

V. Discussion

It seems, that the pilot adaptation was rather successful. Of ten students who started the course, only one failed to finish it. The correlation between the amount of work done during the course and the final exam score is high, which indicates that the tasks completed during the course are useful for learning programming. The students also collected the points from all different types of tasks in the course. The largest relative amount was collected from ViLLE exercises, which is probably due to the small number of exercises (compared to the tutorials) and the fact that they were answered directly after the lecture. The feedback from students was mainly positive, especially at the end of the course. The lower amount of positive feedback at the beginning of the course seems to indicate that there were some problems in getting accustomed with the new method and technical environment.

We have earlier studied the adaptation of a similar course at secondary school level (ages 13 to 15 in Finland). The results of that study (see [16]) showed, that students' performance was highly similar to that of university students taking a similar course in almost all areas of the course. Hence, it seems that the model can be utilized effectively in all levels of programming education. The teachers responsible of the course at the upper secondary school were also interviewed about the adaptation the new method and technical environment, and the feedback was mainly positive and it included some constructive ideas about developing the course further.

VI. Conclusion and Future Work

The high pass rate of the course, relatively high scores collected from all areas of the course, and the high correlation between the work done during the course and the final exam grade seem to indicate, that the proposed course model can be successfully utilized to teach programming at upper secondary school level. However, it should be noted, that the number of participants in the study was quite low. In the future, the study should be expanded, and the second course should be researched similarly to fully ensure the effectiveness of the new course model.

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A Model for Gamifying Programming Education: University-Level Programming Course Quantified

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Abstract - **Utilizing gamification in course holistically requires that all areas of the course can be quantified, and the progress made transparent to students as well. However, keeping track of all students' scores, submissions and other tasks can be too big of a workload to be practical, especially in the larger courses. We have successfully adapted a collaborative education tool to university-level programming courses. The tool is used to record student performance in all areas of the course, including for example attendances, demonstration and tutorial scores, weekly surveys and additional exercises. In addition to providing comprehensive statistics to teachers, all progress is also visible to students in real time. In this paper, we describe the re-design of the course, with gamification and transparency to students in focus. Moreover, we analyze students' scores in different components of the course, and find out if there are correlations to be found between different areas. The results seem to indicate, that methods emphasizing active learning are the most beneficial for students' performance in the course.**

Programming education; gamification; quantification; student performance;

I. INTRODUCTION

Programming is an essential skill in computer science and information technology education. Hence, various studies have been conducted about how the introductory programming courses should be taught, and what kind of tools can be utilized to improve student performance. Typical changes in the course methodology include for example emphasizing active learning (typical application is Flipped learning, [1, 2]) and utilizing gamification [3]. However, often the effect of changes in the methodology is not evaluated in detail. Although holistic changes in the student performance, motivation or other factors are important, it is interesting (and also important) to find out how the students perform in courses' different components and what is their effect into the final performance.

We have previously presented a tutorial-based programming methodology [4, 5] which was applied to an introductory programming course. The emphasis of changes is in active learning, which is implemented with tutorials (combinations of learning material and automatically assessed exercises), additional exercises and demonstrations. Gamification is utilized by making all scores transparent to students, by utilizing virtual trophies and by offering external reward (in form of small bonus to course grade) to student for completing more than a required minimum.

In this article, we explore the students' performance during the course by quantifying different components. Moreover, we discuss the effect of individual components towards students' performance in the final exam. The paper is structured as follows: first, related research by the community is presented. Next, the redesigned course is discussed along with the educational technology used and the quantifying of different components in the course. Next, students' performance in different components (and in total) is visualized and the correlation of components with the final exam presented. Finally, the results are discussed and the article concluded with possibilities to future research opportunities..

II. RELATED WORK

Programming is a difficult task to learn. According to several studies (for example [6, 7]), typical issues are for example the lack of adequate mental models, using overly simplified strategies and too little time spent on planning and testing problems. Several solutions have been provided to fix this problem. Educational technology, for example, can potentially help students to perform better. Examples of such technology are program visualization [8, 9], where program visualization is made visible step by step, and the tools for automatically assessing program code [10, 11], which can significantly reduce the time spent on evaluating the programs written by students. However, the tools alone cannot solve the problems in the programming courses, more important is how they are used and how active learning is emphasized in courses.

Different methodologies have been utilized to try to improve the outcome and the students' experience in programming courses. Boyle et al. [12] report an experience where blended learning was utilized in introductory course. They found out, that the online environment used in the course (along with other changes) resulted into better pass rates. In a systematic review [13] about different methodologies used in programming education, the authors found that of all reviewed features, the most effective ones were the utilization of relatable content, collaboration and adapting an introductory course (typically referred as CS0) before the introductory programming course.

A review of gamification literature [14] identifies several gamified elements that can be used in education. These include for example points, levels or stages, progress bars and feedback. Gamification can potentially increase students' motivation in courses. In [15] the authors present an experiment where game thinking and game mechanics were utilized with a software development team. The authors found out, that almost 80 % of the students favored the introduced, gamified mechanics in comparison to traditional setups. Similarly, in [16] the authors found out, that utilizing gamification to enhance online student collaboration lead up to 88% more efficient collaboration. Moreover, [17] reports various motivational impacts in different study groups when gamification was utilized by digital badges.

III. About the Course

As an example course, the Basic Course of Algorithms and Programming is used. The course is taught annually at University of Turku, Finland, and serves as essential part of programming education offered for computer science majors and other students. Content-wise, the course is quite typical CS1 course. It is taught using Java, and focuses on procedural paradigm. The course lasts for seven weeks and is concluded with a final exam at the eight week.

The topics covered in seven weeks of the course are listed in Table 1.

Table 1. The contents of the course, divided into 7 weeks.

Week #	Topic
1	Introduction to course, transfer from Python to Java
2	Variables, strings, conditional statements
3	Repetition
4	Methods (i.e. procedures and functions)
5	Arrays
6	Using external modules, other data structures
7	Summary

As seen in the table, the course covers basic introductory concepts related to procedural programming. Each week there are two 2-hour sessions. Moreover, there are a total of four 2-hour demonstration sessions where students demonstrate and discuss their answers to programming tasks.

A. Utlizing Educational Technology

The implementation of the course relies heavily on usage of educational technology. Because of this, a suitable tool was required when the course was redesigned. ViLLE, an exercise-based collaborative education tool was chosen to be used in all areas of the course. ViLLE has a support for multiple programming languages (including Java, Python, C#, C++, JavaScript, to name a few). Moreover, there are more than one hundred different exercise types. A number of these types are designed especially for programming education, including for example program visualization [18], Parsons puzzles [19] and code writing. There is also a program simulation exercise, where the students need to simulate program code execution (for example by creating and modifying variables and method instances) while the example program is executed. All these exercise types are automatically assessed and provide immediate feedback upon submission. An example of programming-related ViLLE exercise is shown in Figure 1.

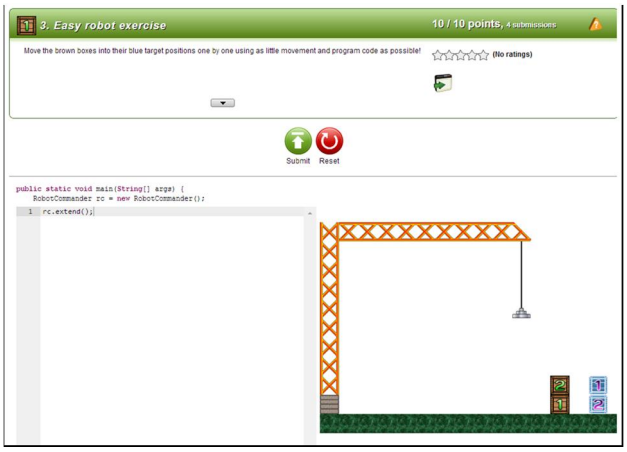

Figure 1. An example of programming-related exercise in ViLLE. The students need to move the boxes into their target positions by writing a program.

ViLLE works as a web-based application, usable with any modern browser with no additional plugins required. The exercises are collected into rounds, and a number of rounds form a course. There are three types of rounds needed in the programming course: normal rounds, exam rounds and tutorial rounds. All rounds have an opening and closing times set by the course teacher. Exam rounds offer a possibility to modify several properties, including the amount of feedback given. Tutorials in ViLLE are combinations of learning material (such as text, images, videos or code examples) with automatically assessed exercises. All exercises in ViLLE can be done in collaboration, but the group work is emphasized in tutorials. Both students (or all students, as the group size can be anything between 2 and 9) sit in front of same computer solving the exercises together, and the points are awarded to all students in the group.

ViLLE can also be used for recording other course activities. Student attendances can be collected automatically by using RFID (Radio-frequency identification) tags handed to students. When a tag is used with a reader in any classroom, the attendance is automatically registered. The same mechanism can be used to register demonstration points as well. ViLLE has a support for surveying students' perceptions, which can be a powerful tool in course quality control [20]. Survey answers and all other statistics can be easily viewed in ViLLE by course teachers. The statistics can also be exported as a plain text file or as a Microsoft Excel spreadsheet for further analysis. Comprehensive description of the tool can be found in [21].

B. Course redesign

With the redesign, several design principles were chosen [5]. The redesigned course emphasized active learning by replacing half of the lectures with tutorials.

Moreover, the remaining lectures were accompanied with additional ViLLE exercises which were meant to be answered right after the lecture. To enable student feedback, a simple survey was used after each lecture and tutorial. The survey consisted of three questions: "What did you learn this week?", "What things remain unclear after this session?" and "How would you improve this session?". The answers to these questions were analyzed after each session, and the consecutive sessions were modified, if necessary. Finally, the course final exam was transferred into electronic exam. Utilizing electronic exam enables the students to test, modify and debug their answers, bringing the whole process a lot closer to real programming. Combining electronic exam with automatic assessment also reduces teachers' workload significantly and can make the assessment process more reliable. In the redesign process, three non-affiliated researchers confirmed that the electronic version is at least as difficult as the traditional one.

The structure of the redesigned course and a comparison to course instance before the redesign process is displayed in Table 2.

TABLE 2. COURSE INSTANCES COMPARED.

Component	Old instance	New instance
Lectures	7 x 2 x 2h	7 x 2h
Tutorials	None	7 x 2h
Demonstrations	4 x 2h	4 x 2h
ViLLE exercises	None	3 to 5 weekly
Exam	Pen and paper	Electronic
Exam tasks	2 to 3	8 to 9
Attendances	Not registered	Registered

There is not a significant difference in students' work load when measured in hours in a week. However, in the new instance, the amount of active learning via different kinds of exercises is a lot larger than in the old version.

C. *Quantifying the Course and Utilizing Gamification*

As seen in Table 2, the new course instance consists of five components: lectures, tutorials, demonstrations, ViLLE exercises and the final exam. The first four components are split among several weeks of the course. A maximum score for all areas was defined to give them proper weight in the whole evaluation scheme. The scores are displayed in Table 2.

TABLE 3. THE MAXIMUM SCORES AND REQUIRED MINIMUMS FOR DIFFERENT COURSE COMPONENTS.

Component	Max. score	Required minimum
Lecture attendance	200	None
Tutorials	650	325 (50 %)
Demonstrations	400	200 (50 %)
ViLLE exercises	200	100 (50 %)

Hence, the total maximum score at the course becomes 1450. The final exam was scored in scale of 0 to 90, but this score was independent of the course total score. Exceeding the minimum limits gave student a small bonus into the final grade. However, this bonus was only applied if at least 50 % of the points was collected from the final exam.

To enable the gamifying effect from collecting points in different categories (and in total), the progress must be made visible to students. Hence, in ViLLE the students can see their real-time total score, round scores and the scores of individual assignments all time. The effect can be boosted by using virtual trophies: hence, a bronze trophy is awarded from reaching minimum score in a round (50 %), silver trophy for 75 %, gold trophy for 90 % and the diamond trophy for the full score. An example displaying the trophies and the score in ViLLE is displayed in Figure 2.

Figure 2. Students' score displayed with a progress bar and virtual trophies.

The figure displays one round with 6 exercises. The user has completed the first five exercises with full points but has not started the final one yet. The bar in the top displays the full score gathered from the round (50 out of 60) and the trophies already reached (bronze and silver).

D. *Earlier Results*

In [5] we studied the effects of course redesign on student performance on the course. An old instance of the course (N=210) was compared to an instance using the redesigned methodology (N=193). We found out that the pass rate increased statistically significantly in the new instance. Curiously, the course average grade remained almost the same. A summary of the results is collected into Table 4.

TABLE 4. THE RESULTS OF THE OLD METHODOLOGY AND NEW METHODOLOGY COMPARED.

	Old methodology	New methodology
N	210	193
% passed course	53.33 %	80.82 %
Grade mean (1 to 5, 5 best; of accepted)	3.63	3.57

As seen in the table, performance-wise the redesign was highly successful. The pass rate in the new version of the course is significantly better. Next, we quantify the students' performance in different areas of the course, to try to find out how the better pass rate was achieved.

IV. RESEARCH

ViLLE automatically collects a lot of data from every submission made by students. For example, submission score and the time used answering are required. Additionally, exercise-related data is stored. A coding exercise, for example, stores all code student has written for the submission. This opens up new possibilities for studying student misconceptions and coding style [22]. In this paper, the focus is in quantifying students'

performance, and hence on the scores collected. A single instance of the course is studied. For consistency, the same instance is observed than in the previous study [5] about students' performance.

A. *Results*

Students' total scores are visualized in Figure 3.

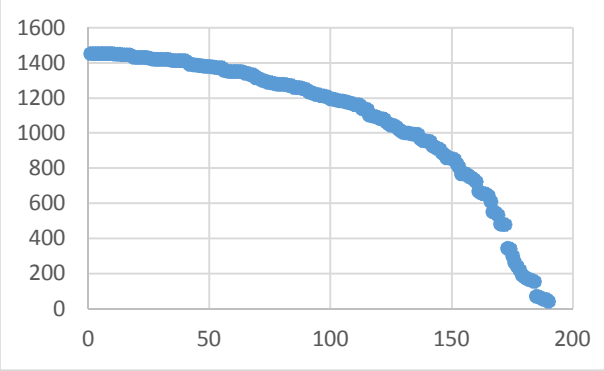

Figure 3. Students' total score collected from the course visualized.

As seen in the figure, majority of students collected points quite well. The average number of points collected was 1077.0 out of 1450. The distribution of total points between different course components is visualized in Figure 4.

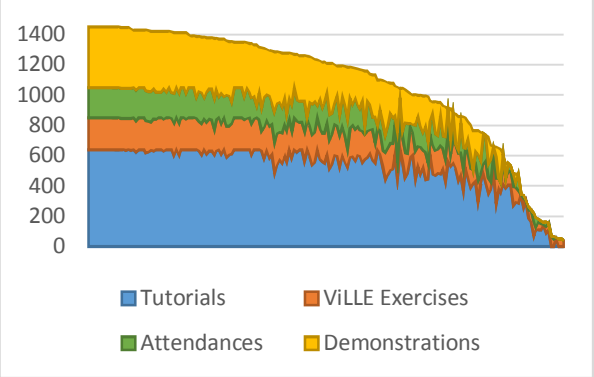

Figure 4. All students' score collected from the course categorized into different components.

As seen in the table, the majority of collected points comes from tutorials and the demonstrations. This is in line with the intended workload of the components.

The course lasted for seven weeks (with exam at the eight week). The average points collected from the tutorials, ViLLE exercises and attendances each week are displayed in Figure 5.

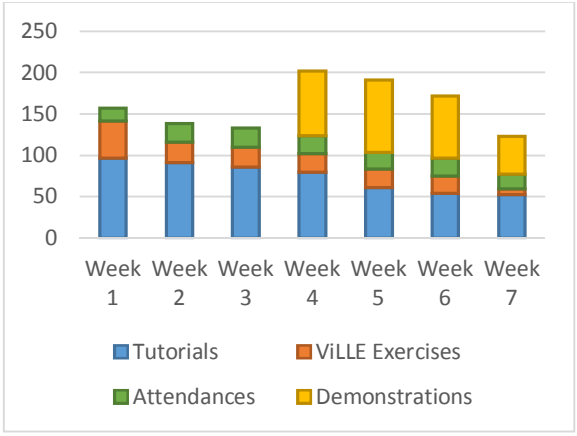

Figure 5 points collected from all components of the course weekly.

There are some important points to notice about the figure. First, the maximum amount of ViLLE exercises was 50 at the first week, and only 10 at the last week. For weeks 2 to 5 the maximum was 30 points. This explains the larger average on the first week and the smaller one on the last week. Second, attending the first lecture only provided students 10 points, while all the remaining ones awarded 15 points. Hence, the average number of points collected from ViLLE exercises and attendances is quite constant during the whole course. However, the number of points collected from the tutorials drops noticeably in the second half of the course. This is very likely due to topics getting more difficult when the course advanced. There were four demonstrations, taking place in weeks 4 to 7. The amount of points collected seems to drop a little towards the end (the average for last week was 45.7 while in the first three weeks the average was more than 75 points). Again, the last set may have been more difficult than the previous ones.

To find out whether the work done had an effect to the course grade, a correlation between total points collected and the final exam points (without bonus) was calculated. The mapping of students is shown in Figure 6.

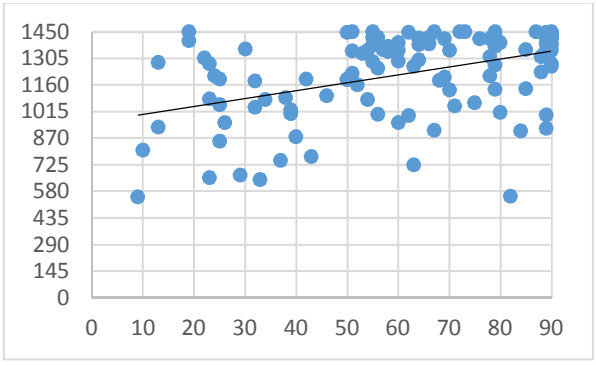

Figure 6. Students plotted according to their total score collected (y-axis) and the point in final exam (x-axis) without added bonus.

The figure is by no means ambiguous. Still, it seems that the majority of students who collected a lot of points during the course also did quite well in the final exam. As there were minimum requirements for collecting points from different components, the students who did not meet them were not allowed to participate into the final exam. Hence the bottom half of the figure is mostly empty. A

correlation value of r = 0.443 between the total points collected and the final exam score does indicate a moderate correlation – a fact that is also visible in the figure. The exam score correlation with all course components is displayed in Table 5.

TABLE 5. CORRELATION BETWEEN COURSE COMPONENTS AND THE FINAL EXAM SCORE WITHOUT ADDED BONUS.

Component	Correlation with exam score (r)
Total score	0,443657
Tutorials	0,495501
Attendance	0,156899
ViLLE exercises	0,345411
Demonstrations	0,39234

As seen in the table, the tutorials have the highest correlation with the final exam score. Hence, the emphasis of tutorials in the course total score seems to be justified. Curiously, lecture attendances only have a minor correlation (0.157) with the points collected from the final exam. Hence, active learning methods seem to be the most beneficial for learning.

V. DISCUSSION

The students seem to have collected points quite well from all course components. The average amount of 1077.0 (out of 1450) is rather high average score, especially since the students who dropped out from the course (pass rate was 80.82 %) are included in the number. Most of the points collected came from tutorials and demonstrations. This emphasizes the course's focus on active learning. Curiously, the amount of points collected from these topics also decreased towards the end of the course. We can think about two possible explanations for this. First, it is possible that the exercises got more difficult towards the end of the course, and the students were not able to complete as many of them as in the beginning. Second, it is also possible that the students were not as eager to collect points when they had completed the required minimum amounts from all components. However, the average amount of points collected from ViLLE exercises and attendances remained constant during the course – likely because the points were easier to collect from these categories.

There is a moderate correlation (r = 0.443) between the total score collected and the final exam score (without the bonus points collected during the course). This indicates, that although there is a correlation between the work done during the course and the skill level in the final exam, there are some exceptions that need to be considered. Collaboration has been proven quite useful to programming learning [23, 24, 25, 26]. However, there is a possible downside to doing tutorials and demonstrations collaboratively: although the students are instructed to work together and change the operator (i.e. the student who is using the keyboard and mouse) frequently, it is still possible that some students may have adopted a passive role. Similarly, it is possible to copy the demonstration answers from other students. There are also some students who did quite well in the final exam without completing much points during the course. These are probably students with previous programming knowledge.

Of all course components, tutorials had the strongest correlation with the final exam score. Moreover, lectures had the smallest correlation with the exam. Hence, it seems that active learning methods are the most useful for students' performance. Although not explicitly researched in this study, we think that making scores of all components transparent to students is important. Displaying score (with possible virtual trophies) and offering a reward for completing more than the required minimum are important, gamifying factors that may have a positive effect towards student motivation.

VI. CONCLUSION AND FUTURE WORK

Quantifying the individual score components seems to provide valuable information for teachers and education researchers. Students' interest in completing different areas can potentially be increased by utilizing gamification by making the scores transparent and providing rewards on completing more than required work. In the future, the effect of gamification should be observed better. There are some possibilities to complete this: first, we could have course instances that are similar by all other aspects, but the other would provide gamified features (such as ones utilized in the course described here). Second, it may be useful to survey students for their perceptions about gamification in learning context.

Although there was only moderate correlation between the total score collected in the course and the course final exam scores, it still seems that the students benefit from learning actively with versatile methods. In the future, it would be useful to observer the correlations and specific effects of individual components in the course even closer. This way it would become possible to emphasize the most effective methods. Still, utilizing different kinds of methods in the course provides students heterogeneous ways to learn the topic, and can hence increase motivation and make learning programming more interesting. Finally, yet another direction to future research is to quantify the effect of components in different kinds of courses to find out if the effects can be generalized.

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Designing and Creating a Framework for Learning Analytics in Finland

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***Abstract* – Digitalization and technology in schools continues to be hot topics. In this paper, we share our experiences and findings on how to build and distribute an educational system that can be used as a framework for learning analytics. We discuss the key features and ideology behind the system but also how to train teachers successfully to use the system. For this, we present three different training models and share our experiences and teachers' feedback on them. The number of user has increased rapidly after implementing the different training models and feedback from teachers is very positive.**

Keywords – Computer-assisted learning; Learning Analytics; Teacher training

I. INTRODUCTION

Learning analytics has great potential on improving the way individuals learn, how teachers teach and how national curricula are designed and implemented [1]. Better and more detailed knowledge on learning and needs of learners open new possibilities for more targeted teaching and efficient usage of human resources [2]. In best case scenario, learning analytics will save time, money, and improve learning. Fournier, Rita and Hanan [2] define learning analytics as *"the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimising learning and the environments in which it occurs."*

Despite all the promises and possibilities, learning analytics has two major challenges. First: *How to collect data from every day school life?* Second: *How to use the collected data to improve learning proactively* instead of post-analysis. At the moment, the data collected for many studies conducted on learning is based on post-analysis. The research tends to observe marks, pre-knowledge and background information. The problems with this approach is that it is already too late for the test subjects to make any changes in teaching. The two aforementioned challenges are not the only obstacles [1] but they are very profound for utilizing learning analytics efficiently. One very descriptive example of this dilemma is from a national mathematics conference, where a scientist announced (freely translated form Finnish to English): "*We have been talking about the same topics for 30 years but nothing has changed*".

Norris et al. [3] have listed demands for building an environment designed for learning analytics. Some of the demands are more political, like forming policies, but here we concentrate in the technical demands:

- Scalable solution (easily used and adopted by large number of pupils in different subjects)
- Continuous improvement of value (content and analytics)
- Make improvements transparent for all stakeholders, including teachers, students and students' parents.

These aspects, presented by Norris et al. [3] are discussed in this paper, first from more technical point of view, introducing our in-house developed learning environment called ViLLE. After introducing the system, we share our experiences from more practical point of view. We introduce our training models, and feedback and experiences from the trainings. Finally, we conclude the paper by answering the questions on how to collect data from every day school life and how to improve learning by using the data.

II. DESCRIPTION OF THE FRAMEWORK

Finland's education system is highly valued and often considered as one of the best in the world. Finland has achieved excellent results for example in PISA (Programme for International Student Assessment) tests [4]. One of the characteristics of Finnish education system is our autonomous teachers. In practice, teachers are allowed to decide for themselves which tools they want to use. This means, that educational tools need to provide clear advantages for teaching and learning in order to be chosen by teachers. For this reason, we have created electronic learning paths for mathematics (with integrated programming) for grades 1 to 9 (ages 7-15) and for Finnish language for grades 1 to 6 (ages 7-12). There are about 15 000 exercises for mathematics and 10 000 exercise for Finnish language.

All exercises are created in collaboration with Finnish teachers and researchers to ensure their suitability and quality. Every week, our researcher attended one mathematics lessons where pupils used the exercises, designed and created together with the teacher. After the lessons, the exercises were adjusted based on the feedback and experiences. The collaboration with the users is continued after the initial steps. For example, an easy way to leave feedback from any exercise is provided to both, teachers and students. This ensures that the designers can

be quickly informed if there is are issues and are hence able to fix them swiftly. The content is also developed according to feedback from teachers. After all, they are the ones teaching with the material and are also experts in pedagogy.

A. *Electronic Learning-Paths*

The exercises are divided into lessons for better usability. There is one lessons for each school week in both subjects, following the national curriculum of Finland [5]. Teachers are able to choose the order of prepared lessons to follow the textbook used in the class. This means that using the material provided in learning paths does not require extra work. Teacher opens a new lesson every week and concentrates on following the learning outcomes from statistics. For pupils, the content is gamified. Pupils complete exercises from each lesson and collect points. When they have enough points, they achieve trophies. Minimum requirement is 50% (bronze) all the way to 100% (diamond). This allows pupils to follow their own progress and set goals for themselves.

The learning paths are built using ViLLE, which is an exercise based learning environment developed at the University of Turku [9]. Main emphasis on the system is on automatically assessed exercises that give immediate feedback for the pupils. The system contains over 100 different kind of exercise types. Figure 1 shows an example of one of the game-like exercise types. Every exercise also saves all students' answers. The data stored is used to give teachers in depth statistics about pupils' learning and learning performance.

Figure 1. Three examples of mathematics exercises and lesson view for student.

ViLLE is used from pre-school to higher education. Each level has differences in focus but the underlying idea is similar. Automatic assessment and immediate feedback aims to reduce workload of teachers, increase the quality of learning and make studying more motivating. In addition, the tool offers teachers more information about students and their learning process. In this paper, our emphasis is on the primary education.

B. *Providing Practical Learning-Analytics*

The saved data can be used for continuous assessment. Using technology in teaching is no more an additional game or entertainment, but rather it takes as important role as exercise books in traditional teaching. Teachers also notice that regular usage of ViLLE enables them to use continuous assessment efficiently and are able to reflect their teaching. Statistics reveal new information about pupils' learning and study habits. For example teachers see how much time pupils use for actual work during lessons and how much time they use for studying at home. Traditionally this information has not been available. The tool can also show automatic and real time data on detecting students' misconceptions in mathematics (see Figure 2). The data provided by ViLLE was compared to standardized Finnish test (MAKEKO (*Tests for essential contents in mathematics*) [8]). The comparison concludes, that ViLLE can detect mathematics misconceptions at least as accurately as the test [10].

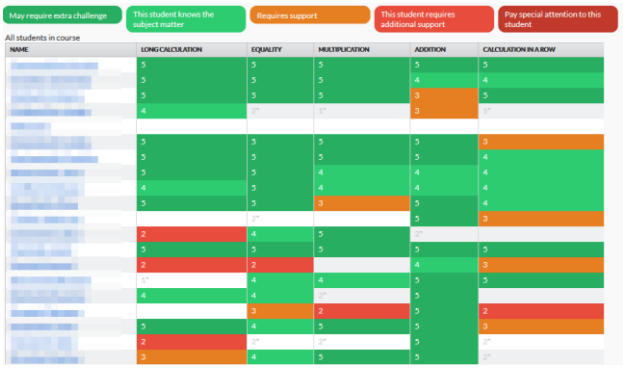

Figure 2. The Misconception View provides real-time information about students' misconceptions in different topics.

Last but not least, we have studied the effectiveness of using ViLLE in mathematics. In grades 1 and 3 (ages 7 and 9) we have shown that one weekly ViLLE lesson will improve mathematics performance compared to classes not using ViLLE [11][12][13]. Improved learning performance can be explained by increased amount of completed tasks but it is important to note that the pupils are also very motivated to work with computers.

III. TRAINING MODELS

Introducing new ways to work requires cultural change on organizational level [5]. Using educational technology instead of (or to complement) textbooks requires different approach in pedagogy, proper infrastructure for network and of course proper amount of devices. Uluyol and Sami [15] found out that teachers require clearer proof of benefits of using technology in education. They also would like to have more support during introduction to new technology. Finally we need to arrange enough opportunities for teachers to get training. For these reasons, we have different models that provide sufficient support and opportunities for teachers. Of course all this requires resources, time, money and people.

A bottom-up model was selected for the training. When a new school joins ViLLE, there are usually only few teachers participating the training. After they get positive experience using the system, the school or municipality will ask for more training. In this way, the *pioneers* (i.e. the teachers more enthusiastic or open about technology) are first introduced to tools, and later they can convince their colleagues and start making the cultural changes at the organization. Finally, once the cultural changes is far enough, the late adopters can be included in the system. It is worth noticing, that teachers can only join

ViLLE after participating some form of training. In addition to our own experiences, research also supports the idea that social influence and emphasis on positive changes increase adaptation of new technology [7].

After gaining enough experience in using ViLLE, teachers are able to participate in the ViLLE expert training, which enables teachers to give out three additional teacher accounts without training fees. Another possibility is to participate on our mentor training and start training teachers independently.

There are three basic training models for teachers to start using ViLLE (Figure 3). All models are suitable for schools or teachers in different situations. The introduction of different models will start from the most time consuming for the trainer but easiest for the trainee and the last one is the most independent for the trainee.

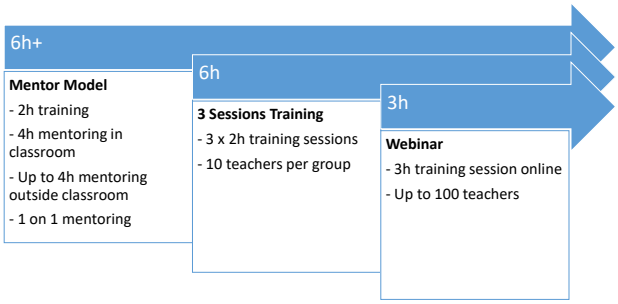

Figure 3. Training models and their time consumption.

All three training models are presented below. The first, Mentor Model, is suitable for teachers who are willing to become mentors later on, or for teachers who are not confident using technology. The three session model is a good compromise between contact mentoring and online training. Last, the webinar is suitable for individual teachers, who want to try ViLLE or who are very familiar with educational technology.

A. Mentor Model

The first and most individualized training model is called the Mentor Model. The model is targeted for one school at a time and it is designed for maximum of 5 teachers at once. The Mentor Model starts with two hours basic training, during which teachers get used to ViLLE as a pupil and just enough introduction to teacher's view in order to arrange first lesson with pupils. This includes copying necessary content and creating student accounts. The basic training is then followed with a ViLLE-lesson, where the mentor is present. The teacher has the main responsibility on teaching but the mentor is there to help and support the teacher in every turn. During or after the first lesson, the mentor shows different statistics and learning analytics and demonstrates on how to utilize them. The mentor is present in four lessons in total, and during those sessions, the mentor ensures that the teacher gets adequate knowledge on motivating the pupils, differentiating exercises for pupils with different learning profiles and of course the basic usage of the system.

The mentor tailors the training on the go to match the needs of the teacher. Some teachers might need more emphasis on student motivation or differentiation and some teachers are more interested in more advanced features, like electronic exams and creating content by themselves. The amount of mentoring given outside classrooms depends on teachers' needs.

B. Three Sessions Training

The most common training model is the Three Sessions Training. This training offers a good compromise between contact training and training a larger group of teachers. As the name states, the training consist of three mandatory sessions. Each session lasts two hours. The whole training takes six hours. If the training is arranged in distance location, it is divided to two three hour sessions. The idea of this training model is to divide the workload of learning the technical and pedagogical aspects into smaller chunks. Each session is a week apart.

The first two hour session covers general introduction of the system and the pedagogical ideas behind it. A big part of the training is dedicated to testing the system as a pupil. The mentor is not present during any of the ViLLE-lessons, therefore the trainers try to minimize the anxiety of using a new system by introducing the most typical exercise types and features. After this session, the teachers have pupil accounts and are able to continue testing the system at home. In many cases, teachers might test the exercises on individual pupils at school.

During the second session, the pupil accounts of teachers are upgraded to teacher accounts. Together with the help of the mentor the teachers prepare their courses and pupil accounts for their class. Moreover, the basic usage of the system is covered during this session. After the session (and before the last session) teachers should have their first ViLLE lesson with their classes.

In the third and the final session, experiences, problems and achievements are discussed in a group. Then the statistics and analytics from the first lesson are introduced. Now, the teachers have data from their own class, which makes viewing it more interesting and engaging. They can also ask better questions based on the data. Finally we see, how to differentiate pupils in several different ways to make completing exercises more motivating.

C. Webinar

Finally, the most independent form of training is provided by online training session, called webinar. The training session lasts for three hours and the completion of the webinar requires teachers to pass an online test. During the webinar teachers will get basic information about ViLLE and the pedagogy, brief introduction to pupils' view and walkthrough in teachers' view. The online test is a tool for teachers to test that they are familiar with all the key features in the system. Teachers also have access to the support material. The duration of the webinar is three hours, excluding the online test

IV. EXPERIENCES AND FEEDBACK

In order to start using ViLLE, the teachers need to participate in some form of training. Unfortunately there is no clear statistics at the moment on different training models. Instead, Table 1 shows the development of number of teacher accounts and student accounts. Same data is visualized in Figure 4.

TABLE 1. NUMBER OF TEACHERS AND STUDENTS IN VILLE.

Time	Teachers	Increase of teacher accounts (%)	Students	Increase of student accounts (%)
1/2014	944	-	12 586	-
1/2015	1 315	39.4%	17 646	38.8%
1/2016	2079	58.1%	26 461	50.0%
1/2017	3 389	63.0%	47 451	79.3%
1/2018	5 598	65.2%	106 681	124.8%

Before autumn 2015, mostly upper secondary school teachers and higher education teachers were trained. Teachers were able to create their own content and create electronic exams. After that, the emphasis on the trainings sifted to primary education and existing content was provided to teachers as electronic learning paths. Most of the training was done by the Mentor Model. In 2017 the Three Sessions Training model was introduced, and it quickly became the most popular model. Figure 4 shows the growth of student and teacher accounts over time.

The increased number of students also indicates that we trainings have met the needs of the teachers and they are using ViLLE successfully with their students.

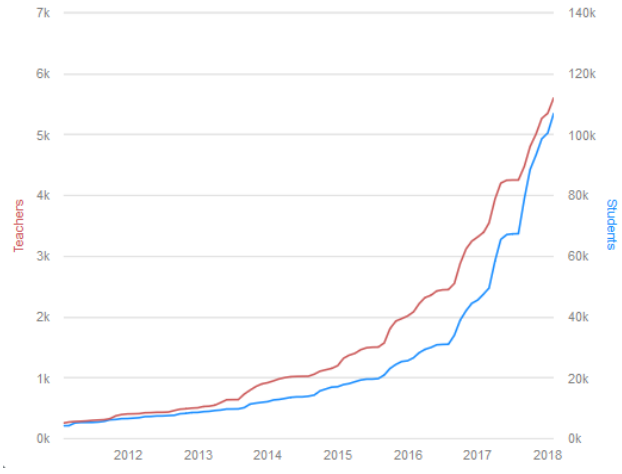

Figure 4. Growth rate of teacher and student accounts.

In Figure 4 we can better see the increased interest for ViLLE. In addition to adding The Three Sessions training model, teacher have started spreading their positive experiences through their networks. This has increased the interest towards ViLLE and the trainings.

The mentors' experiences from the Mentor Model are very positive. Teachers are very satisfied with the easy first steps. The model is very low-stress and easy for even teachers who have no prior experience with any learning environments. Only in a few cases, the more experienced teachers have given feedback about the lack of support. These statements are based on the mentors' experiences and no formal survey was conducted. In previous experiences implementing ICT in education there have been good experiences on tutor/peer training [14].

Before a Three Sessions Training starts, teachers tend to ask whether it is necessary to have three different sessions instead of just one longer session. After all three sessions are completed, they have usually changed their minds and thank the trainer for dividing the training in smaller chunks. After having their first ViLLE-lesson, teachers lighten up and start to understand the system and the pedagogy better.

During the spring of 2017, feedback about the Three Sessions Training was collected. 235 teachers from pre-school to junior high school teachers answered the survey. The survey was conducted to further develop the training methods. The teachers answered questions in 1-5 scale (1 being the worst and 5 the best). The results are shown in Table 2.

TABLE 2. TEACHERS' OPINIONS ABOUT THE THREE SESSIONS TRAINING AND VILLE (N = 235)

Question	N	Mean	Std. dev.
I can recommend this traning for other teachers	215	4.8	0.39
The training gave me proper skills to use ICT in teaching	215	4.4	0.65
Evaluate how well this traninig model meets your needs	215	4.4	0.66
Evaluate how well ViLLE works from technical point of view	212	4.4	0.59
Evaluate how good ViLLEs content is pedagogically	212	4.2	0.59

The quantitative results from the survey are very positive. In general, the teachers were satisfied of the training, and the training model, and it seemed to meet their expectations. Teachers were also very satisfied in ViLLE from technical and pedagogical point of view. Moreover, the answers to the open questions were quite interesting. Next, we will give some examples of the feedback translated from Finnish. A total of 99 explanations were given for the answers.

Very good training. Content was presented in clear manner. The training made me use my skills immediately, which made adaptation much easier. I am certain that I will continue use the system… …Excellent material for teaching - 1st grade teacher

I am very satisfied with this training and I got many new ideas how to use ICT in my teaching. - Junior high school mathematics teacher

Good and efficient package. Helpful and encouraging training. More content like this! - 3rd grade teacher

In many positive feedbacks teachers gave thanks for practical training and well thought content that can be adapted easily in the classroom.

Additionally, some critique and ideas on how to improve the training, the content, or the system from a technical point of view were given:

There could be more training on creating own exercises, but I think there is a separate training for that. - Junior high school mathematics teacher

Student differentiation could be easier. I don't know how. - Special education teacher

The system still needs developing but is very promising. Students seem to like it. I would still like to see more content especially in junior high school mathematics. - Junior high school mathematics teacher

There wasn't enough content to justify 70km trip three times. Otherwise training was excellent and students in my school seem very enthusiastic. - Junior high school teacher

In general most of the feedback was still positive. The trainers have heard quite often that the training and ViLLE system are just the kind of technological pedagogy they have been waiting for schools. In addition to mostly positive feedback, the improvement ideas show that teachers are critical and willing to participate in development of educational tools.

Online training is the easiest possibility for individual teachers. Although there is no formally collected data, informal direct feedback during or after webinar sessions or through mentor teachers in schools is collected by the trainers. For average teacher, following an online training is not fluent. Asking questions is more difficult than in person, and there is pressure not to slow down other participants. More advanced teachers enjoy the freedom and appreciate the possibility to join in the training at home or school. For future development, the webinar could maybe be divided into smaller chunks and enable teachers to have ViLLE-lessons between sessions.

V. DISCUSSION

In this article, we tried to answer the two research questions. The first question was about *how to collect data from every day school life*? Instead of creating a system that is just an electronic data collection tool, we need to build tools for teacher. If the system is obviously meant for data collection only, it is basically just like a traditional national test but in digital format. However, if the system is used actively in teaching, the data collection can be done additionally. It also means, that the results are based on actual school work and not on data recorded on single day and with a specific setup. This wat, we measure the things we are actually teaching.

However, we need to get the teachers to use the system in order to have valid data. This can be achieved by developing the system together with teachers. There needs to be a system that provides clear advantages for the teacher without increasing the daily workload. It is important that the teachers can benefit from the provided learning analytics and statistics in their work so it is not just for administrators. To ensure that the system is used by teachers, we need to provide sufficient support for teachers. This is a combination of proper training, available support and building a network of local experts in schools. We need to build an ecosystem that teachers do not *have to use* but instead they *choose to use it.*

To answer the second question, *how to use the collected data to improve learning*, we need to consider also the practical aspects. Learning analytics is only valuable if it leads to change. If we use a well-tailored learning environment as a part of education and also use the same system to collect data for analytics, it is possible to adapt the material used in schools. For example in Finnish national test, it was found out that students have difficulties in mental arithmetic and fractions. We increased the number of exercises in those domains in learning path for mathematics. How is the rest of the field adapting to these results? We can only hope publishers read the same articles and maybe they will adapt their material in their next exercise book edition. It takes even longer to make the needed adjustments in to national curricula.

National tests are very common in many countries. However, we still haven't seen a system capable of real time analytics on learning. Best results on learning will probably be achieved by combining automatic data collection and analysis to traditional methods. This also enables validation of data and results the two methods.

VI. CONCLUSION AND FUTURE WORK

To enable a large scale educational data collection and meaningful and useful learning analytics, it is essential to provide both, useful tools and pedagogical training for teachers to utilize the tools successfully in their everyday school life. In this article we presented a framework for training teachers to utilize educational technology and learning analytics to teach mathematics and Finnish language easily in elementary school level. The results show, that the teachers have happily adapted the tool into their teaching and have been utilizing it later on. In the future, we plan to provide more comprehensive analysis of teachers and students using the tool, and provide changes into the tool and the training methodologies based on the feedback and other results.

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Adjusting university education with workspace training and self-education

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***Abstract* – Close to 100% employment of students and easy access to abundance of information on Internet has essentially changed student's learning practices and their earlier knowledge background, especially on rapidly progressing field of Software Engineering. On workplace they have to use technologies, which are used in practice of their employing enterprise, but often do not understand the scientific and/or technological principles on which these technologies are based. They seek explanations on Internet, but information on Internet is often low quality, one-sided and presented with business targets on mind - to get more users to technologies developed and sold by a business enterprise. Thus university has to explain basic principles of technologies what students already know and have used and correct some popular beliefs, which are supported by software vendors and based their business interests. Non-formal sources of knowledge – workplace training and Internet – do not reduce teacher's task, but force teachers constantly study all new which appears in this field, thus increase teachers workload. Students increasing use of non-formal sources of knowledge imply need for flipping the process – instead of teaching students are set to learn from provided detailed tutorials. Use of Internet and work has made self-study, seeking information from Internet sources very customary for current students, thus such flipping worked very well in a game programming course provided by the first author.**

Keywords – univwersity education; working students; Internet; SE, IT, JavaScript, HTML5, CSS, game programming

I. Introduction

A course is interaction of teacher with students. To implement an effective course teachers should constantly consider who our students are, taking into account their prior knowledge and practices.

Employment of students already during university study time is increasing; e.g. in Estonia more than 75% of students are working [1], [2]. On Software Education (SE) and Information and Communication Technology (ICT) specialties the rate is close to 100% both in Estonia and in Finland.

Less than half of working students had entered the labor market because of economic reasons [3], most of them wanted to get work experience and work in their professional field, thus their work significantly enriches their professional knowledge. Student's employment is a sign of their ambitions and a test of their capabilities, thus their attitude to their work is very intense and emerging, they always try to make perform and deliver [4].

II. New Formats of Education

Enterprises growing need for highly educated workforce and rapid appearance of all kind of education/knowledge sources in Internet together with difficulties in universities caused by reductions of government financing are increasing pressure for constant reshaping of education and have created for traditional formal university educations strong competition in various forms of non-formal education, especially in most dynamic fields of SE and more generally, in whole ICT.

Modern enterprises use complicated high-level technologies and procedures which often are not available in universities. Thus enterprises complain, that traditional university and technical education does not provide for them the kind of workforce what they need. This has created in many countries a push for returning to historically long-forgotten training-education format – apprenticeship. Success of the apprenticeship system in Germany [5], where more than half of the country's young people enter vocational training programs instead of university has made it attractive in many countries: in USA [6], in EU [7], in UK [8] etc.

For learning programming have recently become popular another non-formal mode of education - programming bootcamps.

Figure 1. Worldwide rise of interest in programming bootcamos in 2011..2018 (Google trends)

Programming bootcamps appeared first in North-America, USA and Canada. Free summer camps for introducing teens to programming and robots have been organized e.g. in Estonia [9],[10] and in Finland [11] for several years, but currently introduced in Europe [12] have become a serious business activity. The main target

are adults who have decided to learn new skills or even change their profession, thus they are mostly for money, typical cost being 4500..10000 € (some are free). They are very intensive 6..16 weeks highly immersive courses on most popular SE areas: JavaScript, HTML and CSS, intended to give students skills which are the necessary to transition into the field of browser-based communication.

Another rapidly growing source of non-formal learning is Internet. Many CE and ICT students already consider Internet already as the most valuable resource of knowledge. Apart from numerous MOOC (Massive Open On-line Courses) - Coursera, edX, FUN, FutureLearn, Miríada X, OpenClassrooms etc. quite effective resources are also YouTube videos [13], tutorials on Facebook [14] and in many smaller sites. There are many sites which act like teachers – you can ask or just read, e.g. only stackoverflow.com [15] hosts (at the moment of writing this) 221353 experts/teachers and over 50 million users visit the site monthly to learn or share their knowledge.

In SE the most dynamic area is front-end development, creating web pages and applications – technologies, based on HTML5, CSS and JavaScript. This area of SE was also the basis for first author's course "Browser Games and Programming of Virtual Worlds".

Course participants had very different start level – some worked as web developers, some – as Java programmers or database developers, but for several the HTML, JavaScript and CSS were totally new areas. The differences in preliminary knowledge and (for some working students) habitual technologies not suitable for creating games appeared during the course very clearly and forced search for new, different teaching and material presentation methods.

III. Differences of education formats

Universities and enterprises have different (sometimes diametrically) understanding of education - what youth should get. Universities want to produce educated members of society having wide basic knowledge in different fields of knowledge, also on very theoretical subjects - a well-educated man should have (basic) understanding of everything. Enterprises need workers, who have needed in production process skills and are not interested in providing deep theoretical explanations; enterprises want specialists, who know well a narrow field - like workers in Ford assembling line, whose task is produce just one movement, they “know ‘everything about nothing”.

Different goals create also different education/training styles practiced in teaching programming in universities and in enterprise/apprenticeship training and commercial programming bootcamps.

The classical style used in schools and universities is 'bottom-up' – a course starts some simple program (e.g. classical "Hello World"-program), which is then step-by-step made more complex, e.g. made interactive allowing user to enter their own name, so that program (for student called John) already produces "Hello, John!". When student already understands, what is happening, are added loops (program outputs "Hello, John" ten times), some *if-then*, *if-the-else*, do_while, do_until etc.

In business enterprises instead of teaching programming is considered 'software product development'. This follows the main industrial production practices and is 'top-down'.

A software product production begins with creating a project using some project management system: Eclipse, Microsoft's Visual Studio, Android studio, node.js or some other high-level environment. These are rather big and thus also complex systems (e.g. Android studio - > 1.2 GB, 11326 files) and their projects are also big, e.g. the size of simple user's registration example project in Android studio is 16.3 MB and it contains 1643 files in 411 folders – a mess, difficult to understand, especially for students. This is clearly a technology for software developers with years-long experience.

Learning from Internet is mostly 'from the middle' – from Internet one searches answers to all problems weather from top, bottom or middle. Use of Internet sources presumes, that learner itself is active leader of the learning process – in lecture hall and sometimes also in workplace training this is not always so.

IV. 'Fake news' and cancer tumors in software development

The main task for participants of the course was to develop and implement their own, original browser-based game (it was allowed to use also some other game-programming platform, e.g. Unity); the game should allow easy creation of mobile version. This made the task rather different from creating popular web applications – business web-sites, e-shops etc. A browser game should load quickly and work without interruptions, thus all its resources (scripts, images, sounds) should be minimized, loaded before the game starts and anything what could be removed should be removed.

Thus in browser game development should be avoided tremendous apparatus of project management systems, JavaScript libraries and packages – game programming begins from bottom and is directed 'bottom-up'. Browser executes web pages in an isolated sandbox. It can exchange information with the server from which it was loaded, but during play these exchanges are not desirable, they may make game slow and in mobile – increase players mobile bill.

For students who had previously created web applications in 'top-down' style - using project managers, version control, many external libraries and frameworks the 'bottom-up' and minimization requirements of games introduced totally new approach to application development.

Their confusion has deep roots in current situation in history of web programming, which is often called front-end development.

V. 'TOP-DOWN' TECHNOLOGY IN WEB PROGRAMMING

Overwhelmingly used in commercial web production 'top-down' technology has currently developed into complex area of competing ideas - in SE competition is strong and growing. Every software house or often even a single developer want to author some program, package, framework what hopefully becomes widely used – at first free and when it gets already some users appears a paid 'pro' version and then hopefully some money could be earned with Google AdWords [16], i.e. from advertisers.

In order to give developers programming tool which enables creation of interactive web pages was in 1995 for famous Netscape browser [17] introduced a scripting language - JavaScript. Microsoft introduced for their Internet Explorer browser year later something similar - VBScript and Jscript. Although Jscript was reverse-engineered from JavaScript, it was/is (Microsoft is still using it) in details different. The API (Application Programming Interface) for handling HTML and CSS was also different thus it was quite difficult to create an interactive webpage which worked well in both browsers – Netscape and Internet Explorer. Therefore John Resig introduced in 2006 a JavaScript library jQuery [18] – which programmatically created a 'common ground' – an API which web developers could use without thinking about browser differences.

JQuery is based on browsers 'native' API and JavaScript, it is just a layer of code above them - browsers are not allowed to access anything in the local computer. Since Microsoft browsers for quite a long time ignored standards for HTML, JavaScript and CSS was jQuery quite useful and many developers use it.

The current Microsoft browsers – Internet Explorer 11 and Edge – are already 'law-obedient', compliant with the HTML standards which define the web – the HTML5 test site [19] indicates, that Edge passes 476 tests from the set of 555 tests (Firefox – 486, Opera – 518, Chrome – 528). Thus jQuery has become obsolete, it is just a thick layer (the latest version 3.3.1 - 10364 lines) of code which creates over native JavaScript new layer of objects with different syntax, thus provides more possibilities for errors and makes finding errors more difficult. There are many examples showing that in current browsers accessing native JavaScript and API is simpler and quicker [20], [21], [22] etc.

But jQuery started a trend and in the same vein appeared on the base of originally very simple JavaScript myriad of other libraries – according to [23] there are (at least) 1237 of them.

Old habits die hard – the punch-card-era relict Cobol is still present (on position 41) in the IEEE Spectrum interactive ranking of programming languages [24].

The same way many developers still believe that '*jQuery is protecting us from a great demon of browser incompatibility*' [21]. Thus Microsoft's long-time non-compliance with standards has created tumor in the web development - jQuery has created a myriad related to it libraries. From the 1237 libraries in the list [23] 489 libraries (40%) are somehow related to jQuery. Many of them are simple copy-paste compilations from other similar libraries, but in this field plagiarism is not yet considered.

VI. PROGRAMMING WITH PACKAGES

Many of libraries have dependencies, i.e. use other ones. In order to use these libraries they should be linked, not downloaded and included – they are still under development and may change, there will be bugs, they may be improved (become quicker, use less memory) etc. Thus there appeared a format to present them as packages.

Many html-pages and their components (scripts, stylesheets) depend on other resources (images, stylesheets, other packages), e.g. the lodash [25] library presents 59932 dependents. In order to manage all these files – ensure, that everything gets loaded and everything is updated when needed were introduced package managers. With node.js [26] appeared at the end of 2009 also npm (Node Package Manager), which collects all dependent resources and builds from them one file which is easier to manage. This currently most popular package management tool boasts, that its registry hosts almost half a million packages [**Error! Bookmark not defined.**].

Very soon appeared also other higher-level bundling tools Webpack [27], Browserify [28], Bower [29], jspm [30], duo [31] etc.

Programming with packages become the major programming style, currently (appeared in less than ten years) there are (at least) 433 package managers [32]; npm is still overwhelmingly best known and biggest.

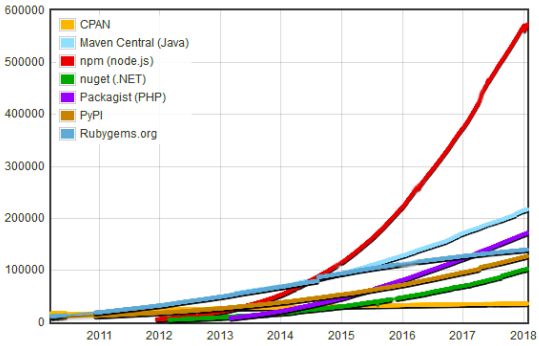

Figure 2. Number of packages in some package repositories (graph from [32])

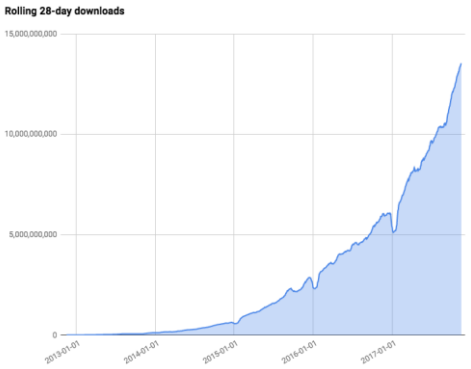

Figure 3. Package downloads in the npm Registry in last five years (graph from [33])

This is not programming in classical sense - creating a program from programming language's commands. This is metaprogramming, creating a program not from commands but from pre-programmed libraries; coding has become "*stringing together APIs*" [34]. This is a top-down activity: instead of actions for solving the task (program commands) is first created a (thick) layer of code needed only for organization of libraries and packages containing the actual task-solving code. The whole process of creating a solution to some programming problem (creating a software product) begins with piling together packages and libraries, often 'just for case'. This is like building a house starting with roof.

Usually developer does not yet know all the details of the problem - a typical situation in top-down approach. Thus libraries/packages are added by 'we always use this'-philosophy. This creates lot of overlap and quite often are included libraries/packages which actually are not needed. This happened also in some student's projects presented in the course.

Students are always eager to try something new, different. Thus in the games presented by students also appeared some of these 1237 libraries and half a million packages - something, what was not considered in the course. Nonet of them were needed and several even not used at all.

And it is rather probable, that working and web-searching students discovered a different libraries/packages. Most probably there will be errors what teacher should (at least try to) correct and also explain, how it would be possible to avoid these libraries and packages altogether – the game would download and run quicker. Thus teacher should also learn (at least something) about those libraries and packages. Students are (very) eager to try new software (which is advertised on the software's website as 'the best!'), but mostly do not understand the limitations and sometimes also errors/mistakes contained in this software, useless functions etc. Software contains always errors and the task of discovering these errors remains to teacher. So teachers should study those 1237 libraries and half a million packages. And their number grows very fast, new ones appear constantly.

VII. CURRENT FRON-END DEVELOPING REVOLUTION

Computers are less than 100 years old, but the computer technology has witnessed several revolutions.

The first computers were intended purely for calculations. Calculations on lowest level, in processor, are nearly incomprehensible for ordinary humans, since they deal directly with memory locations, see e.g. the code example from e-mail from Linus Thorvalds [35]:

```
.LFB2408:
        .loc 2 6487 0
        .cfi_startproc
.LVL1355:
        pushq   %rbp    #
...
```

The first revolution – Fortran, Lisp, Cobol and other high-level languages – hide references to memory locations and made program code similar to language of mathematics, where we deal with variables and do not consider where these variables are stored – in computer memory, written on paper, on blackboard or only in our heads.

The next revolution was Internet – computer screen become the main medium for communicating with humans. The main task of programming become just communication; calculations become far less important. For instance, when comparing programming languages the first task to consider is the famous program 'Hello Word!". But this is not any more a calculation, this is a message, communication.

Humans want their messages to appear pretty, with nice formatting, thus to the Internet language HTML was added a component for formatting HTML-page's content on screen – the CSS (Cascading Style Sheets).

CSS was not invented on empty place – CSS is based on SGML (Standard Generalized Markup Language), a mark-up language enabling authoring and sharing large machine-readable structured documents. CSS was originally very simple and natural format to describe formatting of web pages. But innovators claimed that "CSS is primitive and incomplete" [36] and introduced layers of code reorganizing use of CSS features. Thus appeared numerous extensions - Sass (Syntactically Awesome Style Sheets) [37], LESS [38], Stylus [39], Handlebars templates [40] etc. which introduced variables, nested rules, mixins (patterns of property value pairs), inheritance, allowed to omit braces and semicolons in CSS rules and other goodies. Sass was extended with scripting language SassScript and the CSS authoring framework Compass [41] was introduced. Now for writing CSS style rules become needed two interdependent frameworks, compiler for the Ruby language and several Ruby Gems to output CSS – a browser still accepts only CSS (currently version CSS3).

The original design of HTML and CSS languages introduced actually a programming language - a web-page (HTM+CSS, later also JavaScript scrips) is a code for browser to interpret on screen. For beginner this code is not very easy to understand, e.g. the very first programming exercise, the "Hello World" page in HTML looks like this:

```
<!DOCTYPE html>
   <html lang="en">
     <head>
       <meta charset="utf-8">
       <title>Hello World!</title>
     </head>
   <body>
     <div id="root">
       <h1>Hello World</h1>
     </div>
   </body>
</html>
```

The HTML code is not very similar to ordinary human language and not very easy to understand. Only when browser has interpreted this will we see on screen

Hello World!

But most of webpages are much more complex - highly decorative (lot of 'visual sugar'), containing lot of colors, sounds, images, videos. They are not only interactive, but have already some intelligence - ask us something e.g. indicate, that we should register and remember our answers. User's answers/selections are processed using several databases and inference logic and then user gets decorated, nicely formatted answers suggesting what we should buy, what to do next etc. Webpages already communicate with us. Google search understands (somewhat) natural language and googling produces better results if query is given as a natural language question and not just some keywords (but in answers the Google-owned YouTube videos will be shown first – business is business...).

For (mass) production of such interactive/intelligent webpages/sites have been developed several formal models and programming frameworks. The best known and used most often is the MVC (Model-View-Control) metaphor. Model – this is the database of knowledge, View – the input-output interface, Controller – the inference engine, which searches databases and creates response to user input. This is a (rudimentary) intelligence – structure of a system which uses stored in its memory data to response to user input.

Thus web-pages – HTML+CSS+Javascript are already quite complex, but developers want them to be easy to create (or even to generate), understand and maintain. All these thousands of libraries, packages and frameworks follow just this goal. The current proliferation of libraries, packages and frameworks is the next computer technology revolution aimed to create human-computer communication medium, which is aimed for encoding and presenting information in form, what is for humans easy to understand and pretty – this makes it also easy to comprehend.

All libraries and packages compete in achieving this goal. Currently we do not yet have a clear winner – it takes time for situation to stabilize. And it may well happen, that stabilization can take quite a time because of different interests of very many players – by estimation [42] in 2017 there were 22 million developers worldwide, but the number could be 26 million by 2022. For comparison – programming languages have been developed ca 79 years, according to [43] in the first 50 years (by 2001) there were developed 2300 languages and some of the very first ones (Fortran, Cobol) are still very alive, thus it may take quite a time for the front-end development tools to settle.

In the following is the above 'Hello World' program in one of currently most popular frameworks React, which is maintained and pushed forward by Facebook:

```
ReactDOM.render(
  <h1>Hello, world!</h1>,
  document.getElementById('root')
);
```

This is a script in React's JSX language – a preprocessor step adding XML syntax to JavaScript. It should have attribute `type="text/babel"`; the Babel transpiler converts it to JavaScript which is then executed by React engines, thus in the HTML document head should be loaded three other scrips, together nearly 2 MB:

```
<script src="js/react.js"></script>
<script src="js/react-dom.js"></script>
<script src="js/babel.min.js"></script>
```

Thus to understand what is going on here one should learn JSX, Babel, React (Virtual) DOM, ES6, npm etc.

Exactly the same result could be achieved with just one line of native JavaScript without 2MB burden:

```
document.getElementById("root")
.innerHTML="<h1>Hello, world!</h1>"
```

But it is difficult to explain to student, that the simplest way is the best for them.

And besides React there remain other 1236 libraries and half a million npm packages.

Libraries, packages and frameworks are upper level of software mass production practice, a level for professionals who know and understand well, what happens below, on lower levels. React “elements” used in JSX are building blocks of a new kind of computer-human communication language, words in this language. Proliferation of different languages and frameworks show, that many people have recognized need for a new, higher-level computer-human communication format. Unfortunately by now we have not yet agreed, what should be essential features of this new format. The most useful formats are extensively downloaded and tested, but there is no convergence yet.

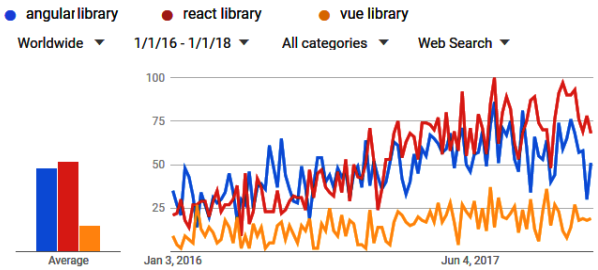

Figure 4. Use of the three most popular libraries in last two years

All these new formats are intended for mass production (often generation) of web pages and sites. But games are not mass products, every game is an individual art product and the 'top-down' mass production methods are here not applicable.

Students love games; games are for them essential part of their cultural intake. In the first task of this course - assessment of a game – on participant (young lady) complained – "The only problem with my game was that it was too short – I finished it already in ten hours!" Thus they were interested in course topic, in one previous game-programming course one participant stated: "Programming games is even better than playing them!"

VIII. ADJUSTING DIFFERENT KNOWLEDGE LEVEL IN A GAME PROGRAMMING COURSE

Programming is an ability to foresee what happens when the program is executed.

Early participation in commercial software production, acquiring technologies aimed to produce a product – web-page, e-shop interface – has made for many students habitual the top-town programming approach even if they do not know, what happens inside of these high-level tools what they use. Thus they actually do not know how to program, they just pile together frameworks and packages. They still have to learn to program either in university or themselves, seeking resources from Internet.

But early participation in work and active use of Internet has also changed student's learning habits and attitudes. From passive listeners and note-takers in lecture halls they have become active seekers of new knowledge, their learning is very intense. Internet and other non-formal sources have already become the biggest source of programming education and its importance in providing programming wisdom is growing rapidly. In survey made by the world's programmer community site Stack Overflow in 2017 [44] said 90% of programmers that they are at least partially self-taught; a year earlier this percentage was only 69% [45],[46]. How many years it will take (3..5 ?) when the word 'partially' will disappear from the above statements?

Even in computer class, instead of asking teacher they prefer to seek answers from Internet themselves. They also always immediately test these answers – they know already, that with frantic temp of development of SE technology many answers provided on Internet are already old-dated ('fake news')..

Their activity somewhat reduces the teacher's task, e.g. it is not needed to explain syntax. Modern browsers (Firefox, Chrome, IE 11, Edge) all have quite decent Developer Tools, which allows to follow execution and shows errors; they also have console, from where programmer can experiment with code. This allows student's to solve all problems with syntax themselves. Use of Developer Tools makes apparent also another big disadvantage of libraries and packets – these libraries often do not convey error messages or if they do, it is difficult to find from where it originated – there is thick layer of code above the native JavaScript objects.

Instead of problems with syntax students had many problems on upper level, considering program structuring and use of different technologies, especially those who had previous 'libraries-gluing' experience.

Games (especially browser games) require some specific methods of code organization:

For fluid gameplay everything should be downloaded before game is started. JavaScript is a single-threaded language, i.e. everything is executed in order it is written, but Internet operations are asynchronous – browser cannot know, when something arrives what it has requested from server (and browser has to create a request for any single item not contained in the page-s HTML-file, but only linked). Thus developer should know and understand the events and callback arguments (in recent update to ES6 – promises).

Game developer should always consider speed burden imposed in interactions with hard disk memory or server, even garbage collection. At the play time objects should not be deleted or new ones created– these operations arise communication with Operating System (OS) or automatically evoke JavaScript garbage collection – both may bog down gameplay. Thus game programmer should also understand object pooling [47] and cashing [48] and many other programming patterns [49], which are not considered in libraries-gluing development culture.

Very important is some knowledge of handling images. Games are visual media and browsers expose four different rendering interfaces: the text-oriented HTML (with inserted sounds, images, video), pixel graphics based canvas 2D rendering, WebGL 3D rendering and SVG-based vector graphics rendering; CSS3 also presents many possibilities for presenting and transforming graphics – when to use what? In previous year we did some exercises where several of these technologies where involved [50] and results showed, that proper code organization can create essential benefits in speed.

The organization of the course was an attempt to adjust to these changes in heterogeneous student population, taking into account also their already strongly rooted habits in learning.

We can learn a new piece of knowledge only if it is on right level, we can tie it with what we already know, but it still contains also something new and surprising. For teacher message, in order to 'get there' it should be on right level: if it is on too low level, does not contain anything new, student gets bored; if it is on too high level, student does not understand anything and also loses interest. It is nearly impossible to prepare interesting lecture for heterogeneous audience with very different previous knowledge, and the course population was just such.

Therefore the process was flipped and big part of active lecturing was replaced with students self-learning – instead of teaching students were provided possibility to learn.

The lectures and exercises were joined to one rather long (180 min) session in computer class (at the evening: 17.45-20.45), where every student was working with his own computer (many preferred their own laptops); all computers (also student laptops) had Internet access.

Programming, i.e. SE is a technology. Learning a technology is always based on practicing, thus class sessions were based on studying example games; the non-technological issues (economy of games, gaming events, gamers demography etc.) were briefly covered in class, but mostly left for participants to investigate themselves from links to webpages on course homepage.

Those examples were presented as tutorials with fully working program code plus detailed comments on essential issues in code. These covered the main data structures used in game programming – sprite sheets, AABB – Axis-Aligned Bounding Box, bounding circles

and main functions: object animation, collision detection, physics (we used the Box2D.js library [51]), creating 3D objects and sandbox environments (using the three.js library [52]). Games were designed from the very beginning with perspective to transform them to mobile; creating mobile games was covered using the Apache Cordova [53] library.

At the end of tutorials were questions, problems and suggestions for modifications and further improvements – those provided opportunity to work for more advanced students. At the beginning of class was presented short introduction (10..20 min) about main features of this lesson's game; after that all students started to study the tutorial and implement some of presented there modifications or invented their own modification – this covered the main time of the lecture/exercise combo, 120..150 min.

All students were absorbed in work and besides tutorials presented in course homepage their main tutor was Internet. They had (at least) three open windows in their desktop – the code (mostly Notepad++), the browser window for testing the code (often from several browsers – Chrome, Firefox – they show errors differently) and several browser windows for googling to get help from Internet. The (nearly) did not ask anything from teacher or from other students, but preferred googling – this has already become a deeply rooted habit.

We did not have breaks and several times the lesson was finished by cleaning woman – she had patiently waited behind the door for the lesson's official ending time, but when we continued (in nearly total silence!) she indicated, that the official time is over and she also wants to get home. Never did any student show signs of 'shorten attention span'.

As a result the 25 participants presented 20 fully working games; (at least) one mobile game (for Android phones) was already uploaded to Google Play [54].

Figure 5. Rotame – a mobile game developed by course participant; player has to keep with tilting the rotating figure on the edge.

IX. CONCLUSIONS

Teaching is a very challenging job; a lecture/exercise never come out exactly in the way they were planned.

This unpredictability in teacher's work is increasing: current students contingent is more and more heterogeneous concerning their earlier, basic knowledge, their interests and their practices in accessing non-formal educational sources, first of all Internet sources. This makes teaching more difficult, since teaching should always be interactive, based on student's already existing knowledge and interests.

The input to student's knowledge from non-formal sources, which are not in reach for teacher is constantly growing and difficulties are also growing. Importance of Internet as source of knowledge is increasing rapidly.

Teaching, especially in technology, is a race with development. We should know all the latest developments in rapidly changing technologies. We should be able (somewhat) even predict the future. Students are interested in future, future technologies and practices - their life will happen in the future. If they recognize, that a teacher is not on level even with the current technology, they are not interested in this teacher anymore. And this constantly increases teacher's workload.

The main goal of all what we do should be to increase our fellow citizen's emotional well-being – to make them happier. The main source of happiness is 'between your ears' – your self-consciousness, i.e. it is in your inputs and how you interpret your inputs.

Good, rare inputs are called art. Art is something, what is exceptionally good, better than 99,99% of other products in the field.

Producing good software is an art. Computer games (good ones) are even more so [55] and they make humans happy [56].[57].The Supreme Court of USA ruled already in 2012 that video games are art [58] and in 2016 video games even got (finally!) their own World Video Game Hall of Fame [59].

But delivering good teaching is much more an art. Especially teaching youth to become game programmers.

"We learn through experience and experiencing, and no one teaches anyone anything. This is as true for the infant moving from kicking to crawling to walking as it is for the scientist with his equations. If the environment permits it, anyone can learn whatever he chooses to learn; and if the individual permits it, the environment will teach him everything it has to teach."

Viola Spolin [60]

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Ethical Background of Using Modern Internet Technologies as a Medium for Communication in the Educational System in Macedonia

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***Abstract* - It is very easy to dismiss the modern Internet technologies systems as an obsession of the young generation, but, by doing so it minimizes one of the fastest growing trends in technology. These technologies are offering tools that become a way through which schools or businesses quickly and efficiently share information. Due to the almost universal approach of those, especially social media systems, to all demographic groups, most often touch people with whom traditional forms of communication fail. Initially starting with the generation in which the verbal communication was in the first place, through the generation that always inserts new ways of communication, up to the latest generation that lives with the development of technology and modern ways of communication. The aim of this paper is to analyze how different generations in the school environment coexist through the communication offered by social media and modern technologies which is a complex issue that can provide an answer in many areas of interpersonal relationships in the observed region. The results of this case study pointed on many positive and negative aspects of application of the social media in educational system in Macedonia, taking care of its ethical background. The result showed that by using modern Internet technologies has increased the frequency and quality of cooperation among students and teachers.**

Keywords – social media; internet technologies; education; communication; ethics

I. INTRODUCTION

The presence of schools on the Internet has exceeded the school website. Now it includes a Facebook page (www.facebook.com), blogs by teachers and authorities, a Twitter Account (www.twitter.com), as well as YouTube (www.youtube.com) and Flickr (www.flickr.com) to share videos and pictures of events in the schools [1].

If we look at the data from Internet world statistics shown on Table 1, we can determine that in Macedonia with about 2 million inhabitants, about 1.5 million people have Internet access, which represents 72.2% of the population, and 1 million are users of Facebook or more precisely 48% of the population [2].

According to the strategic plan of the Ministry of Education and Science 2015-2017, the Priority 3 aims on: "*Greater application of the achievements of the modern information and communication technologies for increasing the educational level, investing in education*" [3].

TABLE I. STATISTICS ON THE REPUBLIC OF MACEDONIA FOR INTERNET COVERAGE AND THE NUMBER OF USERS USING FACEBOOK

Macedonian (FYR)
MK - 2,083,308 population (2017) - Country Area: 25,433 sq km
Capital city: Skopje - population 480,116 (2007)
1,503,315 Internet users in June, 2017, 72.2% penetration, per IWS.
1,000,000 Facebook users on Jun 30/17, 48.0% penetration rate.
Local time and weather in Skopje, Republic of Macedonia

Moreover the objectives for Priority 3 are the following:

- Concepts for development of the education and science and for technological development; programs for development of scientific-research activity, for technological development, for technical culture and international scientific and technical cooperation; and measures to be taken in legal, institutional and financial sense for realization of the proposed concepts and programs;
- Creating conditions for the establishment of a national information system for education and scientific research;
- Establishing and developing an information and documentation system in the field of education, science, technological development and technical culture; full application of ICT in educational institutions.

In the last years, all of us either as citizens or as professionals of different fields are monitoring the rapid development of science and the advancement of new technologies. At the same time, we are witnessing that the world is facing new challenges and perception crisis. Lifestyle is changing gradually, conditioned by the use of current technologies.

Nevertheless, the ethics should not be neglected in any way, as a study of how to know what's right and what's wrong, and as a mechanism that need to be used conscientiously and continuously for maintaining the direction, stability and human society equilibrium. Beside

the advantages and benefits that the human society has from the Information Technologies (IT), there is always the possibility that the IT can be abused by various users. In this context the role and importance of ethics is undeniable. In particular, in advising and suggesting users to use the IT resources correctly and fair.

It is understandable that beside the integration trend of the modern information technologies in all areas of human activities, the process of education could not be avoided. In this context we can say that, in recent years the integration of technologies and computers in the educational process is increasingly becoming an integral part of the education system. This trend has begun to be extended to primary and secondary education, but currently it is more expressed at the university level.

This does not mean that learning in general, as a social process that is realized through communication between the learner, teacher and others, can be effectively replaced by technology. But instead, the technology can enhance the education process in many ways. Research, presentation, communication, collaboration, problem-solving and creativity, all are now under the influence of today's computers and other technologies that have become an important part of our daily lives. Therefore it is equally important to integrate the same technologies in the education process.

In recent years, ethics is accepted and treated very seriously in every modern society. This approach toward ethics has begun to affect community life, family life, human relationships, democracy, and in the broadest sense the education as well. This new field has also led to new university courses where curricula materials contain ethic based courses such as: professional ethics, social ethics, information technology ethics, public ethics, administrative ethics, business ethics, global ethics, ethics in religion, environmental ethics and journalism ethics. Moreover there are new research centers, professional organizations, and conferences where ethics related questions are discussed and taken into consideration by being opened to different points of view.

So ethics on the Internet should be treated quite seriously and should follow the current trend of human society development, because with the recent changes, the start of the new century represents a new page of history which does not accept the values and ethics of the previous century. As well as Huddleston notes: "*We cannot survive the 21st century with the ethics of the 20th century*" [4]. In this context, United Nations Educational, Scientific and Cultural Organization (UNESCO) may also contribute as an organization that supports global, scientific and cultural education of the human society. Also, the current motto of UNESCO published on its official web-site, "Building Peace in the Minds of people", among other things may be understood as a message of mutual respect among people while being on-line and as a message that does not recognize any crime, including the alleged computer crime.

Internet ethics represents one of the main concerns in the framework of the International Network of UNESCO Chair in Bioethics, which until now comprised of more than 100 units within the different countries around the world, located mainly in education and research institutions. Their activity is closely related to the use of modern technologies and also the promotion of ethical values in the usage of the same. The paper summarizes the findings in relation to the positive and negative aspects of the application of the Social Media in Education in Macedonia taking care about their ethic background.

II. METHODOLOGY

To determine the application of modern communication technologies in schools, (i) a student survey, (ii) a teacher survey, and (iii) research on trends in the world as well as in the Republic of Macedonia, with the greatest emphasis on social media, were applied. It will feature best practices and experiences on the use of social media according to world resources and statistics found on the Internet. The both surveys were conducted in the period of October 2017. This student survey consisted of _ questions, whereas the teacher surveys consisted of _ questions. Not all the survey results are presented in this paper, just are extracted the ones that are closely related to the objectives of this study. The teacher survey covered 105 teachers from secondary and primary schools in Macedonia in order to learn the attitudes of teachers in the application of communication tools in the education process. Also, the second survey includes the opinion of 78 students from secondary schools in order to see the students' attitude towards the application of ICT in teaching, with a focus on the communication among the stakeholders in the school. The teachers were surveyed with 8 questions and the students with 6, which are especially formulated for the needs of this study.

A. *Social media in education*

Social media is often seen as a key starter for communication and marketing. In the educational process, social media are tools that teachers can apply to make the classroom more motivating, relevant and culturally diverse. Nowadays, a growing number of schools and teachers apply social media in the classroom to engage students in the learning process altogether.

There are two main benefits from the use of social media in the classroom: the sense of community that develops among students and the ability of teachers and students to share information among them.

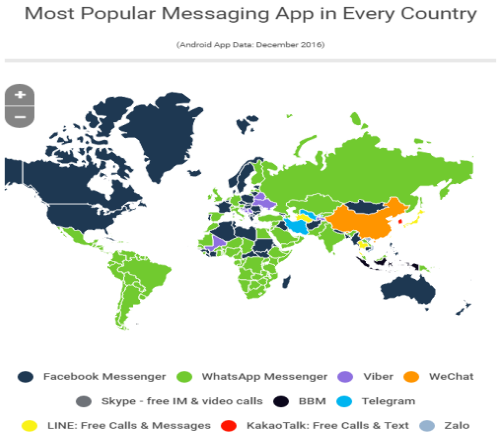

Figure 1. The most popular applications for communication in the world

Engaging students outside the school will increase the achievements and their presence in the learning process. In this way, students will understand the learning as more relevant and meaningful.

The survey of more than 1,000 teachers found that 47% of all K-12 teachers reported that participation in social media can help improve the education of students [5]. According to Fig. 1, people in the world mostly use Facebook or WhatsApp for communication. The list includes Viber, Skype, Telegram and others [6].

According to Alexa statistics, as shown on Table 2, among the most visited websites in Macedonia is Facebook, which points to the popularity of this social network [7].

TABLE II. MOST VISITED WEBSITES IN MACEDONIA BY ALEXA

Site	Daily Time on Site	Daily Page views per Visitor	% of Traffic From Search	Total Sites Linking In
Google.com	0.305556	7.93	0.045	3906801
Youtube.com	0.340972	4.68	0.157	2972831
Time.mk	0.311111	3	0.059	2726
Facebook.com	0.459722	4.21	0.082	7730654

As presented on Table 3, Facebook is considered as the most used social media in Macedonia according to statistics of Statsmonkey for the year 2015 [8].

TABLE III. STATISTICS ON THE USE OF SOCIAL MEDIA IN MACEDONIA FOR 2015

Rank	Macedonia	Social Network Usage	%Social Network Usage
1	Facebook	96.76	96.76
2	Twitter	1.21	1.21
3	Tumblr	0.78	0.78
4	Pinterest	0.44	0.44
5	Reddit	0.42	0.42
6	StumbleUpon	0.24	0.24
7	Google+	0.09	0.09
8	LinkedIn	0.04	0.04
9	YouTube	0.01	0.01

III. RESULTS OF THE SURVEYS

In relation to the surveyed teachers, to the question: "How often do you use Information and communication technology (ICT) in communication?", teachers said they use ICT every day for communication, mostly with colleagues, then with students and the least with parents (Fig. 2).

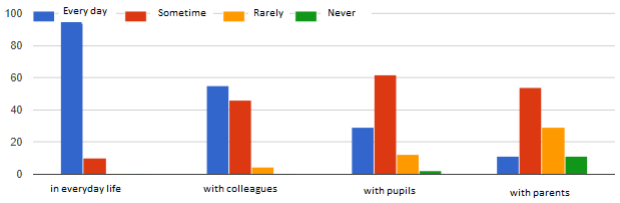

Figure 2. Teacher survey for use of ICT in communication in schools in Macedonia

On the other hand, students state they use ICT for communicating with their classmates on a daily basis, but "sometimes" and "rarely" with teachers (Fig. 3).

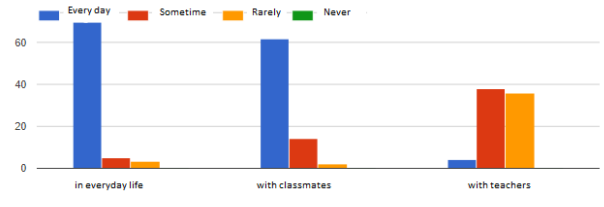

Figure 3. Student survey for use of ICT in communication in schools in Macedonia

These results indicate that the teachers are offering more information to the students than oposite, which leads them to the main iniciators for this kind of communication. So, both teachers and students use ICT for communication on a daily basis, but it is also necessary to increase the application to improve the communication between them. One way of doing this in the Learning Management System (LMS) usage inside schools.

Regarding the applications that are used both professionally and privately, teachers responded that 98.1% of them use Facebook, 88.6% Google, 82.9% Viber, 81.9% YouTube and 79% Messenger (Fig. 4).

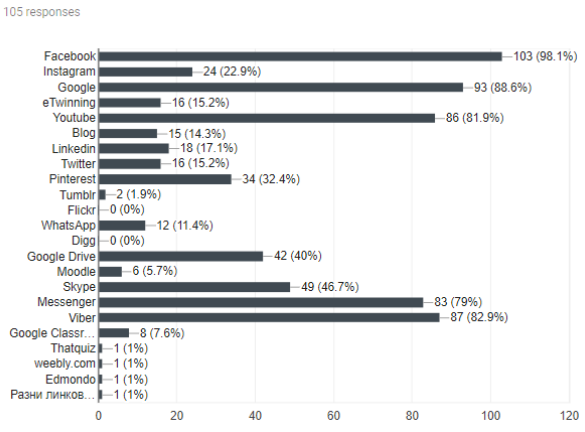

Figure 4. Teacher survey for Social network usage in Macedonia

The students reported that 96.2% of them apply Facebook, 91% Instagram, 89.7% of them use YouTube, Messenger and Viber, 88.5% Google, whereas over 70% of the surveyed students used Twitter, WhatsApp and Skype (Fig. 5).

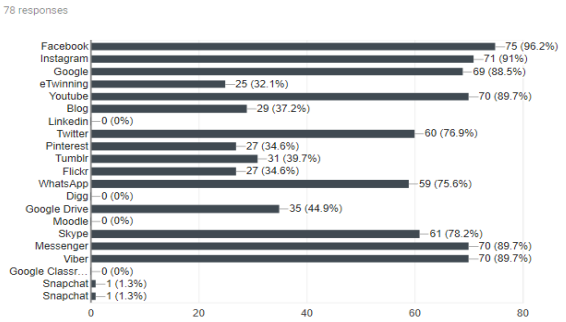

Figure 5. Student survey for Social network usage in Macedonia

From the data presented, it can be concluded that both teachers and students prefer Facebook, but students use a wider range of applications to meet different needs.

Teachers state that social networking, e-mail and communication tools are most commonly used to communicate with students (Fig. 6).

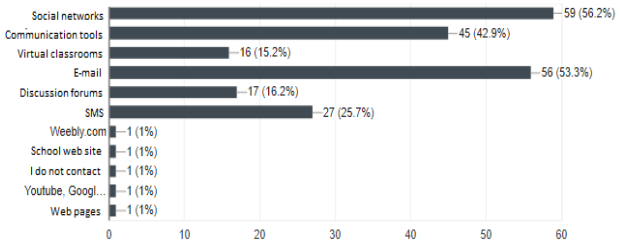

Figure 6. Teacher survey for ways of communication with students

The same statement is similarly confirmed by the students (Fig. 7).

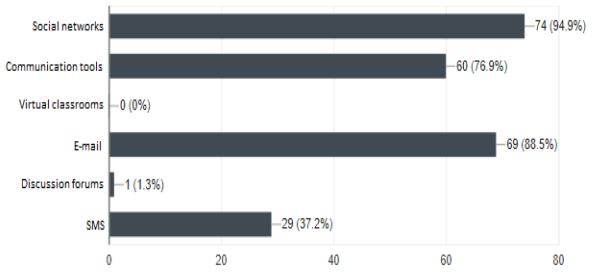

Figure 7. Student survey for ways of communication with teachers

On the one hand, it can be concluded that communication between students and teachers is realized mostly through Facebook, e-mail and communication tools. On the other hand, there is an opportunity for advancement because there are still many technologies that can be applied for communication, but their primary function is not intended for communication, and therefore are not accepted as a communication medium.

Teachers believe that the application of ICT facilitates communication in the school and it corresponds with the way the students function today. Due to the fact that information is quickly shared with the use of ICT tools, their application becomes the main competence of the modern teacher. Teachers consider that ICT tools enable better collaboration, but still question the fact that ICT is a motivation for students (Fig. 8).

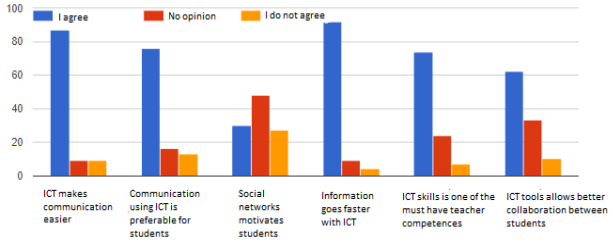

Figure 8. Teacher survey for ways to facilitate communication with students

Students generally agree that ICT facilitates school communication and information is quickly shared with the use of ICT tools. They also believe that ICT tools enable better collaboration and somewhat agree that ICT tools motivate them. Contrary to the teachers, they have no opinion on the statement that the ICT tools correspond to the way they are functioning nowadays and that the application of ICT should be one of the main competencies of the modern teacher (Fig. 9).

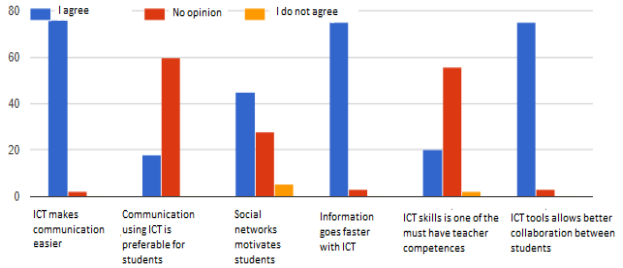

Figure 9. Student survey for ways to facilitate communication with teachers

It can be concluded that somewhat the views are the same, but what is crucial is that neither teachers nor students are sure that the application of ICT in teaching motivates them to achieve more.

As the most common problems in the application of ICT, teachers emphasize the lack of technology and the lack of culture in Internet communication (Fig. 10).

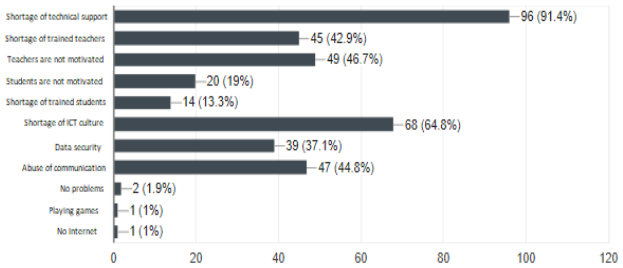

Figure 10. Teacher survey for common problems in the application of ICT in schools

The students emphasize that the greatest disadvantages in the application of ICT in communication are lack of technology, insufficient motivation of students and misuse of communication (Fig. 11).

One can conclude that the lack of technology is one of the biggest problems in the implementation of ICT in teaching as well as the ethics and culture of communication itself. In any case, students emphasize that they are not motivated enough.

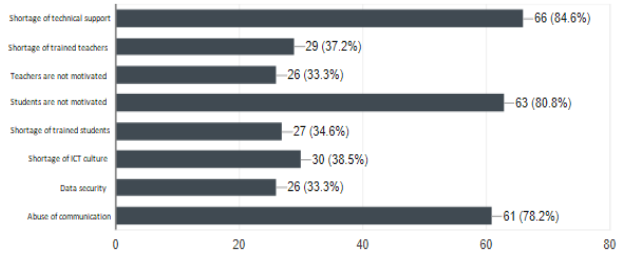

Figure 11. Student survey for common problems in the application of ICT in schools

Well-integrated use of technology resources by thoroughly teachers makes twenty-first-century learning possible and improves quite the quality of teaching. The teacher has a very important and undeniable role in education process. Therefore a construction of a model of communication through technology deserves to be considered as a important need for the educational process.

Moreover, according to the conducted research from surveys with students and teachers, the following can be determined:

- Teachers and students use ICT for communication on a daily basis, but it is also necessary to increase the application to improve the communication between them.
- Teachers and students prefer Facebook, but students use a wider range of applications to meet different needs.
- On the one hand, it can be concluded that communication between students and teachers is realized mostly through Facebook, e-mail and communication tools. On the other hand, there is an opportunity for advancement because there are still many technologies that can be applied for communication, but their primary function is not intended for communication, and therefore is not accepted as a communication medium.
- Neither teachers nor students are sure that the application of ICT in teaching motivates them to achieve more.
- The lack of technology is one of the biggest problems in the implementation of ICT in teaching as well as the ethics and culture of communication itself.

The world has never been more interconnected than it is today. For all of the advantages that this interconnectivity brings, there are also new threats that arise. One of these threats that have been taking over the news headlines and growing in size is cyber threats [9]. Due to its high benefits, combined with the easiness to conduct it, cybercrime has been on the rise in Macedonia since 2012. This forces Macedonian bodies to pay more attention on the strategies of prevention and working on the cybercrime legislation [10].

Based on the gethered results, it was also noted that students do not have Etchics in their curiculum. So, it is necessary to be implemented an ethical education for using modern technologies in education.

It should be stressed that beside the advantages and benefits that the human society has from the use of Information technology, there is always the possibility that the IT can be abused by various users. In this context the role and importance of ethics is undeniable. In particular, in advising and suggesting users to use correctly and fair the Information technology.

IT professional ethics is the one that should suggest the user how to operate in various situations, such as: cyberbullying, cyberstalking, encounters with sexual predators, privacy, anonymity, freedom of speech, intellectual property, etc. So there are a number of questions in quite different fields and many ethical dilemmas for which, the explanation is the IT ethics.

IV. CONCLUSION

Globally speaking, there are several positive and negative aspects of the application of modern information technologies as a medium for communication in the educational systems [11, 12, 13]. IT are used everywhere in world. Modern technologies are invaluable tools but they may have serious ethical consequences. The way an IT tool affects sensitive issues, including ethical asspects, has a direct impact on its effectiveness and usability. In relation to above mentioned and based on the performed surveys, following are stated the main findings of this study. First lets take a look on the negative aspects:

- Many students base their access to information on social media and the Internet in general, to find answers. This leads to a reduced focus on learning and finding out information.
- Students who apply multitasking, checking the social media pages while studying, show reduced academic performance.
- The more time students spend on social sites, the less time they spend in personal socialization. Due to lack of body language and other non-verbal communication, social media is not an adequate face-to-face communication.
- The popularity of social media, as well as the speed at which information is published, has created a loose attitude toward proper spelling and grammar. It reduces the ability of a student to write effectively without relying on a spell-checking feature on the computer.
- Anonymity and the extent to which private information is available online makes students forget about the need to filter the information they publish.

After summurizing the negative aspects, the following positive aspects were also determined:

- Social networking has increased the frequency and quality of cooperation among students. They show greater ability to communicate at meetings and share information very quickly, which can

increase productivity and help them learn how to work better in a team.

- Social networks teach students the skills that they will need to survive in the business world. The ability to create and maintain relationships with many people in many industries is an integral part of career development or the establishment of a business.
- By spending so much time working with new technologies, students develop greater familiarity with computers and other electronic devices. The increased focus on technology in education and business will help students build skills that will help them throughout their lives.
- The ease with which students can adjust their profiles makes them more aware of the basic aspects of design, which is often not studied in schools. Creating a résumé and personal web pages that are increasingly used as online portfolios, greatly benefit from the skills obtained by adjusting the layout and social network profile designs.
- The ability to get instant feedback from friends and family at their creative sites helps students to master and develop their artistic abilities. It can provide them with much-needed confidence or help them decide on their future career.

In addition to this, the application of suitable ethical tools is a prerequisite to consider significant aspects in all phases of IT systems development, implementation and use. Ethical tools are necessary not only to construct a modern IT system that avoids conflicts with significant moral principles but mainly to have a successful system that will play a significant role in satisfying the most important values of its users. The IT is used significantly, but the knowledge about the IT ethics are not enough. Large number of IT users with different knowledge on IT, need to be informed regularly about issues that deal with morality and ethical issues in order to follow the actual trend for advancement of IT without negative impact on the society. Probably there is a need for better supervision of juvenile on using the IT. Codes of ethics should be published in every working environment where the IT is used to remind users about freedom, rights and obligations on using IT.

It is understandable and worth mentioning that the results of this case study have a local character, because they were conducted only in Macedonia. Therefore, they cannot be generalized as a whole. But, they can remain as conclusions to be addressed, analyzed and can be further debated, compared and distinguished with other countries.

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Self Learning Trends in the Field of Introductory Programming

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***Abstract* - The changing nature of trends and technologies in computer science field is one of the things that make this field even more challenging. New developments may appear and attract learners, while older topics may have slighter importance from learners. Studying how trends evolve in Computer Science can be interesting from many perspectives. Furthermore, it can be used to craft learning paths. There are many ongoing studies that investigate the trends based on the research papers and publications in the field. In this paper, the trends are explored from the learners' perspective. Furthermore, since most of the learners today gain a good part of their skills and knowledge form the self learning online tutorials, in this paper the trends are analyzed based on the self learning tutorials and their statistics.**

Keywords – programming languages, trends in CS, self learning, tutorials

I. INTRODUCTION

Web 2.0 is shifting the way students learn. We live and learn in a time in which rising media and information revolution are redefining education, socialization, and access to social and intellectual capital. Individual learners, regardless if they are affiliated with a formal educational institution or not, are less dependent on an institution that provides information to the learner and keener to draw their own learning path from multiple sources. As a result of new media, the role of the teacher has changed considerably from one that is focused on the one-way transfer of information to one that trains students how to participate in digital environments with intelligence, skill, and literacy [4],[8].

The online learning tutorials are one of the most frequent means for both teachers and students to share and to gain new knowledge. One of the main advantages of these tutorials is self-paced learning. It can provide to a wide range of students the opportunity to extend their learning using an approach that allows each student to make progress at a pace that is appropriate with their previous knowledge. In addition to this they can always go back and explain the same point over and over again. In short, the students work at an individual student-centered tempo, rather than at a tempo set by others [7]. On the other side, studies conducted on e-learning research papers show that more and more authors and cases of enhancement of learning experiences are present [9].

Web 2.0, is usually referred to a variety of social networking platforms and media for collaborative content development, such as blogs, wikis, YouTube, Facebook and similar generally referred to as participatory culture [6]. The focus of this participatory culture shifts from individual expression to community involvement [5],[6].

YouTube provides a variety of possibilities for teaching and learning through video as a new moment on the concept of self-publishing, making content on hand for anyone who is interested in it. Furthermore, the social networking tools engage users by bringing them in to surroundings that encourage them to meet each other, read and share views, and become part of a learner community [10].

The role of YouTube in teaching and learning, include the practice of viewing videos and engaging with the content as constructive critics and creators, activities that enhance students' visual literacy - an significant skill in today's electronic culture [3],[11]. As a social-software application, YouTube is part of a trend among Net Generation students to substitute passive learning with active contribution, where everyone has a voice and anyone can contribute.

The aim of this study is to use this 'voice' to identify the trends in introductory programming languages. Actually, due to the exponential grows of technology, all HE institutions but in particular Computer Science departments are brought to a situation to rethink their curricula, with special focus given to redesigning the introductory programming course, which has a key role and wider impact in students' programming profile. An introductory programming course gives to the students the fundamentals of programming skills and knowledge which are later upgraded in following courses.

The complexity of teaching introductory programming is generally acknowledged among educators [2],[12], being listed as one of the seven challenges in Computer Science Education (CSE) [1]. One of the factors that influences the overall course achievement and learning how to program is the choice of the programming language as well [14]. In this regard, the objective of the research conducted is to identify tendency in terms of programming languages and their popularity based on the statistical data gathered from the online tutorials. In addition, this would contribute to the design of more contemporary syllabuses in the field of introductory programming. More precisely, the study presents the trend analysis of learning tutorials of the three most widely used

introductory programming languages: C++, Java and Python [13],[14].

The section II, presents the methodology applied for gathering the data on learning tutorials available on YouTube, while section III gives a detailed analysis on statistics, some of the metrics for these tutorials over the years and knowledge gained from the analyzed data. The last part presents the pedagogy, the trends in the programming online tutorials and the directions to which this environment might be shifting.

II. METHODOLOGY

The research presented in this paper includes investigation of the publicly available data for YouTube tutorials for three most used programming languages in introductory programming course: C++, Java, and Python.

For this purpose, the YouTube Application Programming Interface (API) is used:

- A search for a list of keywords (in this case the programming languages) is done, using YouTube web services.
- The callback for every single search is a list of attributes such as: title, published date, categoryID, videoID, channelID, tags, description etc.
- The search includes all the relevant tutorials for each keyword, returned by the YouTube API.

In this way we have created a database of 1770 unique entities, each of them representing a unique video tutorial about a particular programming language. We should emphasize that in this dataset are included also the tutorials presented in 2018, but they normally embrace only data for the first month of this year.

TABLE I. NUMBER OF TUTORIALS, VIEWS, LIKES AND COMMENTS FOR THE INITIAL DATASET

Progr. Language	Nr. of tutorials	Total number of views	Total number of likes	Total number of comments
C++	600	55193768	398055	71423
Java	591	98367483	624769	101571
Python	579	57315700	448425	54783
Total	1770	210876951	1471249	227777

III. ANALYSIS

In this section are presented the statistics, trends and knowledge gained from the analyzed YouTube data regarding the programming languages: C++, Java and Python.

More precisely, some of the metrics for these tutorials over the years were analyzed. Additionally, we have done the same analysis over a subset of the initial dataset, taking only those tutorials that have more than 30000 views (862 tutorials).

A. Overall number of tutorials and their distribution over years

Table I gives an illustration about the number of tutorials for each programming language for all gained data, together with the total number of views, likes and comments. As it can be noticed from this table, the first dataset gives almost an equal distribution of tutorials for all programming languages.

If the total number of views is compared, it can be noticed that the programming language Java has much higher number of views compared with the other two programming languages (Python and C++), which on the other side have approximately similar values for this metric. Consequently, total number of likes and comments is much higher for Java than for C++ and Python.

TABLE II. NUMBER OF TUTORIALS, VIEWS, LIKES AND COMMENTS FOR THE LIMITED DATASET

Progr. Language	Nr. of tutorials	Total number of views	Total number of likes	Total number of comments
C++	245	52111493	375168	66828
Java	354	96349345	609029	98419
Python	263	54503082	417689	49360
Total	862	202963920	1401886	214607

Table II gives the same metrics for the subset of those tutorials which have the predefined number of views.

Here, the number of tutorials is slightly higher for Java, compared to C++ and Python tutorials. Similarly to the initial dataset, here again Java has much higher number of views, likes and comments.

The above described and analyzed metrics give an illustration in absolute terms – they provide a picture of overall number of tutorials and their attributes for a period of 12 years. Despite this, we wanted to investigate how the tutorials publishing evolved through years. Fig. 1 and Fig.2 illustrate this evolution for the initial and limited subset, respectively.

From both figures, we can deduct that year 2013 has significant decrease in number of published tutorials, and year 2014 has the highest pick regarding this issue.

It can be also noticed that the first tutorials start to show in 2006 (one tutorial for Java), followed with only three tutorials in 2007 (two for C++ and one for Python). In 2008, most of the tutorials were for C++. This situation

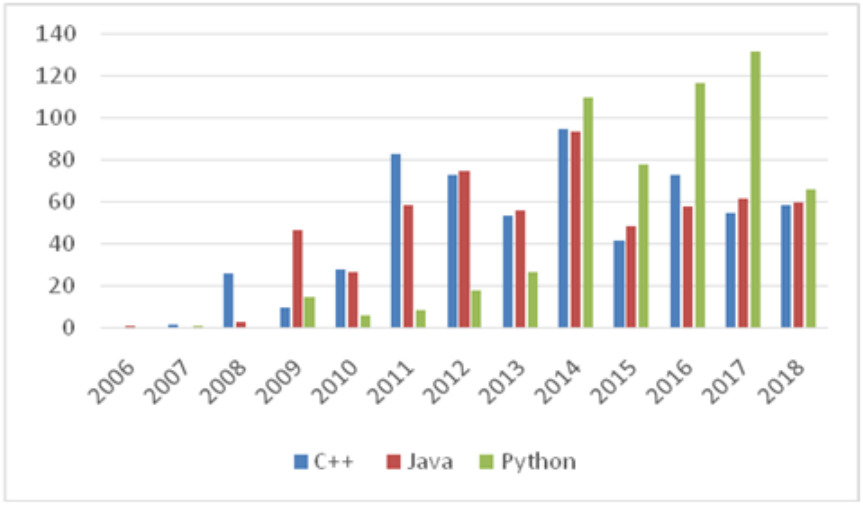

Figure 1. Number of tutorials over years for every programming language in the initial dataset

is repeated only in 2011, while in 2010 it has a slight difference with Java (Fig.1).

Starting from year 2012, C++ has continuous decreased number of newly published tutorials. Contrary to this, Python shows increased amount of new published tutorials year by year. Namely, starting from 2014 this programming language has the highest number of tutorials compared to Java and C++.

B. Increase ratio and weighted average of the tutorials

The investigation of the programming tutorials timeline for the chosen programming languages further on included increase ratio and weighted average.

In fact, we found these metrics as useful indicators that improved the view and the understanding of the changing path and trends in a certain programming language over time.

- *Increase ratio* for each programming language. This metric is calculated only for last six years, dividing the number of tutorials for the period 2015-2017 with the number of tutorials for the period 2012-2014. We wanted to measure the increase/decrease for produced tutorials. Due to limited time series and variable changes between those few years, we wanted to have one single indicator to show what programming language was more popular in the second half of the time period versus the first half of the time period. For that purpose, we used the simplest possible indicator - the sum of the total number of produced tutorials for the last three years divided by the sum produced tutorials for the previous three years.
- *Weighted average* for each programming language. This metric is calculated aiming to find the year when a programming language was most popular. We use weighted average instead of a simple average since we want to give weight to particular years depending from the produced tutorials for a year. These weightings will determine the relative relevance of each year on the total average. The weighted average is calculated as sumproduct of the years array with the number of produced tutorials (per year) array, divided by the total number of tutorials produced over years.

TABLE III. INCREASE RATIO AND WEIGHTED AVERAGE FOR EACH PROGRAMMING LANGUAGE

Program. Language	Initial dataset		Limited dataset	
	Increase ratio	*Weighted average*	*Increase ratio*	*Weighted average*
C++	0.77	2013.68	0.28	2011.98
Java	0.75	2013.73	0.46	2012.54
Python	2.11	2015.34	1.24	2014.42

Table III gives these metrics for the initial and limited dataset.

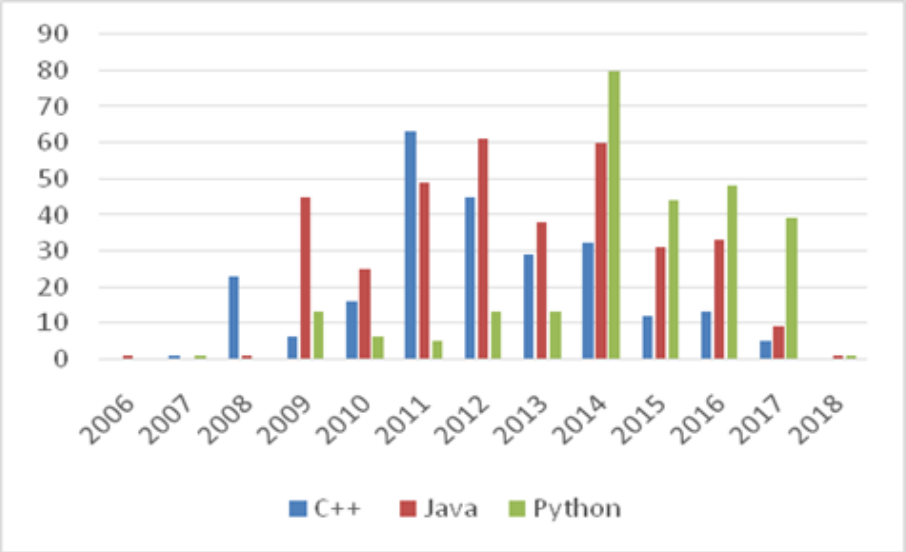

Figure 2. Number of tutorials over years for every programming language in the limited dataset

As it can be noticed in Table III, in the initial set Python has very high increase ratio compared to C++ and Java, which show approximately average decrease.

In the limited dataset, again Python has the highest increase, but now C++ has higher decrease compared to Java.

In terms of weighted average, Python again shows up as the most contemporary language, both in initial and limited dataset. C++ on the other side turns out as the most outdated programming language.

C. *Distribution of the tutorials by category*

Since the initial aim of this study was to contribute towards the selection of the programming language for introductory program courses and at the same time to help to novice programmers in identifying the most popular programming language, the data analysis presented in this part includes selection of the programming languages' tutorials filtered by category.

As it can be seen in Table IV, under the category of education, C++ has slightly more tutorials followed by Java and Python at the end.

TABLE IV. TYPE ANALYSIS OF NUMBER OF TUTORIALS BY CATEGORY

Category	Programming Language			Total
	C++	Java	Python	
Gaming	15	4	5	24
People & Blogs	58	65	67	190
How to & Style	45	70	64	179
Education	416	400	363	1179
Science & Technology	66	52	80	198

TABLE V. TYPE SIZE FOR CAMERA-READY PAPERS ANALYSIS OF NUMBER OF TUTORIALS BY LANGUAGE

Language	Programming Language			Total
	C++	Java	Python	
english	450	419	495	1364
slovak	67	57	35	159
german	31	52	17	100
not known	13	13	22	48
spanish	8	9	2	19
greek		13		13
estonian		11		11
italian	2	7	1	10
romanian	8	1		9
catalan	7	1		8
french	3	1	2	6
portuguese	1	2	3	6
indonesian	3	1	1	5
afrikaans	1	2		3
czech	1	1	1	3
arabic	1			1
welsh	1			1
croatian		1		1
dutch	1			1
albanian	1			1
tagalog	1			1

D. *Distribution of the tutorials by language*

Table V includes investigation on language of the tutorial. It is interesting to note that while Python is leading in the English language tutorials, in German language tutorials, the largest number of tutorials is for Java.

Also, C++ is leading in the tutorials in Slovak language. The other languages have very low number of tutorials.

IV. CONLUSION

Teaching and learning is going through its own revolution. The development of ICT is having a fundamental impact on education. As a result, theories of learning are shifting from traditional behaviorism towards constructivism and social constructivism. It is exactly the later one - social constructivism that focuses on the role of social-cultural context and in particular interpersonal communications in the development of cognition. In the terms of social constructivist, knowledge has a social nature and it is the result of social interaction and the use of language. Social constructivists recognize the context in which learning takes place and the social context that the learner brings to the learning environments as dominant in facilitating meaning construction.

On the other side, there is a great variety in approaches to introductory programming. This can be understood as a sign of pedagogical innovation or as a ground struggling to recognize best practices. YouTube is already known as one of the frequently used pedagogic tools in teaching and learning. The possibility to share videos is opening new ways for educational process. Online learning tutorials are mechanisms for students to become more autonomous but at the same time students are facing a wide offer of programming languages and are very often on the crossroad where to start with programming.

Based on the above, this research was focused on the analysis of online learning tutorials for programming available on YouTube. Programming is a very popular skill that in most of the cases leads to a rewarding profession. In the past years there is a significant boost on the demand for programmers and consequently the student interest in programming and programming tutorials have become increasingly accepted.

Through the study presented in this paper we aimed to make use of YouTube learning tutorials and their data based on community feedback, for guiding Computer Science students and any other learners about trends in the programming languages.

As it can be seen from the overall study presented, although C++ and Java are present and leading in education category, Python has an overall acceleration on the overall learning tutorials and their popularity among the programming community.

However, it should be noted, that the number of students that learn from tutorials for a certain programming language doesn't imply anything about language's quality, and surely can't tell which language is more appropriate for a particular situation.

Having this viewpoint in mind, however, we consider important to understand and gain knowledge on what programming languages make up the developer ecosystem, and to what trends that ecosystem might be shifting.

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Electronic Waste Disposal in District Sarajevo

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Abstract – This paper analyses the disposal problem of electronic waste in District Sarajevo (DS), Bosnia and Herzegovina (B&H). It provides a brief overview of electronics development including analysis of the quantity of electronics presented in the present market. This analysis is specially focused on explaining how far the electronic development has come and how far is it supposed to go, in the future. It is a fact that electronic devices are overflowing the everyday life of an average citizen and because of the speed of their production and development their numbers are reaching critical figures. Materials found in electronic waste can be divided into two categories: material suited for recycling and material harmful for its surroundings. This paper explains several methods of electronic waste recycling. The recycling itself is explained from various points of view: legislatives, technological procedures, economical parameters, ecological goals and the most important one, the conscientiousness of the community involving the problem of recycling and preserving our natural habitat. This paper presents the analysis of the state of the disposal system concerning electronic waste in the DS, B&H. This district has around 400.000 citizens and it represents a good candidate for this type of analysis. Research shows that amount of electronic waste is concerning, and numbers describing the amount keep increasing. The legislatives concerning this problem, together with the technology used, are not sufficient to resolve this constantly evolving problem. The biggest problem is that the community awareness of this issue is nearly nonexistent.

I. INTRODUCTION

Human action around the globe has shown worrying results, in terms of natural resource extraction. As species humans alter their surroundings to their benefit often disturbing the natural balance of things. Postindustrial society in the 21-st century has seen the need for a different approach to the natural resource extraction. Ecology, in as a whole, has changed the philosophy behind the actions taken for this cause in the 21-st century.

All industrial branches negatively impact the environment. Electronics have become the technological foundation of this new informatics society which led the revolution from the industrial to postindustrial era. This revolution came at cost of certain ecological problems. Products such as: TV-s, PC-s, cellphones etc., have become a necessity in our everyday lives. Everything around us is becoming upgraded with some electronic gadgets including our cars, apartments, working areas, the whole industry is going through the change. The change is happening very fast and as a result electronic products become outdated and replaced before their technological expiration date. It has become a trend to replace cellphones before 3 years have passed, PC-s less than 5 years, TV-s before 12 years of usage. Technological expiration date of all these products is up to 30 years. The junkyards are full of both functional and slightly damaged electronic products, alongside with properly disposed waste. Annual quantities of the products, referring to the electronically based industry, that end up on the junkyards sometimes even rivals the annual production capacity of the same.

All these products are technologically extremely complex. They are composed out of variety of materials. Many of these materials are dangerous for their environment but they are also reusable and suitable for recycling. Recycling can resolve many ecological problems and its main goals are: to separate and properly store any toxic or dangerous materials and to extract and reuse any industrially interesting materials. Unlike other commercial projects recycling is not always a profitable activity. Because of that, this kind of projects need support from the community to survive. The best support is through legislatives, good marketing and fund raising. The development of the recycling technologies proves to be crucial in this department. First world countries have taken the procedures of recycling to a sustainable level. The rest of the world is behind schedule with these activities and some of them even do not support the whole concept [1]. Third world countries are often found to be dump sites for any unwanted waste produced in the technologically advanced countries. B&H has found itself overrun with outdated and used technology and other products found as waste after the war in 1992. Most of those products were of electronic nature, and this trend has never seized stopped then.

This paper analyses the recycling problem of electronic products in B&H from a legislative and an economical point of view. Special consideration was given to the much needed educational system reforms in this matter. As a test subject the DS was chosen as a good representative of the current state of affairs in B&H. Only the problem of electronic waste was taken into consideration, involving only products mostly encountered by people in their everyday lives.

II. ELECTRONICS DEVELOPMENT

Electronics has started developing as a special science branch after the discovery of the diode and triode (1905. Fleming, 1906. Lee De Forest). These components enabled the development of radio technology and cybernetics. Up until WW II electronic devices, based on electron tubes, were being built and used in the fields of telecommunications and radio technology. This process

ensured significant development of military systems for communications. After their application in military systems, these systems were soon applied in the civil telephony and broadcasting. Soon after that ENIAC, the first electronic computer based on electron tubes, was invented (1946. Van Neumann...). After the discovery of the transistor (W. Shockley, W. Brattain and J. Bardeen 1947.) a new revolution was induced in the fields of electronics. The field of cybernetics gave birth to two new branches: Computer science and Automation, which develop as unique fields further on. Telephony and Broadcasting became very popular in the era after the WW II. Soon television was developed. The whole period up to 1950. can be described as a period of intense development in the fields connected to electronics or based on similar technologies. Electronic devices were not yet found a necessity in the everyday life of an average citizen. The problem of disposal of electronic devices did not exist at the time because the average time period of use was over 30 years, and there was a generally small number of disposed electronic devices. In the 50-s another breakthrough was accomplished when the technology of electronic system production was upgraded with the planar technique of production (1957. J. Kilby, 1959. R. Noyce), with this, the era of integrated circuits began. The integrated circuit (IC) technology enabled the production of electronic devices of high performance at low cost. This led to rapid development of everyday use technology. This will eventually lead to the development of technologies very popular in the 21-st century: TV-s, PC-s, cellphones, etc.

A. Television receiver

Television receiver represents a typical electronic device used by people all over the world. Development of this device is in direct connection to electronics development and considering its important role in the Media it is one of the most used electronic devices around the world. First television transmission was made in 1925. (L. Berd in London). Cathode tube television receiver first appeared in 1925., and in 1953. the first color television receiver was made. The era of digital television started in 1993. Since 1925. up to the present day the television technique experienced all the changes in the electronics development: television receivers based on cathode tubes, based on transistors, based on IC with the cathode tubes and after that came the television receivers based on IC with flat screens based on LED or OLED.

B. Personal computers

The era of personal computers (PC) was started in 1971. by Intel when they made a processor on one i4004 chip. In that period, up to 1981., a variety of firms producing microcomputers or personal computers appeared. IBM entered the global market in 1981. with the development of their IBM PC intended for a wide circle of customers. It was affordable, with solid preferences, it was open and modular system what secured its big popularity. A large number of firms copied the IBM-s PC and that ensured the expansion of development and appliance of PC. Today the number of PC-s is a lot bigger than the number of TV-s.

C. Cellphones

The era of mobile telephony started on 3rd of April in 1973. when the first phone call was made. Six years later in Japan the first commercial mobile network was established. In 1981. Scandinavian countries formed NMT (Nordic Mobile Telephone) network. This network expanded rapidly, just like its counterpart in USA. The first digital mobile network was established in Finland in 1991. The GSM (Global system for mobile communications) expanded rapidly throughout Europe. This network, apart from better quality, brought the SMS to life as well. The market soon overflowed with cellphones that could fit in your pocket. In 2000 cellphones were commercially used for making conversations, this era became the era of "smart" phones. 2000s are years of the Internet and the time of mobile telephony and Internet services integration. Mobile phones soon started having functions that enabled using multimedia content with cellphones. The era of 3G network started, with cellphones gaining cameras and operating systems for cellphones appeared. In 2007 Steve Jobs presented the iPhone and its innovational approach determined the future development of mobile telephony. The number of cellphones presently is estimated to be equal to the population count.

III. ELECTRONIC WASTE

The term electronic waste refers to electronic equipment and devices that are not used any longer because they are not functional, they are uneconomical or technologically outdated, and they contain printed circuits boards (PCBs) integrated with electronic components. Considering the quantity and the speed of equipment disconnection this group is made of: TVs, PCs and cellphones. Apart from these, which come in large quantities, it is important to mention a less numerous group such as: electronic toys, industrial and medical electronics, automobile electronics, digital cameras, printers, scanners, copy machines, alarm devices etc.

Electronic devices can be separated in the terms of raw materials used for recycling:

- Housing,
- Cables, connectors, switches, transformers, motors,
- PCBs with electronic components,
- Batteries.

Housing is made from metal or some kind of plastic and they can be completely recycled. The process of preparation for recycling is now conducted by human hands with mere separation of raw materials eligible for recycling.

Cables, connectors, switches, transformers, motors, are made from metal and plastic. The recycling is conducted in two phases: separation from the main e-waste, and separation between fractions of metal and non-metal. These fractions are used as raw materials in production of metal (copper, aluminum, iron) and plastic.

PCBs are the most complex part of electronic devices in the term of recycling. They contain electronic components connected to the printed board with the

technique of soldering. Soldering uses the tin alloy (Sn, 67%), and lead (Pb, 33%), and after 2006 alloy of tin (Sn, 95.5%), silver (Ag, 3.8%), copper (Cu, 0.7%) [2]. The number of different substances on the PBC can range up to 60 [2]. Many of these substances are hazardous, some of them even cancerous. They also contain reusable materials. Connectors, as well as metal processor outputs are gold-plated. Metal lines inside IC, in the part that connects the outputs and the silicon board, are made from gold. Lines are made from copper (Cu), connectors and outputs from aluminum (Al). Recycling one ton of PCBs can produce, in average, 0.28 kilos of gold, 190 kilos of copper, 145 kilos of aluminum, 0.45 kilos of silver, 30 kilos of tin and led, 0.093 kilos of rare materials (Pt, Pd, In) [1]. Fig.1 shows PCBs separated from a desktop PC.

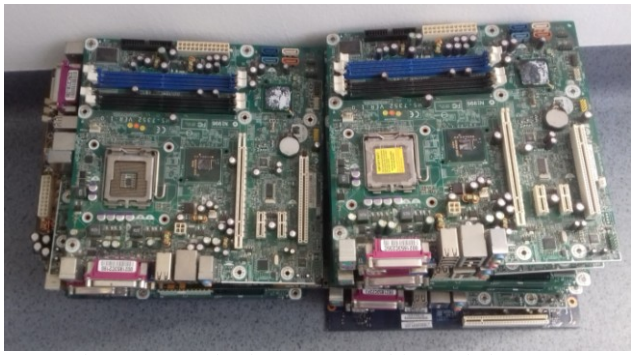

Figure 1. Example of PCBs separated from a desktop PC

Batteries are specially treated in the process of recycling because of their composition. They contain materials such as led, nickel, cadmium, lithium. These materials are found on PCBs, inside laptops and cellphones. In this phase batteries are separated from e-waste and directed to a special recycling process.

Figure 2. Parts from a dissembled CPU

Fig.2 shows a partially dissembled CPU from a desktop computer. Simple analysis shows that these parts are already separated in groups eligible for recycling: metal and plastic, usable components, PCBs, disks that can be additionally dissembled. Variety of materials and the economic question in the recycling process led to the discussion of this problem in many papers [1,2,3,4,5,6,7]. In the paper [2] procentual ratios concerning different materials in electronic equipment are presented. Table 1 shows the results of the conducted analysis. This data was used to assess the quantity of e-waste in this paper.

TABLE 1. PERCENTAGE OF SEPARATED MATERIAL FROM 1 TON OF E-WASTE

Material	% Composition
Mild Steel	23
Strainless Steel	8
Glass	27
Plastics	27
Copper	3
Aluminum	3
Other Materials	8
Hazardous Materials	1

The process of PCB recycling demands special technology and it is economical only if the work force is cheap and quantities of the materials are high. There are several procedures to recycle PCB. All these procedures demand separation of the hazardous materials, batteries and electrolyte capacitors are sent for special processing. Capacitors must be manually separated in this procedure which makes it more expensive. Next step in the procedure is to separate electronic components (connectors, IC, discrete components) from the printed board. Procedure which separates precious materials demands the separation of parts that contain precious materials (connectors, IC). These components are specially processed. Another procedure grinds PCBs together with components, and then with some procedure (electrostatic separation) conducts the separation of metal and plastic content. Further processing uses chemical techniques.

A. Hazardous substances in electronic waste

Hazardous substances which can be found in e-waste are [6]: Lead – causes damage to central and peripheral nervous system, cardio-vascular system, kidney and reproductive organs; Cadmium – causes irreparable damage to human body, because it is precipitated in the kidneys; Mercury – can cause damage to many organs including brain and kidneys, as well as fetal damage; Barium – brief exposure to barium causes brain swelling, muscle weakening, liver, heart and spleen damage; Beryllium – causes lounge cancer; Phosphorus – it is poisonous; Hexavalent chromium – it can cause DNK damage; Brominated flame retardants (BFR) – they are used in plastic housing to prevent fire from spreading and during the process of recycling they generate several dangerous pollutants; Plastic – during combustion it generates a poisonous gas.

IV. TECHNOLOGY OF E-WASTE RECYCLING

Basic techniques of e-waste recycling consist of separating the decommissioned device on: components eligible for recycling, components that cannot be recycled and hazardous components. In general, all separators can be divided in two groups: group with machine grinding and partial manual separation, group with manual dissembling and automatic procedure of separation.

Group with machine grinding works with an assumption of less manual work. All e-waste after the collection (computers (excluding cathode tube monitors), mobile phones, printers and industrial electronics) is

tossed in the grinder. The grinder uses rotating chains to cut the devices in smaller pieces. The rotating mechanism and chain elasticity make sure that components like batteries, electrolyte capacitors, transformers, relays, motors stay in one peace. All the housing, chassis, PCBs, cables, connectors etc., are grinded. Conveyor track transports this mass, while workers separate things like batteries, electrolyte capacitors from the pile. Motors, transformers and other components containing ferromagnets are separated using specific magnets. Plastic and other materials are separated using centrifuge. After separation obtained fractions are directed into special processes. Plastic, PCB, connectors, IC are all additionally grinded, and then using the electrostatic centrifugal separator they are isolated. As a product of this process certain toxic materials are gained (batteries and electrolyte capacitors) and other raw materials used to produce metal and plastic. This kind of processing results only in partial products and fractional separation of dangerous substances. Producing pure materials from these raw materials is a complex process that is completed with certain termic and chemical procedures [3,5]. This demands special facilities which will not allow hazardous materials to form as a result of the recycling process.

With the other system of recycling a larger involvement of manual labor is required because first the dissembling of the e-waste is done and then separation of the components towards the certain recycling directive: housing, cables, motors, relays, PCBs. After this the process is a lot like the first system of recycling, the materials go through the process of grinding and separation. This type of recycling system is mostly used in parts of the world with cheap manpower (China, India), when gold and silver and other precious materials are gained as final products [1]. Nither of systems is able to recycle devices based on cathode tubes (monitors, TVs). These devices demand special recycling techniques.

Inside Countries in development (China, India, Brazil) recycling of PCBs is very economical because of the cheap manpower and low ecological standards [1]. Highly developed countries export PCBs to be recycled in countries in development. Efforts to stop free trafficking of toxic waste are partially successful. International agreement from United Nations about limiting toxic waste trafficking is known as Basel convention [8].

V. State of E-waste in the District Sarajevo

There is no official data or estimations of e-waste quantity in B&H. This waste originates from the industry, households and the public sector. In this analysis only the e-waste generated from households will be taken into consideration. None of the known techniques of estimation will be used because the input data is insufficient. Instead of that this estimation will use the population data together with the estimations of the average time range of the use of devices of interest, based on existing queries. In order for the existing data to be valid and usable for the purpose of this paper, warning of the existing danger and the need for taking up adequate measures for e-waste management, all the estimations were made in their minimal form. This means that real quantities far exceed numbers given in the estimations.

According to the population census from 2013. the DS has 370.890 citizens, 148.871 inside households, and 196.482 has stated they are familiar with computers [9]. It is possible to assume, with decent certainty, that all citizens ranging from first grade of elementary and higher in age possess a cellphone, that every household has a TV and that every citizen that has stated he is familiar with the computer, owns a computer. This numbers 334.637 cellphones, 148.871 TVs and 196.482 PCs. Technological advancement dictates that TVs should be replaced every 12 years, PCs every 5 years, cellphones every 3 years. Fig.3 shows the result of a query conducted among 350 students in DS. The numbers are slightly above the world average because the standard dictates them. Based on this data, the number of decommissioned devices can be calculated: 12.405 TVs, 39.296 PCs and 111.545 cellphones. 30% of these devices end up being reused by another owner. In the end, numbers add up to: 8.683 TVs, 27.507 PCs, 78.081 cellphones. With the assumption that the average weight of TVs, PCs and cellphones are: 25kg, 20kg, 135gr respectively, it is calculated that there are 777 tons of e-waste in DS annually. Recycling this amount of e-waste can produce 210 tons of glass (27%), 210 tons of plastic (27%), 178 tons of mild steel (23%), 62 tons of strainless steel (8%), 23 tons of copper (3%), 23 tons of aluminum (3%), 62 tons of other materials (8%) and 7 tons of hazardous materials (1%).

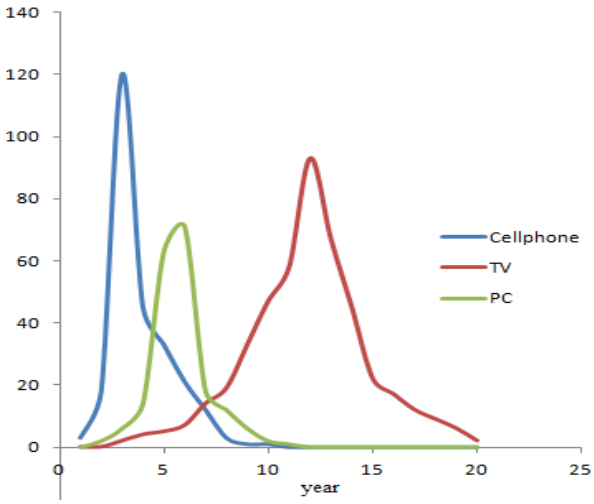

Figure 3. Distribution of the time range of device usage of District Sarajevo, based on the conducted query

VI. Regulation System for Electronic and Electric Waste (EE-waste) in FB&H

There are two control systems for ee-waste management in Europe today: deposit and integral. Deposit system gives full responsibility for collecting, recycling or export of ee-waste to the manufacturer. The manufacturer is obligated to pay defined premiums which are used to cover expanses of the operator who collects ee-waste. Manufacturer is then obligated to take the collected ee-waste and dispose of it according to the legislative. Integral system gives all responsibility for ee-

waste management to the civil services. These services form the needed procedures through their government branches. Those procedures define an operator to collect and dispose of the ee-waste, and then give reports of the progress. Manufacturers pay legislatively defined compensation which includes the collection, recycling and management expenses. Both systems require the consumer to properly dispose of the ee-waste without any compensation.

FB&H declared a legislative in 2012. referring to ee-waste management [10]. This legislative defined several terms: system operator, system user (manufacturers and distributors), final users and ee-waste collectors. System operator is an unprofitable organization which runs on authorization provided by the environment protection Fund and it is in charge of any business regarding ee-waste management. Equipment users are informed of the necessity to properly deposit ee-waste. The final user is obligated to deposit the ee-waste to the predefined locations. System operator is obligated to collect that ee-waste free of charge.

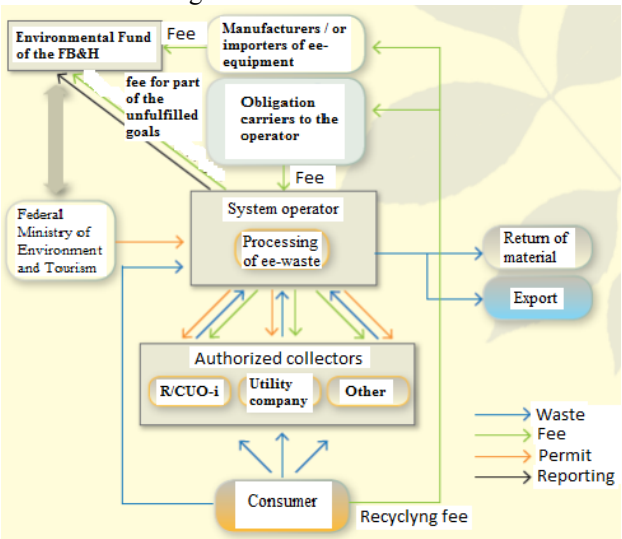

Figure 4. Schematics for ee-waste management in FB&H [11]

Defined goals are to increase the annual rate of collected ee-waste by 5% of the distributed ee-waste related products on the area of FB&H.

Manufacturers and distributors are obligated to inform the users about the type, quantity and place of the hazardous materials inside the electronic and electrical equipment. Manufacturers and distributors are obligated to pay compensation when placing ee equipment on the market.

According to the rulebook of certain devices (TVs, PCs, cellphones) that contain e-waste they can be mostly separated in groups: class 3 – informatics and telecommunication equipment, class 3a – monitors, class 4a – TVs.

Generic compensation goes to the Environmental fund and sustainable development and it is charged by number of peaces placed on the market: *class 3*: 0,03Euro/peace, *class 3a*: 0,5Euro/peace, *class 4a*: 0,7Euro/peace [10].

Compensation for managing the e-waste (collecting, recycling, and disposal) is payed to the system operator and it is calculated by the number of peaces placed on the market: *class 3*: 0,6Euro/peace, *class 3a* 10Euro/peace, class *4a* 14Euro/peace [10].

Fig.4 shows schematics of organizational structure of ee-waste management in FB&H [11]. In FB&H there are two licensed operators eligible to perform this activity. Fig.5 shows a trend of ee-waste collection by each licensed operator in FB&H [12]. The rulebook that was declared in 2012 was revoked in 2016 which resulted in the loss of the collected materials. This operators report has information about TV, fridge and monitor export to Austria but has no records of the hazardous materials disposal. Electronic waste (TVs and monitors excluded) is not even specially recorded.

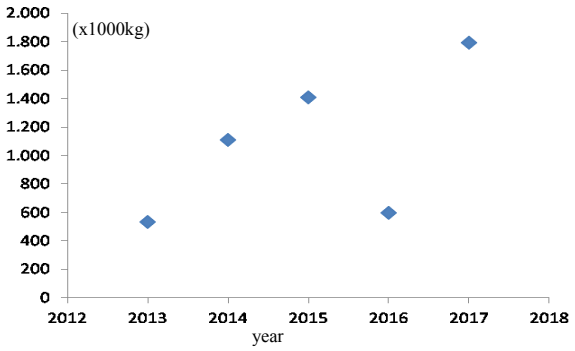

Figure 5. Diagram of ee-waste collection in FB&H [12]

According to the report for 2017 [13] one of the two operators collected 1 794.790 kilos of ee-waste. TVs and monitors were 1% of that amount (17.947 kg). Analyzing the area were this operator functions it can be estimated that 2 tons of TVs and monitors was collected from DS. Reports show what is done with PCB and batteries. These types of ee-waste should be specially marked or placed in the group for export (PCB group, battery group) or in groups for processing. It is well known that B&H possesses nither technology for e-waste processing nor the quantities of this waste to make this technology economical. The only place where this waste should be placed is the export box. The question now is, what happens with this waste: is it still in the customer possession, does it end on depots, is it incinerated, recycled together with other materials (groups of metal) or is it illegally exported? Some of the probable destinations for PCBs are basements and attics, and batteries are mostly found on communal landfills, and some PCBs end up incinerated in the metal recycling process.

The legislative has defined a feedback loop between the operator and the ministry of environment in the form of reports. After acquiring the permit system operator makes a contract with the system users (suppliers and manufacturers) who created the system operator. There is not a clear procedure or supervision of the disposed hazardous waste.

Activities which are not systemically managed because there is no legislative that defines the solution to the specific problem: disposal of tires, disposal of decommissioned vehicles, disposal of industrial oils, disposal of batteries and accumulators. With the exiting

legislative batteries, toners from printers and copy machines do not fall under the ee-waste category.

VII. Educational Sector and its Role in ee-waste Disposal Management

Existing NPP do not consider the current problem of -waste as a big issue [14,15]. A solid solution would be to change school subjects such as: My environment, The culture of living, IT, Technical education, Electronics, Electrotechnics, Chemistry, Biology and enrich them with certain content that is needed for high school education on the topic of recycling, the technology behind it, existing legislatives, dangers of inadequate e-waste disposal and its content.

A. Creating habits and building a healthy conscience

Eco sections that exist in elementary schools and high schools should, with the help of specific school subjects, take it upon themselves to educate the new generations about the organized collection and proper disposal of e-waste. This process should be done in 6 phases: 1. E-waste collection starting from our own neighborhoods; 2. Washing and drying the collection; 3. Dissembling; 4. Sorting; 5. Forming a collection of electronic components for the school workshop; 6. Selling the remaining sorted e-waste to the system users.

Every phase has its own and clear educational value. Some phases are slightly more important than the others. Dissembling and sorting will teach children how to handle equipment and other technology. Forming the collection of electronic components for the school workshop is a layered process which will produce amazing effects such as: learning about components, technical creativity, organization skills, simple and cheap way to acquire components. This activity can produce the most expensive components in electronics: transformers, motors, relays, sensors, switches, coolers, ventilators etc. Sorted waste such as: cables, housing, PCB have its value in money which can be used to raise funds for school trips etc. This is a simple solution on how to organize quality and cheap e-waste management with multiple benefits within the society.

Official system operator web site [16] states that young ecologist from the city of Bugojno together with the association Friends of nature Eko Element Bugojno have organized an e-waste collection event. This event involved all the schools from the city Bugojno and it is considered competitive and educational. This is an example of a good solution to the problem of low awareness about the eco problems considering e-waste.

VIII. Conclusion

Numbers that describe the estimation of the quantity of e-waste in District Sarajevo-Bosnia and Herzegovina are significant. In is unknown where this waste is deposited in the present. E-waste contains a significant amount of both hazardous and usable materials. With inadequate treatment e-waste can cause huge long-term damage to the environment because of these materials: mercury, lead, cadmium, etc. PCB is the most complex part of e-waste and at this moment it is unnoticeable as a separate group in the disposal processes. Considering its quantity and needed technology for recycling this waste should be specially separated and deposited. There are no defined consequences for inadequate e-waste disposal. This process should be started with education in the elementary schools and building a healthy opinion on this matter among the new generations. One of the best solutions to this problem, considering the current state of affairs, would be to educate the children through eco sections in their schools.

The legislative concerning e-waste management is not completed. The only functioning part is the commercials recycling supported with operator taxes. There are no legislatives or rulebook describing how to handle dangerous e-waste. There is no general conscience that supports the care of e-waste and the sense of legislatives supporting it. Electronic waste in the sections that are not commercialized is not treated at all.

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Apprehension of media literacy by the student population

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Summary **- By the development of information and communication technology, media have experienced expansion, especially in the types of media content and their multiplication and distribution, as well as in the ways of access to the media content itself. Due to this fact, the influence of media on all age groups, especially children and young people, is becoming more and more important, and research more intense. Therefore, special attention has to be paid to the understanding of media content and its critical evaluation by the receivers. Based on the conducted survey, the difference between attitudes and opinions on media literacy between the undergraduate students as potential students of Journalism and public relations and graduate students of Journalism and public relations, who will by their professional work actively participate in creating media content apart from consuming media content, has been analysed. Within this research special attention has been paid to the understanding of media literacy, the way of media usage, as well as to the possibilities of access to media and media content. The method of the descriptive statistics was used in the presentation and interpretation of the obtained results.**

Keywords - media, media literacy, media content, student

I. INTRODUCTION

By the development of information and communication technologies, the media have experienced expansion that can be seen in their forms, especially in the types of published media content. In this paper by the term mass media we understand "institutions that meet the needs of society for public communication in which all members of society can participate. Mass media are at the same time communication forms / products, institutions and cultural formations "[1]. By the expansion of the media, the way of using and accessing media by the receivers is changing. Nowadays, the receivers, who are crowded with a multitude of information available in mass media, necessarily select and choose those media contents that they find important and interesting at a certain point in time. Mass media, through their content, influence the shaping of our reality and the formation of our attitudes and opinions. After selection and choosing of media content, the recipients consume the selected content. This brings up some questions: do they understand the selected media content and are they able to critically analyse and evaluate it? In this context, the most frequently examined as recipients are children and young people, as the most sensitive part of the population who are to the greatest extent influenced by media content. To achieve the afore-mentioned skills, in terms of understanding, critical analysis and evaluation of media content, media literacy plays a significant role – as being one of the key literacies of the digital age.

II. THEORETICAL BACKGROUND

The story of the necessity of media education goes back to 1964 when UNESCO encouraged the idea of media education, aimed primarily at the younger population, with the purpose of encouraging them to think about the media, to encourage their understanding and critical evaluation of media content itself. In 1982, UNESCO organized a conference on "Media Education" in Germany, attended by 19 countries that also made the "Declaration on Media Education". The main conclusions of this conference were directed, among the other, to the introduction of media education programs at all levels of education system, pre-school, school and higher education systems; necessity of teachers' education, by conducting surveys in other scientific disciplines (psychology, sociology, communication sciences) with the aim of encouraging the development of media education and supporting UNESCO's activities for the development of media education [2]. "Educating for the Media and the Digital Age" is the name of the next conference organized by UNESCO about concept of media education held in Vienna, Austria in 1999. The conference was attended by 33 countries, and one of the fundamental conclusions of the conference was the use of different media types using different technologies for different approaches to media education [3].

The inclusion of media into educational systems began with the introduction of the concept of media education and media literacy. According to Erjavec [4], there are three groups of countries considering the inclusion of media education in educational systems, referring to the data collected and published by 2005: The 1st group of countries includes media education in the school curriculum: Australia, Denmark, Finland, Canada, Hungary, Germany, Norway, Ireland, Slovenia, Sweden and the United Kingdom. In these countries media education are included in the school curriculum as mandatory or elective courses, the 2nd group of countries includes a minimum level of the media education in the school curriculum: Austria, Croatia, Italy, the Netherlands and the USA, and the 3rd group of countries includes no media education in their school curriculum, primarily referring to Greece. When it comes to France, media education is conducted through extracurricular

activities. Considering the digital age in which we live and the consequences of the development of information and communication technology in the world, we can assume that media education is now significantly more prominent in the educational systems of the mentioned countries. At the conference on media literacy, held in 1992 in Aspen, the first definition of the concept of media literacy was established. Aufderheide, the author, defined the concept of media literacy as "the ability to access, analyse, evaluate and transmit messages through print and electronic media" [5]. This definition, most commonly used in scientific and professional literature, was also the starting point of this paper when defining the fundamental goal of the research. According to the author Zgrabljić Rotar [6], a media literate individual possesses the following competences: 1. technical - media access capability; 2. critical - understanding of media content, ability to interpret and critically evaluate media content; 3. practical - the ability to create media content. In her paper "What is media literacy?" the author Žitinski [7] emphasizes that, besides the basic skills that a media literate individual should possess: to receive, comprehend, analyse and evaluate media messages, media literacy must also have a proactive purpose. In other words, a media literate citizen regardless to his role of an author or a recipient of media content, must reveal but also attempt to change inappropriate media content

In today's digital age, apart from media literacy, other related forms of literacy, such as the notion of information literacy, are often mentioned as well. Stričević [8], the author, explains the concept of information literacy as a skill and knowledge that include: developing of a strategy while searching for information, finding, evaluating and using of the found information to acquire new knowledge. Information literacy by the aforementioned author encompasses basic, computational, media, cultural literacy and distance education as well as e-learning. No matter what kind of literacy we are talking about, each of them influences the quality of modern education, whether it is elementary, secondary or higher level of education. According to the other researchers, the concept of information literacy is defined as one of the degrees of different types of literacy applied in the digital age. The group of authors Tyner, Cope & Kalantzis, Kalantzis & Pandian [9] introduced the notion of "multifacetedness", defining it as all the necessary literacies in the digital age, referring to media, computational, visual, information, network literacy and technology.

Nowadays, the notion of media literacy has become the subject of numerous researches and debates in domestic and foreign scientific and professional literature. Several books, scientific and professional articles on the topic, have been published in Croatia. For the purpose of this paper we will mention only some of them. The collection of papers of the editor Nada Zgrabljić Rotar [10] "Media literacy and civil society" was also published. In it the author defines and explains the basic concepts closely related to the notion of media literacy: media education, media content, media influences, media ethics, education for the media, the impact of harmful media content on children and young people. In 2016, a handbook for the development of media literacy for teachers, students and high school students, "Let's read between the rows" [11] was presented in the edition of the associations GONG and Kurziv. The manual provides theoretical texts on the concept of media literacy, practical exercises of media literacy and glossary. The publication "New time, new media: media literacy in the 21st century - handbook" is the result of the same project, carried out through 10 months in 2015 and 2016 and brings, in addition to basic theoretical explanations on the notion of media literacy and it related terms, an example of a media literacy workshop that was supposed to stimulate critical thinking about media content in the high school population. Volčič [12], the author, analyses the way students from different countries (USA, Norway, Canada and Japan) understand the notion of media literacy and what meaning they attach to it based on subjective perception of mass media. In the paper "Media literacy - student education and awareness of their own responsibility" by Peran and Raguž [13], researchers have explored the understanding of media literacy and ways of using of media and media content evaluation by the students of the Communication Studies of Croatian Studies and the Catholic Theological Faculty of the University of Zagreb. The results of the research confirmed the necessity of media literacy education to enable students to understand and critically evaluate media content and therefore to be an active and responsible participant in social events.

The media literacy was also explored in the context of the media gap, as explained in "Media Literacy in times of Media Divides" by Divine and Ivanišin [14] as a division between the media literate and media illiterate individuals and the partition to those who have formal media education versus those who do not have. In the article "The Past, Present, and Future of Media Literacy Education", Hobbs and Jensen [15] link the concept of media literacy to a critical approach to media literacy education, citing two possible research problems for future research: the relationship between media literacy regarding the integration of educational technology within K -12 of the American curriculum and the relationship between education, media literacy and human sciences, arts and sciences in general. In his paper "Beyond Accessibility: How Media Literacy Education Addresses Issues of Disabilities" Friesem [15] links the concept of media literacy with people with disabilities who are a part of the student population and offers a theoretical and practical framework for media literacy educators for the needs of the aforementioned students. Powers, Moeller and Yuan [17] in a "Political Engagement During a Presidential Election Year: A Case Study of Media Literacy Students " conducted a survey of US presidential elections in 2012 in which they studied student political engagement and digital culture in the example of student population attending a course on media literacy.

III. METHODOLOGY

The aim of the research is to broaden the understanding of the types and frequency of media as well as media content monitoring, the way of access and participation in the media, the trust in the media, and the

self-assessment and assessment of students on the notion and content of media literacy. The research has been conducted on a random sample of students of the Department of tourism and communication sciences of the University of Zadar, undergraduate students of Culture and Tourism and graduate students of Journalism and public relations and distributed through the Merlin e-Learning system. The research was carried out in order to get answers to these questions: how often and which media do students use, how often and which media content do they follow, do they trust to media, how students estimate their understanding of media literacy and their own media literacy competence, and the attitudes of students about: for whom the knowledge of media literacy is meant, to what extent media literacy knowledge can help prevent the harmful media content, how much media literacy knowledge and skills can help them in their future work, do they want to improve the knowledge and skills of media literacy and whether there are differences in attitudes between the students of undergraduate studies and graduate students of Journalism and public relations who are supposed to actively participate in the public media sphere with their future work.

IV. RESEARCH RESULTS

A total of 96 examinees participated in the study, the first, second and third year of undergraduate studies and the first and second year of graduate study in Journalism and Public Relations. The first year of undergraduate studies is attended by 150 students in all statuses. The study involved 32 students, 21.33%., of the first year. The share of the research corps is 33.33%. The second year of undergraduate studies is attended by 88 students in all statuses. The study involved 17 students, 19.31% of the students of the second year. The share of the research corps is 17.7%. The third year of undergraduate study is attended by 33 students in all statuses. The study involved 32 students, 96.96% of the third year students. The share of the research corps is 33.3%. The first year of the Graduate Study in Journalism and Public Relations is attended by 15 students. The study involved 6 students, 40% of students of the first year of graduate studies. The share of the research corps is 6.3%. The second year of Graduate Study in Journalism and Public Relations is attended by 24 students. The study involved 9 students, 37.5% of the students of the second year of graduate studies. The share of the research corps is 9.4%. Out of 96 examinees of the research, 85 were women (88.50%) and 11 men (11.50%). Most of the students were aged between 20 and 24 (61.5%) and younger than 20 (26%). There were 8.3% at the age of 25 to 29 years and older than 30 years were 4.2%. The survey was mostly approached by regular students 67.70%, part time students 32.29%, including students with a special status, while there were no final year students.

When asked about the types and frequencies of media monitoring, the results of the research showed, in total, that students are more inclined to newer media, such as internet portals. 30 examinees answered to read traditional media such as newspapers permanently, often and very often, while 66 examinees responded never and very rarely. When it comes to television (commercial), 52 respondents said to follow it: never, very rarely, while 44 respondents responded: often, very often and permanently. Public television is watched often, very often and permanently by 32 students, while never and very rarely by 64 students. 58 students listen to radio (commercial) often, very often and permanently, while never and very rarely 38 students. 78 students listen to the public radio never and very rarely, while 18 responded often, very often and permanently. As it could have been expected, young people are closely related to new media, so web portals are monitored often, very often and permanently by 90 students, while only 6 students answered never and very rarely.

When asked about the ways of accessing media content, students have also given priority to modern information and communication technology. 96 students said to access media content on their mobile phones often, very often and permanently, 93 on computer, 33 in newspaper, on TV 55 and on radio 45 student. No one answered to access media content on mobile phone never and very rarely, while never and very rarely was answered by 3 students when it comes to accessing media content on computer, 63 in newspaper, TV 41 and radio 51 student.

Regarding the given answers: often, very often and permanently, on the types of media content and the follow-up, we came to the knowledge that students most closely follow social topics (89.58% of students), then entertainment / show buzz (85.41%), informative (83.33%), other (not included in the questionnaire) (71.87%), cultural (69.79%), sports (46.87%), political (39.58%) and bad news (31.25%) considering students and their lives. On the other hand, subjects that they follow up never and very rarely are: bad news, politics, other topics, informative, entertainment / show buzz, and social topics.

When asked about the way and frequency of participation in the media, the answer never prevailed. Therefore, students mostly do not participate in the radio broadcast (97.91%) or very rarely (2.08%). When it comes to the TV program most of the students do not participate (97.91%) or very rarely participate (2.08%). 97.91% do not respond to the newspaper articles, while very rarely responds 1.04% and often 1.04% of students. Considering the proposed activities, there is a smaller difference in commenting on articles on the internet portals, very often 1.04%, 3.12% of students often comment on articles, very rarely 20.83% and never 75% of students.

When asked if they trust to media, examinees were generally careful in their assessment, the most of respondents, when asked about the suggested media, answered that they did trust media to some extent. 13 of respondents did not trust newspapers, 27 of them answered very little, 36 of respondents had some trust when asked about newspapers, 18 trusted quite a lot, and only two respondents completely trusted newspapers. The commercial radio is not trusted by 10 students, very little by 27, somewhat by 41, quite by 17 and is fully trusted by 1 student. The public radio is not trusted by 12 students, very little by 16, somewhat by 47, quite by 18 and fully by 3 students. The commercial television is not trusted by 9 students, very little by 27, somewhat by 41, quite by 16,

and is fully trusted by 3 students. The public television is not trusted by 11 students, very little by 18, somewhat by 44, quite by 19 and is fully trusted by 4 students. The internet portals are not trusted by 12 students, very little by 23, somewhat by 49, quite by10, and is fully trusted by 2 students.

All the students who approached the survey have met the concept of media literacy. They mostly heard about media literacy in high school (46.9%) and during their studies (43.8%). A small number of students heard about media literacy in elementary school, 9.4%. Taking into consideration their studies, undergraduate or graduate, the results of the research have shown that only undergraduate students have heard about the term media literacy in elementary school 11.11%, while graduate students have heard about it in high school, 40%. Nevertheless, most of the graduates met the term media literacy during their studies 60%; 48.14% of undergraduates heard about the term media literacy in high school, and 40.74% of them during the study.

TABLE 1. APPREHENSION OF THE CONCEPT OF MEDIA LITERACY

	US	%	GS	%	TOTAL	%
understanding of media content	67	82.72	13	86.67	80	83.33
analysing the media content	32	39.51	6	40.00	38	39.6
critical evaluation of media content	44	54.32	8	53.33	52	54.2
functioning of the media	16	19.75	5	33.33	21	21.9
use of information communication technology	46	56.79	7	46.67	53	55.2
creation of media content	29	35.80	9	60.00	38	39.6
publishing of media content	19	23.46	7	46.67	26	27.1
participation in the media content	35	43.21	9	60.00	44	45.8
don't know	1	1.23	0	0.00	1	1.04
something else	3	3.70	0	0.00	3	3.13

Description: (US- undergraduate study, GS- graduate study)

Table 1 shows the results of research on the understanding of the concept of media literacy. When asked what they mean by the term media literacy, the respondents were offered the possibility of multiple replies. The largest number of students, 83.33% of them, under the concept of media literacy, presumes the understanding of media content. More than half of students, 55.21% of them, link media literacy to the use of information and communication technology and 54.17% of them link it to critical evaluation of media content; 45.83% of students under the concept of media literacy presume the participation within the media, 39.58% of students presume analysing and creating media content. 27.08% of students presume the publication of media content 27.08%, and 21.88% of students presume the functioning of the media. Three students replied that they presumed something else, while 1 student replied that he/she did not know. By comparing the results of the research, regarding the undergraduate and graduate students there have not been any significant differences in the comprehension of media literacy. 86.67% of graduates and 82.72% of undergraduates under the concept of media literacy presume the understanding of media content; 40.00% of graduates and 39.51% of undergraduates presume analysing the media content; 53.33% of graduates and 54.32% of undergraduates presume critical evaluation of media content; 33.33% of graduates and 19.75% of undergraduates presume functioning of the media; 46.67 of graduates and 56.79 of undergraduates presume the use of information communication technology; 60.00% of graduates and 35.80% of undergraduates presume the creation of media content; 46.67% of graduates and 23.46% of undergraduates presume publishing of media content; 60% of graduates and 43.21% of undergraduates presume participating in the media. 1.23% of undergraduates answered that they did not know, and 3.70% undergraduates answered something else.

When asked who the knowledge of media literacy was intended to, the response to children and adults (86.5%) dominated, while 10.3% answered adults, and 3.1% answered not to know. No one considered that media literacy was intended only to children. By analysing answers, regarding both undergraduate and graduate studies, the response to both children and adults dominated: graduates 93.33% and undergraduates 85.18%; 6.66% of graduate students and 11.11% of undergraduate students believe that media literacy is intended only for adults.

TABLE 2. THE ATTITUDE TOWARD THE IMPACT OF MEDIA LITERACY ON PREVENTION OF HARMFUL CONTENTS

		US	%	GS	%	TOTAL	%
violence	1	2	2.47	0	0.00	2	2.08
	2	9	11.11	1	6.67	10	10.42
	3	23	28.40	1	6.67	24	25.00
	4	27	33.33	7	46.67	34	35.42
	5	20	24.69	6	40.00	26	27.08
porn	1	4	4.94	0	0.00	4	4.17
	2	9	11.11	2	13.33	11	11.46
	3	21	25.93	1	6.67	22	22.92
	4	24	29.63	7	46.67	31	32.29
	5	23	28.40	5	33.33	28	29.17
stereotypes	1	1	1.23	0	0.00	1	1.04
	2	8	9.88	1	6.67	9	9.38
	3	23	28.40	1	6.67	24	25.00
	4	27	33.33	6	40.00	33	34.38
	5	22	27.16	7	46.67	29	30.21
advertising	1	3	3.70	2	13.33	5	5.21
	2	8	9.88	2	13.33	10	10.42
	3	24	29.63	2	13.33	26	27.08
	4	25	30.86	6	40.00	31	32.29
	5	21	25.93	3	20.00	24	25.00

Description: (US- undergraduate study, GS- graduate study. 1- none, 2- very little, 3-somewhat, 4-quite, 5-extremely a lot)

The four media contents, most often described as harmful, in which it was necessary to assess the extent to which knowledge and skills of media literacy could help prevent the appearance of such content in the media, were offered to students (Table 2.) Whether they could prevent violence in the media, students answered: not at all 2.08%, very little 10.41%, somewhat 25%, quite 35.41% and extremely a lot 27.08%. When it comes to pornographic content they answered: not at all 4.16%, very little 11.45, somewhat 22.91%, quite 32.29% extremely a lot 29.16%. For the prevention of stereotypes, they answered: not at all 1.04%, very little by 9.37%, somewhat 25%, quite 34.37%, and extremely a lot by 30.20%. Whether knowledge and skills in the field of media literacy could prevent the appearance of harmful advertisements in the media, respondents answered: not at all 5.20%, very little 10.41%, somewhat 27.08%, quite 32.29%, and extremely a lot 25% . The average response to the impact of media literacy on the prevention of violence of graduate student was 4.2 (STDEV = 0.86), on the prevention of pornographic content 4 (STDEV = 1), on the prevention of stereotypes 6.26 (STDEV = 0.88) and on the prevention of harmful advertisements 3.4 (STDEV = 1.35). The average response to the impact of media literacy on violence prevention of undergraduate students was 3.66 (STDEV = 1.04), on the prevention of pornographic content 3.65 (STDEV = 1.15), on the prevention of stereotypes 3.75 (STDEV = 1.00), on the prevention of harmful advertisements 3.65 (STDEV = 1.08)

The students were asked for self-assessment of knowledge of the concept of media literacy. The students answered, to the greatest extent, that they knew somewhat about the concept (55.2%); 26% of the students answered that they knew enough; 17.7% of the students answered that they knew very little 17.7%, and 1% of students answered extremely a lot. The graduate students said to know, to the greatest extent, quite a lot about the media literacy, 53.33% of them, and undergraduates, 59.25% of them, answered somewhat when asked the same question; 33.33% of graduates answered somewhat, and 20.98% of undergraduates that they knew enough; 13.33% of graduates and 18.51% of undergraduates answered very little when asked the question. Only one student, considering the both groups of students, answered extremely a lot when asked about his knowledge of concept of media literacy.

We were also interested in the opinion of students of how helpful the knowledge and skills in the field of media literacy could be in their future work: 42.7% of students think that it can help them quite a lot, while 28.1% of students think that it can help them extremely a lot. 14.6% of students said that it can be helpful to some extent, while 1% think that it can help them very little. Regarding the graduate students, they think that their knowledge and skills can help them quite (60.00%) and extremely a lot (40.00%) in future work, whereas 39.50% of the undergraduate student think that it can quite help, while 25.92 % think extremely a lot. 17.28% of students think that it can help them to some extent. 1.23% of students think that it can help them very little, and 16.04% do not know if their knowledge and skills can help them in their future work.

When asked whether they considered themselves to be a media literate person, the answers somewhat (40.6%) and quite (39.6%) dominated, 9.4% of the students consider themselves to be very little media literate person, while 8.3% of the students consider themselves to be extremely a lot media literate person. 2,1% of students answered not to know. Three quarters of the students (75%) have a desire to improve their knowledge and skills of media literacy. 3.1% of students do not want to improve, while 21.9% do not know if they want to improve.

Most of the graduate students consider themselves to be quite media literate, 60% of them; 26.66% of graduates considered themselves to be somewhat literate, 6.66% of students answered to consider themselves to be very little media literate and 6.66% considered themselves to be extremely a lot media literate. The most of undergraduate students consider themselves to be somewhat media literate, 43.20% of them, and quite media literate 35.80%; 9.87% consider to be very little media literate, and extremely a lot 8.64%. 2.46% of students answered not to know. The average graduate student response is 3.66, (STDEV 0.72), and the average undergraduate student response is 3.35 (STDEV 0.95)

93.33% of graduates replied that they wanted to improve their skills and knowledge of media literacy, while 6.66% answered not to now. 71.60% of undergraduate students want to improve their skills of media literacy. 3.70% answered not to want to improve, and 24.69% of students answered not to know.

V. CONCLUSION

In today's digital age, users are exposed, by the expansion of media, to different types of media content. Besides accessing and using the above-mentioned content, users need to understand and critically evaluate it, in other words they should be media literate. Regardless to the level of education, inclusion of media, media education and media literacy in the education system of the Republic of Croatia is necessary. Research has shown that children and young people are mostly affected by the harmful media content which is the reason why in this paper the student population was taken as a sample of research. Research results have shown that students are more inclined to new media, internet portals. It can be explained by the fact that they are more accessible, cheaper, can be accessed in many ways and in the time that suits them. These can also be confirmed by the results obtained by responding to the approach of media access, where almost all respondents responded to often, very often or constantly access media content by the computer. Also, none of the respondents answered that they never or very rarely access the media content on their mobile phone. The results of the research have also shown that students are interested in tracking a broad range of topics in the media, starting with social themes, as most frequently followed topics, up to bad news, as content that interests them the least. However, the results have also shown that a small number of students participate in the media in a way that they participate in a radio program or TV show, send supplements to the newspaper, or comment on articles on the internet portals. This research has not

sought the cause of not participating in the media, but we think that this segment should be included in future research. Regarding the trust to the media, students showed a dose of caution and mostly responded to somewhat trust to the media which could be interpreted as they critically reflect on the content they monitor. All the respondents met with the concept of media literacy in high school and their studies. When asked what they meant by the concept of media literacy, there were no significant differences in the responses of graduate and undergraduate students. The largest number of responses had the first proposed feature (understanding of media content) which actually tells us that the respondents are aware that one of the important issues of media literacy is to perceive the perception of content. Given the results of self-assessed studies of knowledge in the field of media literacy, the most of undergraduate students answered to have somewhat knowledge, while the majority of the graduate students answered to have quite knowledge. Most of the undergraduate and graduate students think that media literacy is intended for both children and adults (86.5%). When assessing the influence of knowledge and skills in the field of media literacy on the prevention of proposed harmful content, regarding the average response of undergraduate and graduate students, graduate students consider that in the prevention of violent and pornographic content and stereotype media literacy can affect more than what the undergraduate students think. Regarding the prevention of the influence of harmful advertising, according to the average response, undergraduate students consider that media literacy can have a greater impact than what graduate students think. Future research should analyse and explore practical examples in areas of knowledge and skills that could prevent the appearance of harmful content and reduce the impact of harmful media content on the media audience. The research has shown that the undergraduate students as well as the graduate students mostly think that the knowledge of media literacy can help them quite and extremely a lot in their future work. According to their own estimates in media literacy, the majority of graduate students consider themselves to be quite media literate, and the majority of undergraduate students consider themselves to be somewhat media literate. The average graduate student response is 3.66, and the undergraduate 3.35, taking into consideration the standard deviation that indicates a wider range of responses. More than 90% of graduate students and more than 70% of undergraduate students want to improve the knowledge and skills of media literacy, suggesting that they recognize the importance of media literacy but also implies the need to devise programs to improve these skills.

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Accessible Data Visualization in Higher Education

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Abstract - Many aspects and courses that are part of the higher education system can be quite challenging for many students. Courses such as programming have been reported to be difficult by many students worldwide. In the modern age many courses that encompass new directions in science and professional work such as big data or data mining have emerged. These courses present new challenges for all students and are particularly challenging for students with disabilities, especially for visually impaired students. In this paper, the challenges of visually impaired students regarding higher education and visualization of data are presented and means and technologies for aiding visually impaired students in data visualization are discussed and elaborated. The research results about the usage of these technologies are also presented along with conclusions and comments about the possible future research directions in this area.

Keywords **- data visualization, accessibility, students, visually impaired, higher education**

I. INTRODUCTION

Many courses that are part of higher education can be quite challenging for many students. Courses that deal with programming have been reported as being difficult to understand by different students for many years and animation and other visualization techniques combined with interaction have been reported as one of the steps that can be incorporated into programming education in order to make this kind courses easer for students [1]. However, the means of creating more comprehensive course environments that will be effective or partially effective for an average student are in many cases not suitable for a number of individual students. This is especially true when talking about visually impaired students that deal with programming courses. Visualization techniques that will help other students can in the case of visually impaired students become just another obstacle that needs to be resolved.

Modern scientific and professional directions have brought the courses that deal with big data and data mining into focus. Since these courses present quite a challenge for many students it is more than clear that they present even greater obstacle for students with different types of disabilities. It is particularly challenging to present the data to students who are visually impaired in a perceivable and understandable manner.

Many different measures aimed at providing equal opportunities for students with disabilities have been introduced. From the legislation perspective some examples of such measures are a common legal European framework on non-discrimination with the Treaty of Amsterdam from 1997 (Article 13) [2], several European strategic documents [3; 4] and The United Nations Convention on the Rights of Persons with Disabilities (Article 24) [5]. From the assistive technology perspective there have been efforts to develop tools that can aid students with various disabilities and especially visually impaired to use computers in order to be able to utilize the information technology infrastructure. Most commonly used assistive technology which enables visually impaired to use computers includes the following tools [6]: Kurzweil 3000, Window-Eyes, NVDA, JAWS, Narrator, NaturalReader, ORCA, VoiceOver, Talkback, BrailleBack and Capti Narrator.

However, despite the fact that mentioned efforts exist the fact remains that many of these tools and measures are not utilized in their maximum capacity and that students with disabilities are only 40% as likely to enroll into higher education programs, compared to students without the disabilities [7]. Also, in the European Union 47% of people with disabilities are employed, compared to 72% of people without disabilities [8]. Different aspects of higher education and professional work require different aiding measures and technology. When talking about the data visualization then the same principles can be used to make this aspect of higher education more accessible. In this paper, an overview of types of disabilities and problems that students with disabilities are encountering in their higher education is given, with the emphasis on the aspects and tools in the domain of accessible data visualization. The research results about the usage of aiding means in mentioned domain are also given along with the directions for future research.

II. ACCESSIBILITY OBSTACLES IN HIGHER EDUCATION

When talking about the accessibility many different problems and obstacles can be identified as well as many different aiding means. All obstacles and aiding solutions can be viewed through either the medical or social model of disabilities [9; 10]. Medical model represents the disability as a medical condition which needs to be resolved by using assistive technology as a mean of

treating the particular disability. The example of this kind of approach would be treating the person with a vision problem by using a retinal implant. Social model represents the disability as a result of the way in which the society is organized that needs to be resolved by using assistive technology as a mean of elevating the particular organization obstacle. The example of this kind of approach would be providing the visually impaired person with a book that has a bigger font size in order to enable proper text reading.

There are many different types of disabilities and many different assistive solutions. Each type of disability requires its own specific means of aiding a person to overcome a particular set of obstacles and barriers to achieving equal opportunities. Different types of disabilities are shown in Fig. 1.

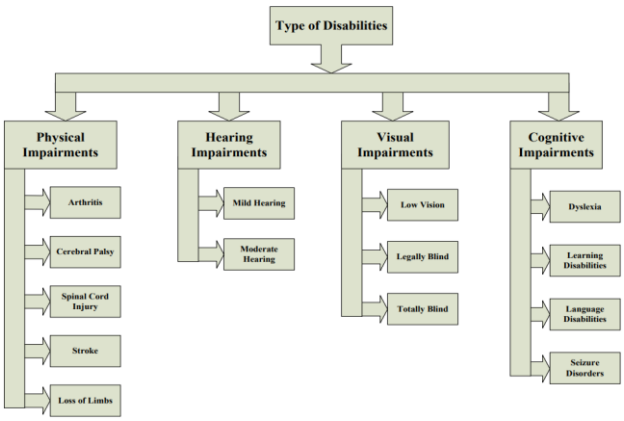

Figure 1. Types of disabilities

In the domain of higher education many different obstacles can be found, such as [11; 12]:

- Inadequate funding
- Physical inaccessibility
- Accommodation process
- Lack of individualization
- Ineffective dispute resolution mechanisms
- Negative attitudes and stereotypes
- Lack of available options
- Lack of information to families or prospective students about options
- Inconsistency (lack of equivalence) between various education providers and sectors
- Insufficient equipment, technological aiding means and other devices
- Disability unrecognized or undiagnosed
- Lack of proper training and support from teachers
- To large class sizes (class sizes need to be reduced where classes are inclusive)

American organization CDC provides the following classification of disabilities [13]:

- Vision
- Movement
- Thinking
- Remembering
- Learning
- Communicating
- Hearing
- Mental Health
- Social Relationship

Another USA classification gives the following categories of disabilities [14]:

- Attention Deficit / Hyperactivity Disorder (AD/HD)
- Autism Spectrum Disorder (ASD)
- Deaf and Hard of Hearing
- Learning Disorders
- Mobility & Upper Extremity Impairments
- Neurological Disorders
- Physical Health Disorders
- Psychological Disorders
- Vision Impairments

World Health Organization (WHO) looks at the disability through three different dimensions [15]:

1. Impairment in a person's body structure or function, or mental functioning; examples of impairments include loss of a limb, loss of vision or memory loss.
2. Activity limitation, such as difficulty seeing, hearing, walking, or problem solving.
3. Participation restrictions in normal daily activities, such as working, engaging in social and recreational activities, and obtaining health care and preventive services.

Private news and information source Disabled World gives the following categorization of disabilities [16]:

- Mobility and Physical Impairments
- Spinal Cord Disability
- Head Injuries - Brain Disability
- Vision Disability
- Hearing Disability
- Cognitive or Learning Disabilities
- Psychological Disorders
- Invisible Disabilities

Another disabilities classification, from the United Kingdom comprises of the following categories [17]:

- Physical or Mobility Impairment
- Visual Impairment
- Hearing Impairment
- Learning Difficulties
- Mental Health Difficulties
- Medical Conditions

As can be seen, there are some differences between various classifications that are available, but the obstacles that different groups of people with disabilities encounter remains virtually the same for each disability type.

III. ACCESSIBILITY TOOLS IN HIGHER EDUCATION

Along with legislative and organizational measures, in order to try to prevent discrimination of students and to try to create equal opportunities, a number of different aiding tools have been developed and implemented at many higher education institutions. A special focus has been put on students with various degrees of visual impairment. For example, the Classroom and Lab Computing (CLC), a part of Teaching and Learning with Technology (a unit of Information Technology Services at the Pennsylvania State University), and Office for Student Disability Resources / Educational Equity provide the following list of recommended accessibility tools [18; 19]:

- ZoomText
- Duxbury Braille Translator
- Kurzweil 3000
- Read & Write Gold
- Balbolka
- PowerTalk
- WebAnywhere
- JAWS
- NVDA
- Dragon Naturally Speaking Premium
- Thunder
- Voiceover
- Voiceover
- Livescribe Pen

In order to facilitate accessible content World Wide Web Consortium (W3C) provides the following set of principles titled Web Content Accessibility Guidelines (WCAG) 2.0 [20]:

- Principle 1: Perceivable - Information and user interface components must be presentable to users in ways they can perceive.
- Principle 2: Operable - User interface components and navigation must be operable.
- Principle 3: Understandable - Information and the operation of user interface must be understandable.
- Principle 4: Robust - Content must be robust enough that it can be interpreted reliably by a wide variety of user agents, including assistive technologies.

As a part of the mentioned principles W3C provides the following guidelines [20]:

- Provide text alternatives for any non-text content so that it can be changed into other forms people need, such as large print, braille, speech, symbols or simpler language.
- Provide alternatives for time-based media.
- Create content that can be presented in different ways (for example simpler layout) without losing information or structure.
- Make it easier for users to see and hear content including separating foreground from background.
- Make all functionality available from a keyboard.
- Provide users enough time to read and use content.
- Do not design content in a way that is known to cause seizures.
- Provide ways to help users navigate, find content, and determine where they are.
- Make text content readable and understandable.
- Make Web pages appear and operate in predictable ways.
- Help users avoid and correct mistakes.
- Maximize compatibility with current and future user agents, including assistive technologies.

When talking about students with visual impairment then a number of different aiding means can be identified [21]:

- ICT based specialized vocational training to perform functions within abilities
- Specialized keyboards, such as Braille
- Braille printer
- Conversion of local language to Braille
- Screen readers
- Touch screens
- Eye tracking
- Talking word processors
- Screen magnifiers

IV. ACCESSIBLE DATA VISUALIZATION

Despite the fact that many different aiding solutions exist, many aspects of higher education still remain challenging and this is particularly prominent in the case of visually impaired students and in the case of some particular courses. According to the World Health Organization (WHO) there are about 314 million of visually impaired people worldwide [21]. Many courses that are part of the higher education are especially challenging for visually impaired students and these, among others, include courses that deal with big data and data mining. In order to make representation of data accessible several different tools can be found that can make this possible, in lesser or greater capacity depending on the particular data.

Generally, when trying to create accessible aiding tools that will enable accessible data visualization several aspects need to be taken into consideration. These aspects are referred to by the following guidelines [22]:

- All data graphs need to be made as simple as possible.
- All colors should be simplified and made distinct enough one from another.
- The number of colors should be brought to a minimum.
- All elements and fonts should be enlarged.

When analyzing available tools that can help creating accessible data visualization the following tools can be identified [22]:

- Multimodal Graphs
- Pie Chart Sonification
- MultiVis
- BATS
- Graph Builder
- TACTICS
- 3D Shapes Visualization
- exPLoring Graphs
- VizTouch
- MathTalk
- Highcharts
- SAS Graphics Accelerator

Despite the fact that all mentioned tools exist their actual utilization remains a question. In order to assess whether both students and their teachers do know about or use these tools a research has been conducted among 35 college students which have some form of visual impairment. Research participants consisted of 23 male and 12 female students who were 19-24 years old. The selection of research participants was random but it was ensured that all students have been in contact with computer technology both in their private and student activities. The majority of 28 students who participated in the research studied at various computer science colleges and 7 students studied at colleges that deal with other fields of science. Most of the participants in the research were from United Stated of America (30 students) and others were from different European Union countries (5 students). The research was conducted by using a digital questionnaire in which all possible answers were based upon the Likert scale (1 - 5). Research results are shown in Table I.

TABLE I. RESULTS OF CONDUCTED RESEARCH

Questionnaire item	Mean	Std. dev.
I know about some of the tools for making data visualization accessible.	3,82	0,67
I personally use some of the tools for making data visualization accessible.	3,54	0,74
Tools for making data visualization accessible are used as a part of my college courses.	2,31	0,92
I have troubles in visualizing the data in some of my courses.	4,37	0,43
I would like to have more accessible data visualizations available.	4,51	0,38

The research results have shown that most of the students have knowledge about some of the tools that are used for accessible data visualization and that a subset of these students use some of these tools personally. The research has also shown that only a minority of students actually use these tools in their courses. It has also been shown that the majority of students experience troubles and challenges regarding data visualization and that they would like to have more accessible solutions available.

According to the research results one of possible steps in the direction of making visualization more accessible for visually impaired students would be to increase awareness about the various visualization assistive solutions that are available in the academic community. As a part of these efforts appropriate information should be provided to teachers as well as to offices for educational equity which are very important facilitators of assistive technology in college education systems. Personal involvement and motivation of teachers to deal with new assistive technology is one of the key prerequisites for effective implementation of assistive technology solutions in educational processes and the importance of this aspect cannot be overstated. One of possible directions for future research would be to compare the usage of assistive technologies for different purposes. Another possible direction would be to research the difference in usage of assistive technology between United Stated of America and European Union, as well as between other world regions.

V. CONCLUSION

Higher education brings many challenges and some courses are even more challenging than others. A special set of challenges and obstacles are experienced by many disabled students, and visually impaired students encounter very particular set of obstacles. Courses that deal with big data and data mining present a special challenge for all visually impaired students. A number of

aiding tools that enable visually impaired to use computers and learn have been developed. A subset of these tools relates to obstacles in visualization of data. However, despite the fact that this kind of tools exist their actual usage remains something to research further.

In this paper, research results about the questions of using assistive tools for accessible data visualization have been presented. Research results have shown that although some of the students know and even use some of these tools, utilization of assistive data visualization tools in higher education can be improved. Visually impaired students tend to experience problems with visualization of data and they would welcome further aiding efforts in this area. Additional analysis of particular data visualization accessibility tools usage and effectiveness as well as the analysis of means that can improve utilization of these tools will be a part of future research.

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Acceptance of mobile technologies and m-learning in higher education learning: an explorative study at the Faculty of Humanities and Social Science at the University of Zagreb

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***Abstract* - With over 6 billion people having an internet connected mobile device (UNESCO), m-learning has established a solid basis for its implementation worldwide. To become truly successful in this activity, m-learning needs motivated students who use mobile technologies in their educational activities on a daily basis. Since students present a large group of users highly exposed to mobile technologies, it is expected that their views and actual use of mobile technologies in their education will influence the direction of further developments of m-learning positively. One of the recent theories which is related to the acceptance of mobile technologies is the unified theory of acceptance and use of technology (UTAUT). In this paper, this theory is applied in understanding of acceptance and use of mobile technologies by students for further advancement of m-learning. This paper presents the results of an explorative study of the students at the Faculty of Humanities and Social Sciences, at the University of Zagreb, Croatia about acceptance mobile technologies and m-learning. The results of this study would help in further development of m-learning at the Faculty of Humanities and Social Sciences.**

Keywords – m-learning; mobile technologies; higher education; Croatia

I. INTRODUCTION

Information and communication technologies (ICT) has become the integral part of educational process at many universities worldwide. As members of Generation "Z" (people born after 1995) enter universities, they expect that universities will function similarly to the world they were born into with the omnipresent internet, social media and mobile technologies [1]. To fully understand technological needs in education of this and future generations of students, we should first understand their motivation for use of ICT including mobile devices in education. The aim of this paper is to present the results from the explorative study of the students at the Faculty of Humanities and Social Sciences at the University of Zagreb, Croatia about acceptance of mobile technologies and m-learning. The results of this study would help in further development of m-learning at the Faculty of Humanities and Social Sciences.

II. M-LEARNING

Historically, ICT have entered the realm of education several decades ago. One of the most important concepts in education - e-learning - emerged in the late 80s. In the 90s when the power of desktop and handheld devices grew significantly and became more affordable and ubiquitous, e-learning became even more popular [2]. The latest developmental form of e-learning is m-learning. „Mobile learning (m-learning) is a recent technology that has been developed rapidly to deliver e-learning using personal mobile devices without posing any restrictions on time and location" [3]. The widespread availability and relatively low cost of mobile devices opened new opportunities to leverage the power and ubiquity of mobile technologies in order to enhance learning and extend educational opportunities [3]. As a result, m-learning offers "the exploitation of ubiquitous handheld technologies, together with wireless and mobile phone networks, to facilitate, support, enhance and extend the reach of teaching and learning. M-learning can take place in any location, at any time, including traditional learning environments such as classrooms as well as in workplaces, at home, in community locations and in transit" [4]. M-learning has many benefits: continuous, ongoing, flexible learning; it enables time for reflection; it facilitates informal and formal learning; it supports personalization; it is readily available; ubiquitous; contextual and relevant; it provides ubiquitous access and supports user-generated media [5]. In its Higher Education Academy report, JISC [6] identified a number of potential benefits of mobile and wireless learning. These include: mobile/wireless devices tend to be personal, private and familiar; they reduce perceived barriers to learning; mobile devices are pervasive (most learners have a mobile phone); mobile/wireless devices are highly portable, allowing access to learning from anywhere; using mobile devices, learners can fit learning into their life, including "dead" time such as traveling, queuing; mobile devices allow immediacy of communication, including speech and data sharing; laptops and wireless networks allow access to learning by learners in dispersed communities and isolated situations; context awareness brings a new

dimension to learning in the field; mobile devices can be used to record data and to capture the process of learning wherever it happens; mobile devices allow on-the-move contact with mentors, tutors, or other learners; mobile phones are considered an acceptable way for learners to receive reminders and chasers, and to manage their time; bit-sized (just in time) e-learning resources can be delivered e.g., to basic skills learners, or work-based learners; abstract (representations) and concrete (environmentally situated) knowledge can be integrated, connecting field or workplace learning with classroom learning; peer-to-peer networks make mobile learning inherently more learner-centered. Kukulska-Hulme et al. [7] identified several key points of use of m-learning: learner collaboration, the ability to support collaborative and conversational learning taking place outside the classroom, in homes, workplaces and in museums. Mobile technologies are especially good in providing learning environment outside of the classroom and therefore are of great interest for researchers around the world trying to research details about their use in education.

III. ACCEPTANCE OF MOBILE TECHNOLOGIES

Acceptance of technology in general was a topic of interest of many researchers. Over the years, many theories and models were developed to facilitate the research about acceptance and use of technology in different contexts. More recently, mobile technologies also entered the realm of interest of scientists in different scientific disciplines. "Mobile technologies are developing rapidly, and the functionalities available on mobile devices grow more numerous and complex every day" [3]. With the rapid development came technical difficulties such as the reliability of mobile devices, battery life (device autonomy), network connectivity, data loss and compatibility [8]. Use of mobile technologies brought certain benefits such as [2]: learners could interact with each other and with the practitioner instead of hiding behind large monitors; it's much easier to accommodate several mobile devices in a classroom than several desktop computers; PDAs or tablets holding notes and e-books are lighter and less bulky than bags full of files, paper and textbooks, or even laptops; handwriting with the stylus pen is more intuitive than using keyboard and mouse; it's possible to share assignments and work collaboratively etc.. Mobile technologies also have certain disadvantages such as [2]: small mobile and PDA screens limit the amount and type of information that can be displayed; there are limited storage capacities for mobiles and PDAs; batteries have to be charged regularly, and data can be lost if this is not done correctly; they can be much less robust than desktops; it's a fast-moving market, especially for mobile phones, so devices can become out of date very quickly; bandwidth may degrade with a larger number of users when using wireless networks. With mobile technologies, students can [2] "access documents or document libraries; access quizzes and self-assessment as question or games; participate in lessons and tutorials; receive lectures archived or broadcast live; access to video clip or audio libraries; read asynchronous postings; exhibit student work and participate in virtual learning communities on the go".

Although we have learned about the good and the bad sides of mobile technologies, it is still not clear what motivates students to use mobile devices in their education and whether this use has a long-term effect on the development of education in general and personal success in students' education. This is where specialized theories come in to explain the phenomenon of technology acceptance.

The technology acceptance model (TAM) is probably the most famous theoretical model focused on user behavior in contact with technology. This model is based on the theory of reasoned action (TRA) which states that "the individual behavior is motivated by behavioral objectives and these are a function of an individual's attitude toward the behavior and subjective norms surrounding the performance of the behavior [9]. The TAM model consists of two factors: perceived usefulness and perceived ease of use. Perceived usefulness is the prospective user's subjective probability that using a specific application system will enhance his or her job or life performance. Perceived ease of use is the degree to which the prospective user expects the target system to be free of effort [9]. Another attempt to gather the theoretical notions about the acceptance of technology is unified theory of acceptance and use of technology (UTAUT) [10]. The new theory was developed "through a review and consolidation of the constructs of eight models that earlier research had employed to explain IS (information system) usage behavior (theory of reasoned action, technology acceptance model, motivational model, theory of planned behavior, combined theory of planned behavior/technology acceptance model, model of PC utilization, innovation diffusion theory, and social cognitive theory)" [11]. The UTAUT has selected "the critical factors and contingencies related to the prediction of behavioral intention to use a technology and technology used primarily in organizational contexts [12]. Authors proposed four key constructs: performance expectancy, effort expectancy, social influence, and facilitating conditions. Performance expectancy is defined as the degree to which using a technology will provide benefits to consumers in performing certain activities; effort expectancy is the degree of ease associated with consumers' use of technology; social influence is the extent to which consumers perceive that important others (e.g., family and friends) believe they should use a particular technology; and facilitating conditions refer to consumers' perceptions of the resources and support available to perform a behavior [12]. These four key constructs influencing the behavioral intention to use a technology and/or technology use. A group of authors [11] decided to expand the UTAUT theory with additional constructs such as hedonistic motivation (the fun or pleasure derived from using a technology, and it has been shown to play an important role in determining technology acceptance and use); price value (cognitive tradeoff between the perceived benefits of the applications and the monetary cost for using them) and experience and habit (opportunity to use a target technology and is typically operationalized as the passage of time from the initial use of a technology by an individual and the extent to which people tend to perform behaviors automatically because of learning). In spite of many efforts to create a

comprehensive theoretical model about technology acceptance and use, one must bear in mind that a "single model could not cover all construct which would potentially affect users' intention to use of various new services or technologies, particularly in the mobile business environment" [11]. This is the reason why each theory has to be expanded with additional variables, which are sometimes not adequately tested.

IV. RESEARCH

Mobile devices have become ubiquitous in learning and their perceived advantages might help in further development of m-learning by understanding the most important aspects, motivation and intentions of use of mobile devices in m-learning. The aim of this explorative study was to collect data about the use of mobile technologies in the learning process of students at the Faculty of Humanities and Social Sciences in Zagreb, Croatia (FHSS). The explorative study in this paper was motivated by the research and articles of Ahmad Abu-Al-Aish and Steve Love [13], Nassoura [14] and Venkatesh, Thong, and Xu [12].

The purpose of this explorative study was to find out what attitudes and perceptions students at the FHSS had in relation to mobile technologies and m-learning. The basic presumptions (hypotheses) were: that students accept mobile technologies in the learning process and that that the potential of m-learning is still not fully used by students at the FHSS. A self-administered online questionnaire survey consisting of 19 closed type questions was implemented using a convenience sample of undergraduate, graduate and postgraduate students at the FHSS. The online questionnaire was available from January 15th till January 31st 2018. An invitation to participate in the research was sent to the students' mailing list at the FHSS and was published on the official Web site of the FHSS. The total response rate was 88 respondents.

V. RESEARCH RESULTS AND DISCUSSION

The following part of the paper presents the results from the research. The questions were divided into three parts. The first part was related to collecting demographic data from the respondents. The second part was related to use of mobile devices and m-learning and the third part was related to the expanded UTAUT model referring to the selected aspects of use of mobile devices in learning.

The first two questions were oriented towards collecting demographic data about the research respondents. The total of 88 respondents participated in the research. Sixty-nine (79.3%) of there were female respondents and 18 (20.7%) were male respondents (N=87). The next question aimed at finding out age of the respondents (N=87). Twenty-one respondents (24.1%) were 18-20 years old (which corresponds to the age of students attending the undergraduate study program), 44 respondents (50.6%) were 21-25 years old (which corresponds to the age of students attending the graduate study program) and 22 respondents (25.3%) were over 25 years old (which corresponds to the age of students attending the postgraduate study program). Very few respondents didn't indicate their gender or age.

The next part of the questionnaire was related to the use of mobile devices and m-learning. The first question in this part was related to the frequency of use of m-learning. The respondents (Table I.) were offered answers on the scale from 1 (never) to 5 (every day). On average, very few respondents (only 3) used m-learning every day. Much more respondents used m-learning on average and above average while slightly less respondents used m-learning below average. Significant 21 respondents never used m-learning, which is worrying, especially because they are in the age category of the graduate students which are near the end of study cycle and have less possibilities to be engaged in m-learning than students who are just entering the study cycle.

TABLE I. FREQUENCY OF USE OF M-LEARNING (N=86)

	18-20 years		*20-25 years*		*25+ years*	
	Male	Female	Male	Female	Male	Female
1 (never)	1	5	1	10	1	3
2	1	3	2	6	2	3
3	2	3	4	9	0	6
4	0	4	2	9	1	5
5 (every day)	0	1	1	0	0	1

The next question in this part of the questionnaire was related to the total duration (or experience) in of use of m-learning. Most respondents (Table II.) (32.2%, N=28) have been using m-learning for 2-3 years, a little less (31%, N=27) have been using m-learning for 4-5 years, and 14 respondents (16.1%) have been using m-learning for longer than 5 years which is significant experience for a significant number of the respondents in this research. Only 20.7% of the respondents (N=18) have m-learning experience shorter than 1 year which could be interpreted as inadequate.

TABLE II. DURATION OF USE OF M-LEARNING (N=87)

	18-20 years		*20-25 years*		*25+ years*	
	Male	Female	Male	Female	Male	Female
Less than 1 year	1	7	2	2	1	5
2-3 years	1	8	4	9	2	4
4-5 years	2	2	1	20	0	2
5+ years	0	0	0	5	2	7

The respondents experienced in m-learning (regardless of the length of their experience), were asked about the perceived advantages of m-learning. Due to the space

restrictions, only the top 3 perceived advantages of m-learning are presented in Table III.

TABLE III. PERCEIVED ADVANTAGES OF M-LEARNING (MULTIPLE ANSWERS)(N=87)

	18-20 years		*20-25 years*		*25+ years*	
	Male	Female	Male	Female	Male	Female
Flexible time for leaning	3	12	7	25	2	16
One's own learning tempo	0	1	1	1	1	0
Learning material available 0-24h	1	4	1	7	1	1

Next, the respondents were asked about the perceived disadvantages of m-learning. Due to the space restrictions, only the top 3 perceived disadvantages of m-learning are presented in Table IV.

TABLE. IV. PERCEIVED DISADVANTAGES OF M-LEARNING (MULTIPLE ANSWERS) (N=86)

	18-20 years		*20-25 years*		*25+ years*	
	Male	Female	Male	Female	Male	Female
Isolation from other colleagues during learning	0	7	4	6	0	6
Inability to ask teacher a question	3	2	1	13	1	4
Inadequate learning material for use on mobile devices	1	4	2	7	3	2

Tables III. and IV. indicated groups of answers important to the respondents during their active participation in m-learning. The advantages showed that the respondents chose answers which suite them best in their everyday learning activities. It is worth noting that the top 3 answers presented in two tables did not include any communication with the teaching staff. The disadvantages also indicated the isolation of students including lack of communication with the teaching staff. Other disadvantages in top 3 included inadequacy of the learning material and mobile devices which could not be easily fixed. While the students valued their independence in learning and availability of the learning material, they lacked direct communication with teachers, which would have enriched and enhanced their learning experience. The students who were active in m-learning were also asked about the perceived improvements in their education based on use of m-learning (N=87). Half of them (50.6%) experienced improvements, 37.9% couldn't estimate whether there was an improvement and 11.5% didn't experience an improvement. The results are encouraging because of the half of the respondents experienced improvements in their education. Next, the students were asked about their satisfaction with m-learning on the scale from 1 (highly unsatisfied) to 5 (highly satisfied) (N=87). Most respondents (75.8%) indicated their average and above average satisfaction with m-learning (values 3 and 4 on the scale) and 12.6% were highly satisfied with m-learning (value 5). Only 10.3% indicated low satisfaction (value 2) and only 1.1% were highly unsatisfied (value 1).

The frequency of use of mobile devices in m-learning is important because it facilitates the discovery of facts about the active participation of the students in m-learning by use of mobile devices (Table V). Sixty-two percent of students (values 1 and 2) never or rarely used mobile device in m-learning, and only 18.4% (values 4 and 5) used mobile device frequently and every day. Nineteen point five percent of students in this research used mobile device occasionally (value 3). Some reasons of lesser use of mobile device in m-learning could be found in the answers in the Table IV.

TABLE V. FREQUENCY OF USE OF MOBILE DEVICE FOR LEARNING (N=87)

	18-20 years		*20-25 years*		*25+ years*	
	Male	Female	Male	Female	Male	Female
1 (never)	1	6	1	10	1	5
2	1	5	5	10	1	6
3	0	1	3	6	2	5
4	2	4	0	7	0	1
5 (every day)	0	1	0	5	0	0

There are very few categories of mobile devices on the market today. All categories enumerated in Table VI. could be used in m-learning. Laptops (89.7%) and smartphones (87.4%) were used predominantly by the students in this research. These two device categories are also present more frequently on the market and are more popular than other device categories in this research. Tablets (25.3%), e-readers (14.9%) and other devices (1.1%) were used less frequently.

TABLE VI. TYPE OF MOBILE DEVICE USED IN LEARNING (MULTIPLE ANSWERS)(N=87)

	18-20 years		*20-25 years*		*25+ years*	
	Male	Female	Male	Female	Male	Female
E-reader	0	2	0	7	0	4
Smartphone	3	14	7	30	3	16
Tablet	1	4	2	7	0	6
Laptop	2	14	7	34	4	16

Other mobile device	0	0	0	0	1	0

The next set of questions was related to the expanded UTAUT model explained in the first part of the paper. Each question in this set was related to one aspect of the acceptance of m-learning and use of mobile device in m-learning. Due to the space restrictions, data in in the tables are presented cumulatively for all age groups. In the first section (Table VII.), the respondents clearly recognized the answer related to usefulness of mobile devices in m-learning as the most important one, As it was a general statement, it was expected that other answers in this section would attract more attention of the respondents.

TABLE VII. EXPECTED EFFORT (MULTIPLE ANSWERS) (N=86)

	N	*%*
Mobile device is useful in m-learning	78	90.7
Use of mobile device helps me in achieving learning goals faster	48	55.8
Use of mobile device enhances collaboration with my colleagues	48	55.8
Use of mobile device enhances chances for achieving goals in my education	33	38.4
Use of mobile device increases my productivity in learning	33	38.4

Answers in this section (Table V.) indicate that the majority of the respondents did not have any major difficulties in use of mobile devices which is prerequisite for successful m-learning.

TABLE V. PERCEIVED EASE OF USE (MULTIPLE ANSWERS) (N=86)

	N	*%*
Interaction with mobile device is clear and transparent	65	75.6
Learning how to use mobile device for learning is easy for me	57	66.3
It is easy to use mobile device in learning	55	64
Learning how to use mobile devices does not require special effort	50	58.1
It is easy to become skillful in use of mobile device in learning	50	58.1

In this section (Table VIII.), the respondents indicated the level of influence of other people on their acceptance of use of mobile devices in learning. Though the number of answers was not high, they indicated that the influence of other people close to students might have influence on adoption and use of mobile devices in learning.

TABLE VIII. SOCIAL INFLUENCE (N=65)

	N	*%*
Persons whose opinion is important to me prefer that I use mobile device in learning	25	38.5
Persons important to me think I should use mobile device in learning	24	36.9
Persons who have influence in my life think I should use mobile device in learning	16	24.6

Ability to use a mobile device in learning is of great importance for success of application of mobile devices in education in general. Over half of the respondents (Table IX.) possessed knowledge necessary for use of mobile device in learning which is a solid basis for active inclusion of the students in m-learning. Other answers in this section also defined the success in mobile learning require additional attention as to create a more successful environment for m-learning.

TABLE IX. TERMS OF USE (N=86)

	N	*%*
I have knowledge to use mobile devices in learning	45	52.3
Mobile devices are compatible with other devices I use in learning	17	19.8
Resources for use of mobile device in learning are available to me	13	15.1
I can get help from other persons in case of problems in use of mobile devices in learning	11	12.8

Hedonistic motivation for use of mobile devices in m-learning provided even more insight into motivation of the students (Table X.). They deemed mobile devices useful in learning, however, their use in learning was not fun or pleasure. Feeling good while learning is important for motivation for participation in learning in general.

TABLE X. HEDONISTIC MOTIVATION (MULTIPLE ANSWERS) (N=79)

	N	*%*
Use of mobile device in learning is very useful	71	89.9
Use of mobile device in learning is fun	21	26.6
Use of mobile device in learning is pleasure	4	5.1

Every generation of mobile devices brings new functions and capabilities. The respondents liked testing ICT devices but they are not early adopters of ICT (Table XI.).

TABLE XI. PERSONAL INNOVATION (MULTIPLE ANSWERS) (N=75)

	N	*%*
I like testing ICT devices	70	93.3

When I learn about a new ICT device I can hardly wait to test it	19	25.3
I'm first to test new ICT device among my colleagues	6	8

Mobile devices presented good value for money for almost half of the respondents (Table XII.), which is a significant result. The more students could afford a mobile device, the more students would be in position to use it in m-learning.

TABLE XII. VALUE (MULTIPLE ANSWERS) (N=78)

	N	*%*
Mobile device presents good value for money	38	48.7
Taking into account current prices, mobile device presents good value	35	44.9
Mobile device has reasonable price	21	26.9

Answers in this section are among the most important ones for acceptance of mobile devices and m-learning as they provide clear indication that the respondents' use of mobile device in learning has become natural or at least a habit (Table XIII.).

TABLE XIII. HABITS (N=84)

	N	*%*
Use of mobile device in learning has become natural to me	45	53.6
Use of mobile device in learning became a habit of mine	31	36.9
I have to use mobile device in learning	6	7.1
I'm addicted to use of mobile device in learning	2	2.4

Continuing from the previous section, the respondents created a habit of use mobile device in learning and also have intention to continue using mobile device for the same purpose, which is encouraging (Table XIV.).

TABLE XIV. INTENDED BEHAVIOR (N=85)

	N	*%*
I intend to use mobile device continuously in learning in future	62	72.9
I plan to use mobile device in learning frequently	13	15.3
I'll try to use mobile device in learning	10	11.8

VI. CONCLUSION

With the increased number of users of mobile devices, m-learning has established a solid basis for its implementation worldwide. To understand motivation of students at the FHSS, an explorative study was initiated. The research results in this paper confirmed both hypotheses related to m-learning: acceptance of mobile technologies in learning and unrealized potential of m-learning. While the acceptance of mobile technologies comes with the wide availability of mobile devices in students' working and personal environment, the acceptance and active participation in m-learning requires additional effort on the side of the students to use it more frequently and on the side of academic institutions to promote m-learning and improve it on the basis of research like this one. Additional research is needed to understand many new and emerging aspects of development of m-learning which are still less researched. This is especially important for new generations of students enrolling universities in near future who will want to experience all the benefits of m-learning.

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Applying advanced linear models in the task of predicting student success

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***Abstract* - The paper presents a comparative analysis of different linear models based on the Moodle data related to the course Programming 2 at the Department of Informatics, University of Rijeka. The task is to predict student final course success based on student activity represented by the initial set of features. We experiment with several methods with the aim to reduce the feature set in order to extract the most representative features thus increasing prediction accuracy. The interpretation of the obtained predictive models is given.**

Keywords - Linear model, regularization, prediction of student success, lasso regression, ridge regression

I. INTRODUCTION

The learning process in e-learning system environments leaves its trace with a large amount of generated log data. Educational data mining (EDM) is the discipline that has emerged in the last ten years and it involves the use of data mining techniques to answer educational questions in order to raise the quality of the educational process [1, 2, 3].

In this paper we present a case study from the Department of Informatics of the University of Rijeka in which a blended course Programming 2 offers several supportive activities to students. The work investigates the influence of these activities on student success by applying advanced linear regression methods such as feature selection and shrinkage methods on Moodle log data.

The main objective of feature selection methods is to identify a subset of variables that best presents relevant information from the dataset. Overview of the methods dealing with variable selection can be found in [4, 5, 6]. Some common feature selection methods are best subset selection, forward selection, and backward selection. Shrinkage methods fit a model containing all features (predictors) by shrinking the coefficient estimates in the linear model towards zero. One can say that shrinkage methods regularize coefficient estimates [6].

In our previous work we conducted objective evaluation of course activities by learning association rules from the Moodle log data [7]. In our present work we use feature selection methods in order to detect activities which have the highest influence on student grades. We compare results obtained by different methods such as subset selection, advanced linear models like ridge regression and the Least Absolute Shrinkage and Selection Operator (lasso) method, and dimension reduction methods like principal components regression (PCR) and partial least squares (PLS) [6]. The obtained models of the student learning process can be used for more accurate prediction of student success based on student activities. The models are easier to interpret than those of classical methods such as the least squares method for fitting a simple linear regression model. Our goal is to find the most significant model features.

The paper is organized as follows. Section two presents related work in the field of grade prediction in the educational context. Section three introduces the data set and presents the approaches we use in order to select features relevant for the prediction of student grades. The comparative analysis of the accuracies obtained and the interpretation of results is given in section four. The conclusion is given in section five.

II. RELATED WORK

Since educational data mining is a very active research area, there are many works in the field. Although methods and goals vary, all these works aim at supporting decisions about how to improve teaching and learning processes and how to organize the learning environment.

There are several approaches dealing with the task of predicting student success based on the log data of student course activities [8,9,10,11].

The authors in [10] give an overview of research dealing with the analysis of data accessible from the course, e.g. student performance in homework assignments, information about video-watching behavior, forum activity and other easily accessible log data. Different data mining models are used for predicting student success, e.g. regression models, decision trees, support vector machines, clustering and nearest neighbors.

In [11] the correlation between prior education GPA in certain subjects and student grades is analyzed.

In [12] classification methods are used to detect connections between prior knowledge and the Moodle course activity in relation to final grades.

The authors in [13] use data mining algorithms to identify behaviour of failing students in order to warn students prior to the final exam.

The research in [14] predicts students' final grades using classification algorithms based on features extracted from the e-learning system log data.

III. DATA SET DESCRIPTION AND METHODS

A. Data set description

The data used for this research comes from the programming course "Programming 2" from the e-learning system MudRi. The data set contains 77 instances and 17 attributes (Table 1). We investigate the significance of the influence that each attribute has on the student grade attribute named final_points. Table 2 lists abbreviations and symbols used in the paper.

B. Feature selection

Feature selection, also known as variable selection, is the process of selecting a subset of relevant features (attributes) to be used in building a model. Feature selection is used for reducing overfitting, shortening training times, and making the model easier to interpret [6].

In this paper we use two classes of methods – subset selection and shrinkage.

Subset selection involves identifying a subset of features that are most connected to the response. On the reduced set of features a model is fitted using least squares [6]. The following methods are used: best subset selection, forward stepwise selection, and backward stepwise selection.

Shrinkage methods involve fitting a model with all predictors (features), but the estimated coefficients are shrunk towards zero depending on the least squares estimate. Depending on the method used, shrinkage can be used for feature selection because some of the coefficients may be exactly zero. The following methods are used: ridge and lasso regression [6].

To perform best subset selection, a separate least squares regression is fitted for each combination of all p predictors. The number of models for one predictor is p, the number of models that contain exactly two predictors is $\binom{p}{2}$= p(p−1)/2, etc. The problem of selecting the best model is solved in two stages (Fig. 1).

1. Let $\mathcal{M}_0$ denote the *null model*, which contains no predictors. This model simply predicts the sample mean for each observation.
2. For $k = 1, 2, \ldots p$:
   (a) Fit all $\binom{p}{k}$ models that contain exactly k predictors.
   (b) Pick the best among these $\binom{p}{k}$ models, and call it $\mathcal{M}_k$. Here *best* is defined as having the smallest RSS, or equivalently largest R^2.
3. Select a single best model from among $\mathcal{M}_0, \ldots, \mathcal{M}_p$ using cross-validated prediction error, C_p (AIC), BIC, or adjusted R^2.

Figure 1. Best subset selection [6]

Step 2 identifies the best model within each size and reduces the problem from 2^p possible models to p+1 possible models. Step 3 chooses the best possible model from p+1 possibilities.

TABLE I. DATA SET ATTRIBUTES AND THEIR DESCRIPTIONS

ID	*Attribute*	*Description*
1	Lectures	The total number of scores the students received within the lectures
2	Quizzes	The total number of scores the student received on two quizzes
3	Labs	The total number of scores the student received in labs
4	Videos	The total number of views of the video lectures
5	Self-assesm.	The total number of clicks in the self-assessment activities – as a measure of activity
6	final_points	Student scores – range 0-100
7	Queue	A binary variable that has value 1 if the student accessed the presentation "Queue" at least once, 0 otherwise
8	Stack	A binary variable that has value 1 if the student accessed the presentation "Stack" at least once, 0 otherwise
9	Dynamic programming	A binary variable that has value 1 if the student accessed the presentation "Dynamic programming" at least once, 0 otherwise
10	Circular list	A binary variable that has value 1 if the student accessed the presentation "Circular list" at least once, 0 otherwise
11	Introduction to trees – part 1	A binary variable that has value 1 if the student accessed the presentation "Introduction to trees – part 1" at least once, 0 otherwise
12	Introductions to trees – part 2	A binary variable that has value 1 if the student accessed the presentation "Introduction to trees – part 2" at least once, 0 otherwise
13	Demonstrature	The number of times the student accessed "Demonstrature"
14	News forum	The number of times the student accessed "News forum"
15	Forum related to lectures	The number of times the student accessed "Forum related to lectures"
16	Forum related to exercises	The number of times the student accessed "Forum related to exercises"
17	Forum related to lab demonstrator classes	The number of times the student accessed " Forum related to lab demonstrator classes"

Out of computational and statistical reasons, best subset selection cannot be applied to scenarios with very large number of predictors. The larger the number of predictors, the greater the chance of overfitting the model on the training data. Stepwise methods are used as an alternative.

Forward stepwise selection is an efficient alternative which considers a much smaller set of models. The selection starts with a model containing zero predictors, and then adds predictors to the model until all are included (Fig. 2).

1. Let $\mathcal{M}_0$ denote the *null* model, which contains no predictors.
2. For $k = 0, \ldots, p-1$:
   (a) Consider all $p-k$ models that augment the predictors in $\mathcal{M}_k$ with one additional predictor.
   (b) Choose the *best* among these $p-k$ models, and call it $\mathcal{M}_{k+1}$. Here *best* is defined as having smallest RSS or highest R^2.
3. Select a single best model from among $\mathcal{M}_0, \ldots, \mathcal{M}_p$ using cross-validated prediction error, C_p (AIC), BIC, or adjusted R^2.

Figure 2. Forward stepwise selection [6]

Forward stepwise selection involves fitting one null model and p-k models in the k^{th} iteration. This amounts to 1+(p+1)/2 models. If the number of predictors p=15, best subset selection requires 2^{15}=32768 models and forward stepwise selection requires only 121 models. However, unlike best subset selection, forward stepwise selection does not guarantee to give the best model [6].

Similarly to forward stepwise selection, backward stepwise selection amounts to only 1+ (p+1)/2 models, it is applied when the number of predictors is large, and it does not guarantee the best model containing a subset of predictors. Unlike forward stepwise selection, the method starts with the full least squares model, containing all predictors, and then removes the least useful predictors one by one (Fig. 3).

1. Let $\mathcal{M}_p$ denote the *full* model, which contains all p predictors.
2. For $k = p, p-1, \ldots, 1$:
   (a) Consider all k models that contain all but one of the predictors in $\mathcal{M}_k$, for a total of $k-1$ predictors.
   (b) Choose the *best* among these k models, and call it $\mathcal{M}_{k-1}$. Here *best* is defined as having smallest RSS or highest R^2.
3. Select a single best model from among $\mathcal{M}_0, \ldots, \mathcal{M}_p$ using cross-validated prediction error, C_p (AIC), BIC, or adjusted R^2.

Figure 3. Backward stepwise selection [6]

C. *Ridge regression*

Ridge regression is similar to least squares, except the coefficients are estimated by different quantity (Fig. 4).

$$\sum_{i=1}^{n}\left(y_i - \beta_0 - \sum_{j=1}^{p}\beta_j x_{ij}\right)^2 + \lambda\sum_{j=1}^{p}\beta_j^2 = \mathrm{RSS} + \lambda\sum_{j=1}^{p}\beta_j^2,$$

Figure 4. Ridge regression [6]

Similarly to least squares, ridge regression makes the RSS small to find coefficients to fit the data. The second term is called a shrinkage penalty [6]. The parameter λ serves to control the impact on the regression coefficients, if λ = 0, ridge regression produces the least squares results.

TABLE II. ABBREVIATIONS AND SIMBOLS

ID	*Acronym or symbol*	*Description*
1	p	Number of predictors
2	R^2	Coefficient of determination. the proportion of the variance in the dependent variable that is predictable from the independent variable(s).
3	M_n	Model with a n index
4	Adjusted R^2	Modified version of R^2 that has been adjusted for the number of predictors in the model
5	RSS	Residual sum of squares
6	C_p	Used to assess the fit of a regression model that has been estimated using ordinary least squares
7	AIC	Akaike information criterion, estimator of the relative quality of statistical models for a given set of data
8	BIC	Bayesian information criterion, criterion for model selection among a finite set of models
9	y_i	i^{th} value of the variable to be predicted
10	β_n	estimated value of the slope coefficient n
11	x_i	i^{th} value of the explanatory variable
12	λ	Tuning parameter
13	MSE	Mean squared error of an estimator, measures the average of the squares of the errors or deviations

Ridge regression produces the best results when the least squares method gives a big variance, i.e. when the number of predictors p is pretty much the same as the number of instances n. If p>n, the least squares method does not have a unique solution, whereas ridge regression can still perform well. Ridge regression shows a substantial computational advantage over subset selection because it only fits a single model [6].

D. *Lasso regression*

A big disadvantage of ridge regression, compared to subset selection methods, is that it includes all predictors in the final model. The penalty shrinks all the coefficients towards zero but not to exactly zero. The only difference between ridge regression and the lasso is that the β2j term is replaced by |βj | in the latter (Fig. 5).

$$\sum_{i=1}^{n}\left(y_i - \beta_0 - \sum_{j=1}^{p}\beta_j x_{ij}\right)^2 + \lambda\sum_{j=1}^{p}|\beta_j| = \mathrm{RSS} + \lambda\sum_{j=1}^{p}|\beta_j|.$$

Figure 5. Lasso regression [6]

As in ridge regression, the lasso shrinks coefficients towards zero, however, the penalty forces some coefficients to exactly zero when λ is large enough. As a consequence, the lasso performs feature selection.

E. PCR and PLS

The principal components regression (PCR) approach involves constructing the first M principal components Z_1, …, Z_M, and then using these components as predictors in a linear regression model that is fit using least squares [6].

Partial least squares (PLS) is a supervised alternative to PCR. Like PCR, PLS is a dimension reduction method, which first identifies a new set of features, and then fits a linear model using least squares. Unlike PCR, PLS identifies these features in a supervised way, i.e. it makes use of the response [6].

IV. RESULTS

First we compare subset selection methods. Best subset selection and forward stepwise selection give the same result in case of four predictors. For models with five predictors there is a difference between best subset selection and backward stepwise selection on one hand, and forward stepwise selection on the other hand. Table 3 shows models with five predictors and their respective coefficients.

The MSE (mean squared error) is calculated on the training data and the model with five predictors has the error of 61.69466, which is the lowest error. The five predictors are: lectures, quizzes, labs, Circular list, Introduction to trees – part 2.

The first three predictors are in direct correlation with the final score because they are part of it. Those three predictors are present in every model. More interestingly, the two presentations which show the highest influence on the final grades are Circular list and Introduction to trees – part 2.

To get the MSE with ridge regression, we calculate the optimal lambda for the method and obtain the value of 2.721739.

Next, we calculate the MSE and get the model with the appropriate predictors. Ridge regression contains every predictor from the dataset. The MSE equals to 95.27977.

We calculate the lasso MSE in a similar manner. The lasso has the MSE of 79.34989. The advantage of lasso regression is obvious since nine out of 16 predictors with their respective coefficients equal zero. The model contains predictors: lectures, labs, quizzes, self-assessments, Circular list, Introduction to trees – part 2, News forum. Circular list is again a key predictor, as in the subset selection model.

Table 4 gives a comparison of subset selection, ridge regression, lasso regression, PCR, and PLS.

Subset selection gives the best result. Lasso regression gives a result better than ridge regression because it ignores nine predictors which results in a more accurate model.

TABLE III. SUBSET SELECTION METHODS AND PREDICTORS' COEFFICIENTS

Predictor	***Best subset selection***	***Forward stepwise selection***	***Backward stepwise selection***
Lectures	1.3433952	1.3671787	1.3433952
Quizzes	0.7047974	0.6921062	0.7047974
Labs	1.3928844	1.3891406	1.3928844
Circular list	-3.3707571	/	-3.3707571
News forum	0.1074683	0.2083947	0.1074683
Forum related to exercises	/	-0.3045908	/

TABLE IV. MSE COMPARISON OF DIFFERENT METHODS

	MSE
Subset selection	61.69466
Ridge regression	95.27977
Lasso	79.34989
PCR	115.9574
PLS	106.0902

V. CONCLUSION

Model selection methods are among the key tools in data analysis, especially for large datasets with many predictors. There is no universal method which works best on any dataset. Each method has its advantages, as well as flaws.

The best results on the data we analyze are obtained by subset selection. Since the size of the dataset is limited, no computational problems occur.

The best advanced linear model results are obtained by the lasso. By eliminating non-important predictors from the model, it yields better results than ridge regression. The problem of lasso regression may be rare models with small number of predictors. However, on the analyzed dataset it turns out to be a very good solution.

The PLS method does not give better results than ridge or lasso regression as its disadvantage is increased variance.

In our future research we plan to use a more in-depth dataset. Instead of binary predictors we might use the exact number of presentation openings, the time needed to complete the self-assessment activities, the difference between the first and the last access to the learning materials, etc.

ACKNOWLEDGMENT

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Why e-Learning in Slovenia is Left Behind?

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***Abstract* - The beginnings of introduction of development of information and communications technology (ICT) in education in Slovenia were promising, where in late nineties, majority of educational institutions were equipped with new technology. In 2017 the first comprehensive survey on the situation of digitalization and e-learning in higher education in Slovenia was carried out. It was designed as a web survey that included all higher education institutions in Slovenia and was comparable with international European University Association survey on e-learning in Europe. Relatively high response rate (45%) and representativeness of the sample distinguish survey results. The comparison with the European data from the point of view of the availability of ICT shows a satisfactory picture, while Slovenia remains behind in terms of using ICT as a means for improving quality and innovating higher education. Majority of HE institutions do not use ICT for other than administration and communication purposes. The paper will focus on identification of key barriers which hamper thorough development of e-learning in higher education in Slovenia. Survey results on respondents' (mainly academic leaders) perception on e-learning will be elucidated; government as important external player of implementing e-learning will also be examined for Slovenia.**

Keywords* - *e-learning, online education, digitalization, information and communication technology, higher education in Slovenia.

I. INTRODUCTION

Higher education (HE) landscape is facing unprecedented challenges how to adapt its performance and services to constantly changing educational needs, induced by demographic and social shift, sharpened financial conditions, globalization and above all ever changing technology. Modern information and communication technology (ICT), is not only a factor which necessitates changes in education, this is also important vehicle for innovating education and its adaptation to modified social environment. Generally, learning supported by technology is known as electronic learning or EL. EL encompasses wide plethora of educational strategies and formats in terms of ICT support ranging from partial and sporadic implementation of ICT in educational processes through blended and hybrid learning to fully online learning.

Educational strategies and policy in EU and in Slovenia put strong emphasis on the key role of technology in modernization of education [1, 2]. Nevertheless, the progress and current state of digitalization and EL are not systematically supported by empirical evidence and only few researches have dealt with development issues at national or international level. Lack of adequate data is especially expressed in sector of higher education (HE). At European level the only surveys which comprehensively covered EL at university level are two international surveys for 2013 and 2014 carried out by European University Association (EUA) with participation of 37 in 2013 [3] and 48 countries in 2014 [4]. In 2017 DOBA Business School carried out a survey of all HE institutions (faculties and higher schools) with the aim to provide essentials on the status of EL in Slovenia. The survey methodology was mainly harmonized with EUA surveys. The survey revealed that EL in Slovenia, in particular online learning, is lagging behind European countries. Range of factors could influence EL development pattern in a country and generate differences among countries. These factors could be roughly classified into three major groups: educational institutions' readiness for EL, government support and capacity of learners and of learners' environment for EL.

The paper aims to assess the current development stage of EL in Slovenia with regard to the various aspects of readiness of HE institutions in Slovenia in comparison to European countries.

The paper is organized in five sections. After introduction, methodology and definitions used in web surveys are briefly resumed. International comparison of current status of EL in HE in Slovenia together with analysis of some institutional factors of EL is given in the third section (Results). In the fourth section (Discussion) the role of government and capacity of the learners and their environment for EL are briefly addressed. In the closing section Conclusion, summary assessments of the factors shaping the development of EI in Slovenia are presented.

II. METHODOLOGY[1] AND DEFINITIONS

The main data source for the research of the impact of institutional features on the current state of EL in HE in Slovenia is web survey which was conducted in May 2017. The survey was anonymous to protect individual delicate data that would reveal respondents. With permission of EUA, we used EUA questionnaire from 2013 as background [3]. Some modifications were implemented to the base questionnaire considering the objectives of our research and results of questionnaire's pilot testing. All HE institutions (faculties, high

[1] Detailed explanations are available in full report [5].

professional schools, art academies) registered in the official evidence of Ministry of Education, Science and Sport (MESS) in October 2016 were invited to take part in the survey by special letter of MESS and DOBA Business School as organizer and resource provider of the research. Of 101 units, 55 units responded. 10 units were deleted from further data processing due to incomplete questionnaires. Net response rate achieved was 45%. Comparison of respondents' distribution by status, size and educational domain proved to be representative of the collected data.[2] About two thirds of all questionnaires were filled in by the leadership of the responding institutions and others by administrative staff.

In order to obtain additional explanations, we also conducted several in depth-interviews with deans or vice deans of various type of HE institutions.

Precondition for quality survey was clear and unambiguous definition of EL. Therefore, it was essential that all surveyed institutions used the same definition and understanding of EL. This aspect of survey methodology deserved particular attention, because nowadays EL is defined and used in multiplicity of perspectives. EL is most often defined as any technology based learning [6]. Such a concept of e–learning was also used in EUA survey: "The term EL in the present survey is a generic expression for all learning involving the use of information and communications technologies (ICT) to support both learning and teaching.« [3]

However, in the era of technology driven society the broad and loose definition of EL has become obsolete. In circumstances where connected computers and other ICT devices are standard equipment of educational institutions such a vague definition does not bring any potential to delineate EL from traditional formats of learning and teaching[3]. Therefore, EL was relied on definitions which clearly expose the purposive use of ICT aiming to improve quality or to innovate teaching and learning[4]. EL could be realized (with all potential benefits) only, when **ICT is inherent element of planning** of teaching and learning activities. It means that ICT role should be explicitly acknowledged when defining learning strategies and learning objectives.

In survey for Slovenia, **the operational criteria for identifying institutions with EL offer was that availability of specific ICT is 'conditio sine qua non' (indispensable condition) for achievement of predefined learning objectives and realization of learning strategies regardless the scope of implementation of EL (institution as a whole, institution's department, teacher)**. Based on these criteria, surveyed HE institutions (45 units) were grouped into three analytical classes: 18 units not engaged in EL, 4 units intend to introduce EL and 23 units implementing EL.

Range of possible formats of EL observed in survey was limited to classification and definitions used in EUA surveys including: blended learning, online learning, both at the level of degree programs or courses and joint online programs.

For international comparison data from EUA survey for 2014 were used, unless the issues compared were dealt only in EUA survey 2013.

III. RESULTS

A. *Offer of e-Learning*

The offer of online and blended learning is apparently weaker in Slovenia than in European countries regardless the categories of EL (Fig. 1). The smallest gap is recorded for the individual blended courses, the simplest and less demanding form of EL. The biggest discrepancy is observed for online degree programs and online joint programs. In Slovenia only about one tenth of the surveyed institutions (45 units) declared the offer of such programs, while in European countries this share is about one third. Considering the methodological differences (i.e. the timing of the surveys and definition of observation units) it can be assessed that the lagging of Slovenia in development of EL is actually even wider.

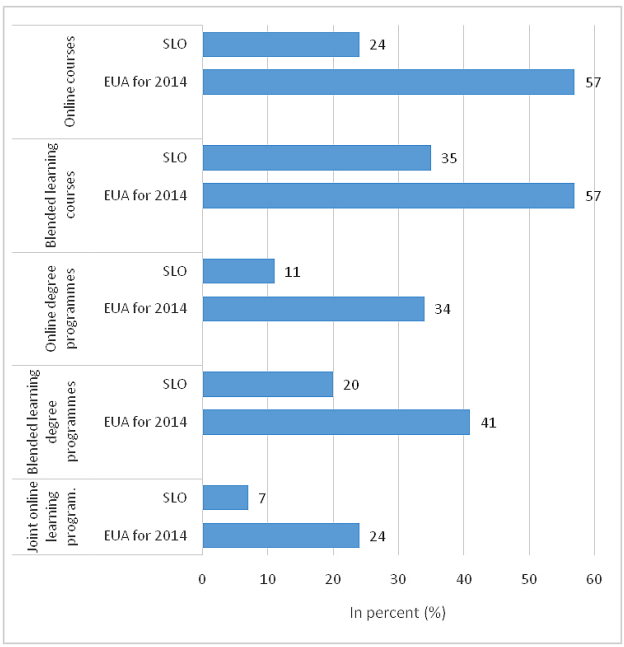

Figure 1. e-Learning offer in Slovenia and European countries by e-learning categories

The achieved level of EL in HE rely on multiplicity of complex and intertwined factors [8]. In this section the readiness of HE institutions in Slovenia regarding technological infrastructure, resource and management

[2] Representativeness of the survey based on comparison of the sample and population distributions by size, status and field of education for HE institutions in Slovenia is explained in [5] on page 22-23.

[3] Inadequacy of the broad definition of EL is also proven by the fact that all respondents expect one in survey for Slovenia declared that they use ICT in educational processes. EUA Survey for 2013, relying on such a broad definition, provided similar picture: 98% institutions included in the survey use EL and 2% of them were in the phase of introducing it [3].

[4] For discussion on EL definitions see references [6, 7].

factors, and understanding and perception of EL will be examined.

B. Technological Infrastructure

The availability of majority of ICT systems and services at HE institutions for all students in Slovenia is at similar or even higher level as it is in European countries (Fig. 2). Especially favorable is the access to wireless internet connection, personalized study portal and social media, where their availability at the surveyed Slovenian institutions (45 units) is even higher than in European countries. On the other hand, the HE institutions in Slovenia are behind regarding the availability of the university e-mail accounts, access of computer laboratories and LMS. The LMS was used by 91% of the members of the EUA in 2013, whereby the Slovene data for usage in 2017 show only 71%[5].

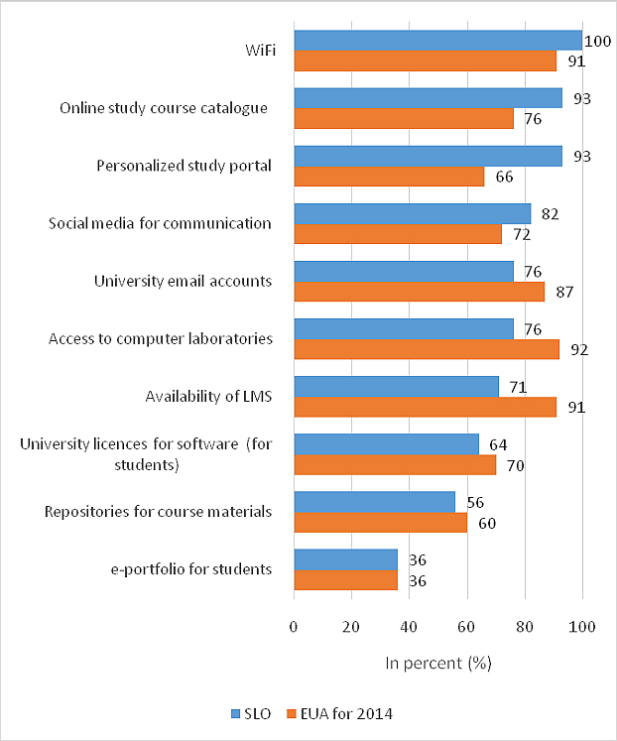

Figure 2. The availability of ICT systems and services for all students at higher education institutions in Slovenia and European countries

C. Resources

EUA questionnaires did not cover the issue of availability of resources neither by direct nor by indirect measures. In the questionnaire for Slovenia, the respondents, which declared that they do not perform neither plan to perform any type of learning (18 units), were asked about the reasons for dismissing EL. Majority of the reasons were relating to the availability of resources. Therefore, respondents' identification of main reasons for EL dismissal to some extent reflects the impact of the resource factors on the offer of EL in Slovenia.

[5] Data on LMS relate to 2013 since question on LMS was not included in EUA questionnaire for 2014.

As the most important reason appears insufficient government financial support for EL (important or very important reason for two thirds of units). As rather important reason was also determined the insufficient qualified technical staff (45%), but as expected (see Fig. 3) not unavailability of the infrastructure and equipment (22%). Rather modest importance was assigned to lack of pedagogical expertise of EL (38%) and work overload of pedagogic staff with regular activities (24%), two factors which are in theory and practice considered essential for success of EL.

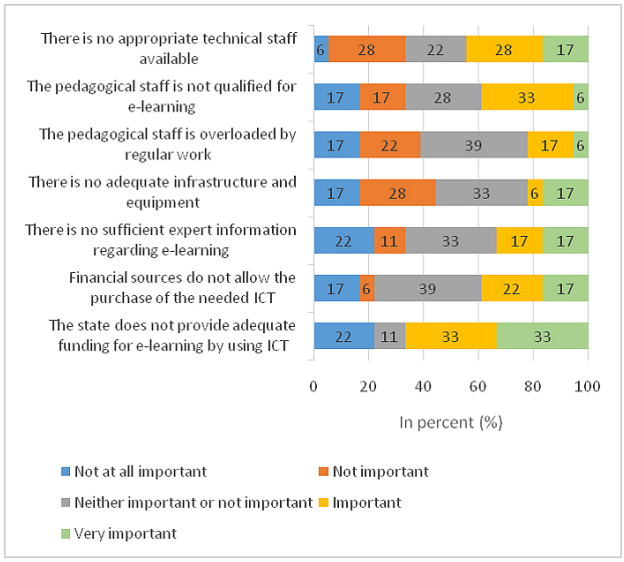

Figure 3. Resources as reasons for not implementing e-learning in Slovenia

D. Management Factors

The role of HE institutions' management on EL supply was studied through availability of strategy on ICT implementation in education, institutions' efforts on quality assurance and organizational aspects of EL.

HE institutions' ICT strategies are (for 13 percentage points) less present in Slovenia (45 surveyed units) than in European countries (Fig. 4). If the timing of the surveys is taken into account, Slovenia is noticeably falling behind the European average regarding strategic consideration of ICT in education at intuitional level.

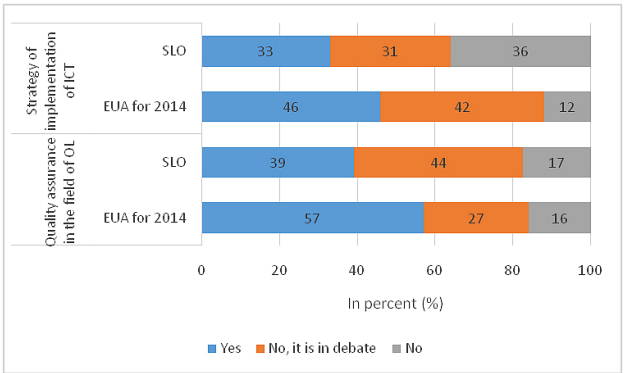

Figure 4. Strategy of implementation of ICT in education and quality assurance in e-learning in Slovenia and European countries

Similar differences are shown when comparing implementation of quality assurance procedures in the field of EL. In Slovenia 39% of the surveyed institutions with EL (23 units) implemented quality assurance procedures for EL, while this share is notably higher in European countries (57%). Approximately only 16% of the institutions do not address the issue of quality assurance, which points to the fact that the majority of the educational institutions in European countries and also in Slovenia are aware of the importance of quality assurance. But far fewer institutions actually systematically take care and monitor the quality of EL. In practice, even the Slovenian Quality Assurance Agency for HE (Nacionalna agencija za preverjanje kakovosti v Sloveniji - NAKVIS) does not have specially defined control over EL.

Comparison of survey data on current or intended organization of EL reveals that responsibility on organization issues in Slovenia is left to the individual teachers in almost half of all institutions surveyed (27 units), while such a solution is exceptional in other European countries (Fig. 5). Ignorance of organized support to EL unambiguously signals that EL in Slovenia has not been accepted as powerful and respectful form of study with well-defined role not only in achieving educational goals but also in terms of strategic and management position in a HE institution.

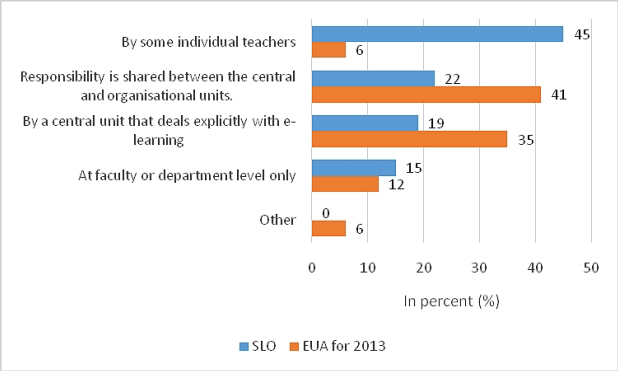

Figure 5. Organisation of e-learning in Slovenia (n = 27) and in European countries

E. *Understanding and Perception of e-Learning*

Generally, HE in Slovenia and other European countries envisage EL as an accelerator for the revision of educational methods (96% in Slovenia and 90% in EUA) (Fig. 6). It is also widely accepted that EL enables monitoring of the students' behavior in the educational process, their progress and achievements (91% Slovenia and 81% EUA). It is worth to mention that considerably more foreign institutions (56%) than in Slovenia (22%) see EL as a facilitating tool for traditional learning process, though with no substantial modifications. In addition, considerable differences are also observed in perception of EL as driver for developing students' reflective learning and critical thinking. About one half Slovenian HE institutions agree with this statement, while in other European countries this percentage is higher (63%). Rather indecisive statements of HE institutions in Europe and in particular in Slovenia on the potential of EL for traditional classes and for developing competences and skills of 21st century (problem solving, critical thinking) indicate that EL is still understood as a technology supported distance education, which has not been recognized as equal to campus universities in traditional academia world.

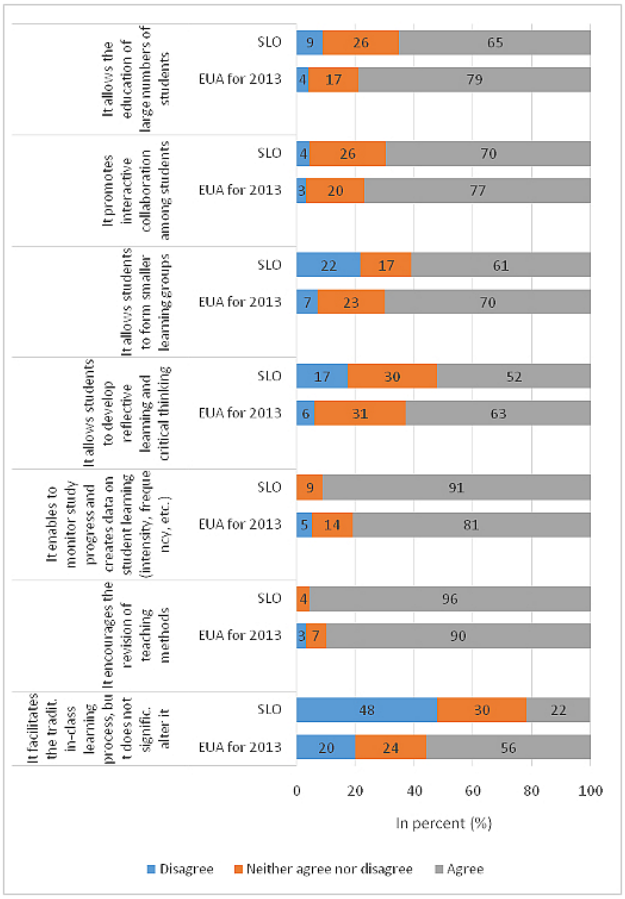

Figure 6. Perceived benefits of e-learning in Slovenia (n = 23) and in European countries

The narrowed perception of benefits of EL is also reflected by differences in ranking EL development objectives [5]. Slovenian survey results (for 23 units implementing EL) expose as the prime of five examined goals the increase of the effectiveness in classroom. This goal is also highly ranked by European countries (second position). But the most important goal of EL development in Europe is to provide more flexible learning while in Slovenia this goal is considered the least important. Surprisingly, in Slovenia very important goal is internationalization, the goal which European institutions treat as less relevant for EL (fifth position). These results point that segment of HE which is already engaged in EL (regardless EL scope and format) mainly understands the role of EL as means of rationalization of the traditional educational processes. In comparison to other European countries, Slovenian HE institutions that implement EL do not put new innovative aspects of studying with greater learning flexibility into forefront.

IV. DISCUSSION

Under the assumption of purposeful and knowledgeable use of ICT, EL could improve quality and innovate higher education in several ways [5]: opening and widening access to knowledge resources; increasing the flexibility and variety in communication among learners, teachers and others and introducing new approaches to learning and teaching; offering more flexibility in time and space of teaching and learning.

Slovenia is currently lagging behind the European trends of EL development and spread. Compared to European countries, EL offer is notably lower for online degree programs and online joint programs. Development and maintenance of these categories of EL is much more complex and demands comprehensive institutional engagement. Individual blended courses, the prevailing EL category in HE in Slovenia are mainly left to the initiatives and efforts of individual enthusiastic teachers.

The research pointed out that the current unfavorable situation in Slovenia in domain of HE EL could be to considerable extent explained by insufficient readiness of HE for EL. No doubt that technology is a precondition for successful EL. Survey data on EL in HE in Slovenia for 2017 show that technology is not a decisive problem for Slovenian EL. Major problems are soft factors: poor strategic management and organization practice together with simplified perception on the essentials and potentials of e-learning by academic leadership; pedagogic aspects of usage ICT in education are not adequately considered. Inattention of pedagogy is also present in teachers' ICT trainings, focused mainly on development of computer and digital skills but neglecting theoretical and practical issues of changing educational paradigm. Not surprisingly, that ICT tools, even specialized for education (such as LMS) are in Slovenian HE predominantly used for administration and communication.

Unfavorable situation in terms of organizational and professional readiness of HE institutions is also result of government position on EL in HE in last two decades. Government policy left HE sector outside national strategic and finance schemes of e-learning and digitalization. Only in 2016 MESS adopted strategic document *Strategic guidelines for further implementation of ICT in the Slovenian education until 2020*, which explicitly defines promotion and spread of EL as one of five strategic goals [2]. However, this document would share the destiny of many useless political papers if it was not upgraded by well specified action plan very soon.

V. CONLUSION

Comparative study of EL in HE in Slovenia and Europe revealed that at institutional level the main reason for lagging Slovenia in development trends is not technology but inadequate management and organization together with simplistic understanding of EL by academic leadership. Furthermore, the need for training and enabling of teachers and supporting staff on EL pedagogy is overlooked. These findings indicate the priority paths of actions which are needed for HE in Slovenia for establishing EL as a way for improving quality and innovating HE in Slovenia.

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Two years of gamification of the course - lessons learned

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Abstract - **Gamification is used in different levels of education (elementary, high school, university). Many research studies deal with ways to improve the education process by using game mechanics and other game-based elements in their teaching activities. This paper presents our experience with a gamified course in two consecutive academic years. In the first year, half of the students used the gamified version of the course (experimental group), and the other half of the students did not (control group). In the second year, the entire student population of the course was using an improved gamified version of the course based on the feedback from the first year. We analysed the data and compared these two years in many elements.**

Keywords – gamification, e-learning, analysis

I. INTRODUCTION

Gamification has been applied in different levels of education (elementary, high school, university) over approximately the last 5 years. Many research studies deal with ways to improve the education process by using game mechanics and other game-based elements in their teaching activities [1]. An important part of the research in the field of education is what part of the course is involved in the research. If only a smaller part of the course (for example, one topic that corresponds to a chapter from common course literature) is included in the gamification research, or if there is a time limit of a few weeks of the course, then one cannot fully realize the good and the bad sides of gamification. Some students get excited when teachers use new methods and lose interest after a few weeks.

The course lasts much longer than a few weeks and it is much harder to apply gamification for the full course content and to keep students' interest during the entire education process, like one semester that usually lasts for 15 weeks.

This paper presents our experience with a gamified course in two consecutive academic years. We gamified the whole course content and learning activities. During the first year, half of the students were in the gamified version of the course as an experimental group, and the other half of the students were in the control group. The experimental group, based on their groupings, had all gamified experiences that standard Moodle distribution provides, and we added some plugins. The control group was not formally and fully included in all aspects of the gamified version of the course but the teachers manually recorded all their earnings (badges, experience points etc.) although the students were not aware of it. We made some comparisons based on these groups and their achievements, the usage of Moodle etc.

We analysed the questionnaires that the students filled in at the end of the course, and the remarks we made during the course. We considered them as inputs for improvements for the next year (for example we provided more information about the best award). In the second year, the entire student population of the course was using the gamified version of the course. We compared these two years in many elements. Some results were expected but some were not. Finally, we compared our experience with other research studies in the area of gamification.

The rest of the paper is structured as follows: Section 2 describes related work and Section 3 enumerates the used methodology. Section 4 presents the analysis we conducted based on different data sources. Section 5 suggests the future work and Section 6 offers a conclusion.

II. RELATED WORK

Gamification has been applied in many different areas. In [2] authors provide a detailed review of gamification usage in different areas like marketing, health and wellness, crowdsourcing, education, etc. In [3] authors did a review of gamification usage in a specific area called software engineering. According to another review [4] the most common context for the implementation is education. There are various elements in education that can be used for gamification. Only a few strategies, like badges [5], leaderboards [6], or combination of both [7] are used, but there are more than 100 strategies that can be used as indicated in [8].

The differences in the previous research exist in the length of the period in which gamification was performed, the elements used and the level of education. For example, in [10] authors have used gamification only for 6 weeks in the sixth grade of primary school. In [7] gamification was implemented in two communication courses using leaderboards and badges through one semester (16 weeks).

Such different research studies are valuable for gathering ideas and gamification strategies. The most interesting are gamifications implemented in computer science courses. We found two closely related works that were in the computer science domain, [5] and [9].

In [9] gamification was performed for one semester (14 weeks), focusing on gamification in the form of ranking blocks (in other words leaderboard) displaying the achieved points. They implemented the gamification in LMS Moodle in the first year of Bachelor's degree studies in computer

science. They state that "the results empirically proved that motivation decreases by introducing leaderboards in given circumstances (students, year, and specialization)" [9].

In [5] authors used gamification in Data structures and algorithms course for one semester. Authors had two groups of students and used badges as the gamification strategy. They "found no significant differences in the behaviour of the different goal orientation groups regarding badges when analysing the log data from the learning environment" [5].

Although [5] and [9] conducted the research in the area that we are interested in, they used gamification only for one semester whereas we used it for one semester in two sequential academic years. Furthermore, we used more gamification strategies as explained in [1].

III. METHODOLOGY

We have planned longitudinal research to study the effect of gamification in the course "Web design and programming" at the 3rd year of informatics undergraduate programme at the University of Zagreb. In [1] we explained how the course was prepared for gamification.

In academic year 2015/2016 there were two groups of students: one was an experimental group and the other was a control group. "We set 50% as maximum members for experimental group with 'first-come' principle and students got involved very enthusiastically so we got even numbers for both groups." [1] The experimental group used the new gamified interfaces and were given experience points, badges, etc. They were awarded during the course if they achieved some goals as explained in [1]. For the control group we tracked all the data manually without them knowing it, but they did not get any awards.

In academic year 2016/2017 all students were involved in gamification. At the beginning of the course they got some information about gamification, and about prizes and awards, but not how to achieve them. This was in contrast to academic year 2015/2016 when the students did not know what the awards were. Another difference was that in academic year 2016/2017 we made some changes to improve gamification based on students' feedback from the questionnaire at the end of the course. The main comment in their feedback was that we should state the possible awards at the beginning of the course. The following section offers other opinions and suggestions we got in the questionnaire.

In academic year 2015/2016, there were 75 students at the beginning of the semester, that were divided into the control group (38 students) and the experimental group (37 students). In academic year 2016/2017, there were 108 students at the beginning of the semester and they were all using the gamified version of the course as the experimental group did in the previous year. In both academic years, some of the students dropped out during the semester due to the fact that they did not satisfy some of the mandatory elements like minimum points from each of two midterms, minimum total points from all homework assignments, minimum points from a project.

TABLE I. NUMBER OF REQUESTS PER STUDENT

Academic Year Group	Average	Max	St. dev
2015/2016 – E	2026,0	3424,0	600,5
2015/2016 – C	1761,4	5951,0	932,7
2016/2017 – A	2107,3	4227,0	759,7

IV. ANALYSIS

In the following subsections we present some of the analyses we conducted based on different data sources.

A. Log analysis

As a data source we used Moodle course log that was exported and prepared for us by our Moodle administrator with the same structure for both academic years due to different Moodle versions. Then we removed all records made by teachers, administrators and test students. That was the initial database. Based on a preliminary analysis we decided to use mainly the records of the students that passed the course. The reason for that was that dropout students were gradually reducing their work on the course and we would get a steeper curve.

Table I shows the number of requests per student. In academic year 2015/2016 the maximum number of requests per student in the control group was almost twice as big as the number in the experimental group. Obviously, we did not expect that. The individual data showed that log records sum of two top active students from the control group was higher than log records sum of all students from the experimental group. The 2015/2016 experimental group had higher average number than the control group, but the students had less scattered usage of LMS than the control group. All three values (average, maximum, standard deviation) of the 2016/2017 group were higher than the values of the experimental group in the previous year. One might conclude that elderly colleagues could have advised the 2016/2017 students to be more active on LMS.

To get a clear picture of how frequently and when the students performed their learning activities, it is not enough to observe only the total number of requests per student. As a teacher, one would like to know whether the students are constantly active or whether they use LMS during the whole semester. For that case, we prepared average numbers of weekly requests per student for three previously mentioned groups but also for the students who dropped out in academic years 2015/2016 and 2016/2017. These two groups have FG suffix. Figure 1 presents a graph with all five groups. A quick look at the graph gives an impression of a slowly falling trend for all groups with few peaks and saddles. In academic year 2015/2016, the experimental group had higher values than the control group for almost all weeks except for the 9th and 10th week where the control group had a slightly higher value. All three 2015/2016 groups had the highest peak in the 5th week and a saddle in the 6th week due to the 1st midterm exam. The students had to prepare for the midterm exam and they had no other important activities on the course so they were using LMS less. The same was for the 2016/2017 group with the exception in the 12th week because it has a peak instead of a saddle.

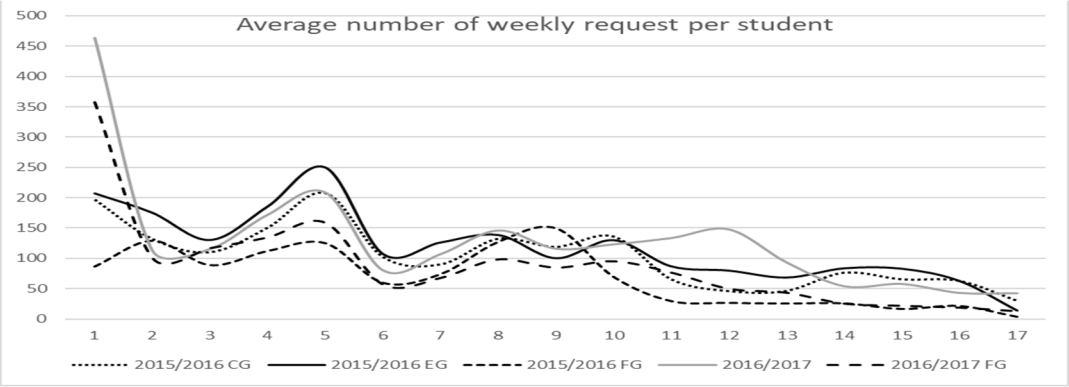

Figure 1. Average number of weekly request per student

The 2015/2016 group with dropout students (FG) had lower values than other groups for all weeks except for the 9th week. When compared to other weeks for that group, the highest value was in that week, and nobody expected it. Why? To give a quality answer we should filter the log data for that week and then sort out on activities. Definitely, the main reason was a student who worked on his Wiki seminar and had almost half of all requests for that week. We can also try to find the cause based on the course timetable to see what activities were performed during that week and the following one. In that case, we would think that the reason was the 4th homework assignment which was one of the most important. Moreover, we would have the wrong conclusion.

A curve for academic year 2016/2017 shows very intensive activities at the beginning of the course during the first week. Again, we must look at the log data for that week to get a proper conclusion. The most influenced students' activities were browsing the course in LMS. Then follow starting activities as "Introduce yourself", forum with Q&A, choosing lab group and seminar group, basic information etc. As in the previous year, the highest peak was in the 5th week and a saddle in the 6th week for the same reasons. The 2016/2017 group had higher values than the 2015/2016 experimental group from the 8th to 14th week. Most of the activities were forum for the 3rd and 4th homework, description of the 3rd homework, Wiki seminars etc.

The data presented here shows that the students from the experimental group had used LMS more than the students from the control group. In the case of academic year 2015/2016 the difference is about 13%. That could be due to the course gamification effect on the students so they want to be more present on LMS.

B. Badges

One part of gamification were badges, a detailed description of the badges system is given in [1]. In short, there were five categories of badges:

1. Medal – given to students who wrote the best homework.
2. Homework – given to students who achieved maximum points in two sequential homework assignments.
3. Forum – given to students with best comments or questions on homework assignment forums.
4. Midterm exam – given to students who achieved maximum points on midterm exams.
5. Test – given to students who achieved maximum points on self-assessment tests.

There were some other badges that we added in academic year 2016/2017: most active students, best video, best-written seminar, and badge for helping us improve the course.

Table II shows the number of badges per category. The column total presents the sum of all badges from all categories. Academic year 2015/2016 has three rows: the first row presents the achievements of the experimental group, the second row presents the achievements of the control group, and the third row shows the achievements of all students from 2015/2016.

Two questions were set. First, is there any difference in the number of gathered badges between the experimental and the control group of students in academic year 2015/2016? Note that we gave badges to the students in the control group when they earned them without their knowledge. Second, are the achieved badges different when we compare academic years 2015/2016 and 2016/2017? Since there are some badges that were newly added in academic year 2016/2017 they were excluded from the analysis. Also, "Best ERA model" badge was removed from the analysis because it depends on the number of students in academic year.

From Table II, one can see that in academic year 2015/2016 there is a difference between the control and the experimental group. The difference is more noticeable in Table III, which shows the same data in percentages. It is clearly visible that 2/3 of the badges in every category are taken by the experimental group. Note that badges were given to students based on *quality of completion* of certain activities for which all students had the same chance to do.

Also for Medal, Homework assignment (HW Assign.) and Midterm exam category, badges were given for quality of activities on which students' final grade depended.

TABLE II. NUMBER OF BADGES PER CATEGORY

Ac. year group	Total	Medal	HW assign.	Forum	Midterm exam	Test
2015/2016 – E	34	12	4	15	1	2
2015/2016 – C	17	7	2	7	0	1
2015/2016 – A	51	19	6	22	1	3
2016/2017 – A	51	19	7	12	1	13

A–All students, E–Experimental group, C–Control group

Based on these results, it can be stated that there is a difference of gathered badges between the experimental and the control group of students in academic year 2015/2016. It can be concluded that the experimental group was motivated to invest more time to do the activities better with the perspective of maybe getting an award.

Table IV presents the total number of badges in the two years. There was a higher number of gamified students in academic year 2016/2017 than in academic year 2015/2016 so we expected that there would be an increase of achieved badges in categories that are not competitive like Homework assignment, Midterm exam, and Test category, and the same number of badges in the competitive categories like Medal and Forum. Table IV shows that in academic year 2015/2016 students got more badges in the Forum category than in academic year 2016/2017. There is a -46% decrease in academic year 2015/2016 when compared to 2016/2017. The Self-assessment test category has a 333% increase and the Homework assignment has a 17% increase in academic year 2016/2017.

The results in the Medal category are not surprising since in both years the top 3 or 4 homework assignments were awarded and the number of badges was the same. The Homework assignment and the Midterm exam category had a different effect. We did not expect that only one more student would achieve maximum points on two sequential homework assignments and for the Midterm exam, there was the same number of students. We must state that for the Midterm exam it is hard to get maximum points but it was not so hard for the Homework assignment. The Test category had a big increase and that was expected. It partially depends on a higher number of students but we believe that gamification had some impact although we do not know to what extent.

The biggest surprise was the Forum category due to a decrease instead of an increase. This maybe happened because students better understood the homework assignment in academic year 2016/2017 that led to less questions and the students did not know what to ask. The only questions in academic years 2015/2016 and 2016/2017 were more or less related directly to misunderstandings of homework assignments.

Based on the results form Table IV we conclude that gamification does not have such a big impact as results suggested for academic year 2015/2016. There is a need to use gamification for a few more years to discover the real impact.

TABLE III. PRECENTAGE OF ACHIVED BADGES IN 2015/2016

Group	Total	Medal	HW assig.	Forum	Midtem exam	Test
Experi-mental	66.7%	63.2%	66.7%	68.1%	100.0%	66.7%
Control	33.3%	36.8%	33.3%	31.8%	0.0%	33.3%

TABLE IV. NUMBER OF BADGES FOR ALL STUDENTS

Ac. year group	Total	Medal	HW assign.	Forum	Midterm exam	Test
2015/2016	51	19	6	22	1	3
2016/2017	51	19	7	12	1	13
Difference	0	0	1	-10	0	10
Difference in %	0%	0%	17%	-46%	0%	333%

C. *Weekly surverys*

Early feedback is important to teachers to know how satisfied the students are with the course and to enable them to react if there is a reason. To obtain that information, we gave students short surveys so they would provide us with feedback on the last week's course material, teaching methods and satisfaction with the teacher. In the gamified version, we extra rewarded students who fill out such surveys.

Figure 2 shows that the interest in filling out these surveys decreases over the semester. The figure presents the percentage of students who fill out the survey each week. We need to use percentages for the data to be comparable between the years. The control group and the experimental group in academic year 2015/2016 showed a clear gap between them, which states that a higher percentage of the students in the experimental group were willing to give feedback if they were rewarded.

In academic year 2016/2017 students dropped out in the middle of the semester so we calculated the percentage for the first five surveys with 108 students and the last five surveys with 105 students.

There were peaks and saddles regarding filling out the surveys in every line in Figure 2. One can conclude that students fill out one survey and then some of them skip the next one. In addition, some students told us that at the beginning they did not know how or could not find the survey, so some changes were made related to that at the beginning.

The most interesting part of Figure 2 are the last five weeks where gamified students were more motivated to fill out the surveys than non-gamified ones. In the last five weeks for academic year 2016/2017 values are all above the 2015/2016 curve.

We can conclude from Figure 2 that gamification can improve the students' motivation to fill out the surveys. It cannot be stated clearly by how much, because there is one problem. Some students may fill out these surveys just to get the points and there is no way to tell in most cases who such students are.

Figure 2. Percentage of weekly survey submission

D. Levels

One of the most recognized goals in computer games is getting the highest level. Table V shows the number of students per gained level and its percentage. In academic year 2015/2016 more students from the experimental group gained the highest level (7) than from the control group.

36.3% of students in the experimental group and 25.7% in the control group had two highest levels (6, 7). Unexpectedly, in academic year 2016/2017 only one student (1.3%) gained the highest level. However, 30.8% of students gained two highest levels, which was very close to the same levels for all students (30.9%) in the previous year.

On the other hand, we must examine three lowest levels in academic year 2016/2017 gained by five students. These students passed the course so we have to ask ourselves about the reason for their poor achievement. Two of them earned many points and got good grades (3 and 4 in a scale 2,3,4,5 where 5 is the best). The other three had more than enough points to pass the course and they earned the passing grade (2). The only reason why they achieved lower levels is that they earned some experience points but did not want to collect them.

There is no doubt that some students would like to climb on the ladder of levels in the gamified course especially if they got a good reward. For others, that is not "their game" and they thought their path is in the usual academic system.

TABLE V. SUDENTS PER LEVELS

Level	2015/2016 – E		2015/2016 – C		2015/2016 – A		2016/2017 – A	
	No	%	No	%	No	%	No	%
1							2	2.6
2							2	2.6
3							1	1.3
4	1	3.0			1	1.5	2	2.6
5	20	60.6	26	74.3	46	67.6	47	60.3
6	8	24.2	7	20.0	15	22.1	23	29.5
7	4	12.1	2	5.7	6	8.8	1	1.3

A–All students, E–Experimental group, C–Control group

E. Academic achievements

The course is organized in a way that students can acquire knowledge and skills in the area of Web technologies through earned points in the following categories: homework assignments, midterm exams, project, and total number of points. Table VI shows points (average, maximum and standard deviation) for three groups in each category.

The Homework assignments category showed, as expected, that the 2015/2016 experimental group had higher values for average and maximum than the 2015/2016 control group. In addition, the 2016/2017 group had higher values for average and maximum than the 2015/2016 experimental group and the 2015/2016 control group.

In the Midterm exams category, the 2015/2016 experimental group again had higher values for average and maximum than the 2015/2016 control group. Contrary to that, the 2016/2017 group had lower values for average and maximum than the 2015/2016 experimental group and the 2015/2016 control group.

The Project category follows the Homework assignments category for average value but maximum value was the same for all three groups.

Finally, for the Total points category, the 2015/2016 experimental group had higher values for average and maximum than the 2015/2016 control group. The 2016/2017 group had equal values for average as the 2015/2016 experimental group and had higher values than the 2015/2016 control group. The 2016/2017 group had higher values for maximum than the 2015/2016 experimental group and the 2015/2016 control group.

F. Final questionnaire

One of the last activities on the course in each semester was to fill in the questionnaire. The questionnaire for academic year 2015/2016 consisted of questions divided in many categories, whereby one of them was about gamification, and it was given only to the experimental group. 76.9% thought they liked the gamified version of the course. The next question was "What was your curiosity level about the secret bonuses (awards)" and for 38.5% of students it was high, whereas 46.2% answered it was medium.

TABLE VI. POINTS IN CATEGORIES

HOMEWORK ASSIGNMENTS			
Ac. year group	Average	Max	St. dev
2015/2016 – E	14.8	23.0	3.6
2015/2016 – C	14.2	22.3	3.5
2016/2017 – A	19.1	29.0	4.1
MIDTERM EXAMS			
2015/2016 – E	9.3	13.1	1.7
2015/2016 – C	9.1	11.9	1.6
2016/2017 – A	7.8	11.7	2.0
PROJECT			
2015/2016 – E	31.1	45.0	8.8
2015/2016 – C	29.4	45.0	9.4
2016/2017 – A	31.6	45.0	7.0
TOTAL POINTS			
2015/2016 – E	66.3	91.4	12.7
2015/2016 – C	63.4	90.0	12.4
2016/2017 – A	66.3	94.7	11.8

A–All students, E–Experimental group, C–Control group

The next question was "Did you expect some special bonuses (awards) based on your success" and 84.6% answered yes. For question "Do you feel that the bonuses were appropriate in terms of the effort you have made" 61.5% answered yes. For question "If you knew about the bonuses (awards) in advance, would you make more effort to win them?", 53.9% answered they would make more effort, 43.3% would make equal amount of effort and 3.9% said they would make less effort. The last question for the analysis was "Would you recommend that the next year course uses the gamified version for all students" and 88.1% chose yes.

V. FUTURE WORK

Gamification is not an easy element to research. Many factors conceal the effect of gamification. To expose the effects of gamification thoroughly, extensive research is needed that should be conducted over several years of using gamification. We will continue using gamification and track the effects of different elements. Next, we plan to do a deep analysis of grades and try to see if there is any correlation between grades and other elements. With every academic year we will try to improve the gamification based on comments that we get from students' final questionnaire at the end of the semester.

VI. CONCLUSION

Some questions have arisen about the efficiency of gamification from the numbers presented in this paper. Is gamification responsible for the higher values or is this just a coincidence? The results show that gamification has some impact on simpler activities like surveys and self-assessment test. On the other hand, it seems that gamification does not have such a big effect on the quality of work. The authors think that students used the course materials more and performed the course activities better because of human curiosity and that is one of the elements of gamification. Both curves for the average number of weekly request per student and the percentage of weekly survey submission have similar falling trend towards the end of the semester, meaning gamification could not maintain the same interest in students throughout the semester. Most academic achievements were equal or higher in the second academic year than in the first academic year regardless of the groups we compared. That is not in direct connection to gamification per se, but mainly to the improvements we made in providing the information about possible awards, which had feedback effect on gamification.

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Learning Scenarios and Encouraging Algorithmic Thinking

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***Abstract* - Although contemporary education places learners at the center of the teaching process, in most of our schools, students are mostly educated by traditional outdated teaching methods. Students should be active participants in the educational process that will, through research in collaboration with the teacher and other students, acquire new knowledge and develop various competencies, especially in the STEM field. The traditional role of the teacher, as the main source and knowledge transferor, is changing, so preparation for teaching should be adapted to such changes. Learning scenarios can contribute to the development of innovative ideas for the implementation of educational activities, including modern teaching methods using digital tools and digital contents. The Erasmus+ project "Games for Learning Algorithmic Thinking" begins with the education of primary school junior grade teachers, who will develop such learning scenarios and apply them with their students. The paper presents how the appropriate learning scenarios can stimulate the algorithmic thinking of young students in everyday situations.**

Keywords – learning scenario, algoritmic thinking, games and learning; primary schools teachers

I. INTRODUCTION

Instead of teaching facts, generalizations and content that was characteristic of the traditional school, in contemporary teaching based on the co-constructivist curriculum, emphasis is placed on active learning, affirmation of pupils' potential and the development of specific interests of each individual [27], [24]. Such a contemporary approach continues to reconsider the roles of the participants in the teaching process, placing students at the center of the educational process. There has been a lot of interest in changing the educational process itself, that is, to provide new teaching methods that can structure the learning task, guiding learners through the process of learning and helping them to understand and apply the acquired knowledge.

In the Croatian National Curriculum Framework for preschool education and general compulsory education in primary and secondary schools, explaining the advantages of the curricular concept, it is stated: "Living and working in a modern society of rapid change and sharp competition require a new type of knowledge, skills, values and attitudes, i.e. new competences of the individual, which emphasize the development of innovation, creativity, problem solving, development of critical thinking, entrepreneurship, computer literacy, social and other competences" [12]. Bearing in mind the demands of the time we live in, it is necessary to approach curriculum reforms following the context of global social and educational reforms.

Contemporary teaching approaches like project based learning, problem based learning, inquiry based learning, scenario based learning and reflective learning in teacher education have recently gained considerable attention. Most of the studies have been conducted with the aim of comparing the efficiency of contemporary teaching approaches with traditional methods. The use of technology in all sectors, particularly in education, requires teachers with certain digital competencies in order to use the teaching technology and make the learning process more interesting to students. Schelfhout et al. [26], emphasize that the most fundamental problem encountered during the learning-teaching process is that students memorize the new information and fail to convey what they have learned into new situations. European Schoolnet launched the European Coding Initiative for the promotion of teaching and learning programming and coding and stronger integration of coding in K12 education. Teachers are provided with support in the form of teaching materials, tools and lesson plans for informal learning. In a study on the level of the European Community, Gander et al. [11] point out that European citizens have become consumers of ready-made software products, and conclude that digital literacy (a set of basic skills) and computer science (research subject) are essential components of modern education. Under the influence of various trends, special emphasis has been placed on the development of algorithmic/computational thinking, which becomes one of the core competencies for the 21st Century [3]. According to the research in CARNet project "e-Schools: Establishing a System for Developing Digitally Mature Schools", schools in Croatia are on average placed under the category "digital beginners", where teachers are insufficiently using Information and communication technology (ICT) to improve teaching. Furthermore, learning to code is not sufficiently present in schools because it is considered that students find programming too difficult and uninteresting. The DigComp Framework pointed out that digital content creation represents one of the five major digital competence areas, which includes the competence of programming, described as "the ability to plan and develop a sequence of understandable instructions for a computing system to solve a given problem or perform a

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specific task." This area is mostly abandoned in primary schools, where students do not have the opportunity to learn programming or algorithmic thinking. Learning outcomes related to programming should be represented in various school subjects and integrated into the daily learning through different school subjects starting from the first day of school.

Within this context, teachers who are one of the most outstanding elements of education should possess skills of being able to implement contemporary approaches that would enable students to carry out active learning. Jakee [15], claims that active learning is a much more effective process than the process in which the teacher "spoon-feeds" students. It is the former process that students gain advanced thinking skills from. Therefore, the traditional teaching methods that are mainly based on an objectivist approach are considered unsatisfying. Contemporary education is based on research, exchange of information, teamwork, connecting different cognitions and applying knowledge and skills. Such a curriculum encourages critical thinking, self-conceptualizing conclusions, solving problems, creativity in approach and communication among students.

II. CONTEMPORARY LEARNING AND TEACHING METHODS

A. *Learning strategies toward active learning*

The founding of modernity in teaching activities is reflected in the interactive relationship between all the elements of the didactic-methodical field which are mutually conditioned. The effectiveness of teaching activities at all stages of the teaching process (preparation, implementation and evaluation) implies a modernity in approaches through the application of strategies, methods and techniques of teaching the workshop, project, bulk-research, self-research type of educational work. Creating teaching scenarios in the teaching process, as stated by Buljubašić & Petrović [4], is based on the features of new generations and new ways of communication, an accelerated and changing environment and on technological advances. In this context, there are numerous opportunities for the development and implementation of the teaching process as a partnership based on the maximum involvement of all participants and on mutual co-operation. Emphasis is put on student-centered learning, tailored to the needs of students.

Teaching activities oriented to discovering cognitions and the productive application of knowledge, provide access to the learning and teaching process, where students create, discover, independently plan, give the initiative, ask questions and investigate. Students are asked to understand, to express their own view of certain phenomena, to critically think, to build a creative approach for problem solving, and not just to reproduce content. "Students are especially encouraged to connect knowledge with personal experiences and knowledge, experiences of everyday life and with the knowledge of other subjects' areas" [2]. Teaching, besides explicit theoretical knowledge, should be focused on the process of gaining knowledge, i.e. on understanding of the process of research and discovery.

Therefore, it is necessary to apply teaching strategies which, according to Cindrić et al. [6] include "a thoughtful combination of methods and procedures that encourage the students' activity and enable him to manage his/her own learning process in order to achieve the goals of education." Marzano et al. [17] discuss learning strategies that affect students' achievements. They are differentiating between student-oriented strategies (e.g. summarizing, recording, nonlinguistic representations, cooperative learning, goal settings, creating and verifying hypotheses ...) and putting them into the context of conducting a research in instruction. The teaching methods as a combination of various methods, through which the learning process is structured in order to achieve predetermined goals that teachers and students apply in the educational process [18], should contribute to the individualization in teaching students and thereby respect the different learning styles of students. Fox & Hoffman [10] define individualization of teaching as a flexible, fair and intelligent approach to teaching and learning and use the terms "different assessments", "inclusion", "learner-centered teaching". Other authors conceptualize this term as "adaptive teaching" or "personalized learning" [32] and "unique learning design" [13]. Taking into consideration the specificities of students in the context of individualization of teaching, the use of various methods and teaching strategies is suggested which will lead to active learning. Active learning in the narrow sense of the word is defined as "learning that provides a high level of autonomy and self-control to students, as well as an application of various mental strategies and specific cognitive abilities for distinguishing important and unimportant information, analysis and comparison, knowledge acquisition based on previous experiences and critical thinking" [21]. As Slavin [29] points out, we are talking about collaborative learning methods for which research clearly suggests that they have significantly improved pupil achievements in most subjects and degrees. Students together plan, investigate, co-operate in order to help each other achieve the intended teaching goal. The aforementioned context of the contemporary teaching process determines according to Suprayogi & Valcke [30] the application of strategies, the diversity in learning activities, monitoring individual student needs and achieving learning outcomes. More attention is focused on the application of modern technology in the teaching process. As emphasized by Pejić Papak & Grubišić Krmpotić [20], technology in this sense is not the purpose for itself. Teaching will not be enriched by formal introduction of ICT-based teaching methods and forms without a critical reflection on the reasons for implementation, learning outcomes as well as a didactic modeling for the purpose of improving the teaching process.

B. *ICT in Education*

Information and communication technologies ensured an application of new opportunities in the educational process. Computer science education in primary or secondary schools has reached a significant deflection, changing its focus from ICT-oriented to

essential computer science concepts. In Croatia, computer science education as a school subject is usually named Informatics. At the very beginning, teaching Informatics started with teaching programming. Programming was a good way to convey a process of problem solving. Later on, the content of Informatics switched to the implementation of ICT, mostly assigned to "applied" Informatics. Mark Prensky stated that "The True 21st Century Literacy Is Programming" [23], but on the other hand, Dagiene and Stupuriene [7] allege that we should avoid 'the equation': computer science = programming, which is accused of killing interest in computer science among school students in 1990. Not all students will become professional programmers, but by writing their own programs, they practice creative and computational thinking, and gain skills of the digital era, which are useful for their professional and personal lives [7].

As technology has emerged in all school subjects, not only Computer science teachers are allowed to use it. Teachers of junior grade in primary school, who are one of the most outstanding elements of education, should possess skills of being able to implement contemporary approaches with or without technology that could enable students to carry out active learning. The results of the research [20] showed (N=220) that 80% of the junior grade teachers and 83.5% of the undergraduate students of the Teacher Study agree with the statement that "Using ICT is an indispensable part of teacher education". This provides a space for further use, development and implementation of modern technology in education. Active learning by using technology enables a faster realization of certain activities. However, teachers will be able to conduct effective teaching when they are fully equipped in their professions. Therefore, it is clear why teacher education is crucial in this sense [14].

III. THE ROLE OF LEARNING SCENARIOS IN MODERNIZING THE TEACHING PROCESS

Teaching has always involved some elements of 'design' in the process of preparation and planning. Classroom teaching with minimal equipment allows teachers to adjust their approach to the immediate needs of learners [1]. Teachers can, only by observing, quickly ascertain if learners are fulfilling their tasks, while they can also rearrange groups or reassign activities, give some additional explanations and ask questions to help learners understand and accomplish their tasks.

Despite afore mentioned, teachers have to plan or structure the learning situations in advance. The situation may be as small as a single task or as large as a whole course. In a learning situation, any of the following may be designed with a specific pedagogic intention: learning resources and materials; the learning environment; tools and equipment; learning activities; the learning programme or curriculum [1]. Student activities should be at the center of the design process, and they should be carefully aligned with the desired learning outcomes and with the processes of assessment and review. Learning scenarios are materials intended for teachers that offer innovative and imaginative ideas for conducting teaching activities using modern pedagogical methods with the use of appropriate digital content and tools [5]. Although it has been mentioned that Learning scenarios use digital content and tools, they can be created for other activities that do not use technology. It is useful to distinguish activities from tasks. In a formal educational setting, tasks are required from learners by the demands of the curriculum. Activities are engagement of learners in response to the demands of a task. [1]

Learning scenarios are designed to motivate students, to bring them closer to the content and to link the content of a teaching subject to everyday life situations. In addition, contemporary education strives for a stronger content integration of different school subjects. That is why the learning scenarios should have accentuated correlations with other teaching subjects, as well as designed activities in order to emphasize and encourage this connection. Designing a learning scenario is a process by which teachers plan or structure a learning situation. A scenario consists of a subject and class, a complexity level, key concepts, learning outcomes and a description of activities complemented with materials and resources for the teacher and students [5]. In line with the focus on activity, learning outcomes are typically expressed in the form learners will be able to /*verb*/ /*qualification*/ where the verb describes the kind of an activity that learners will undertake (e.g. describe, interpret) and the qualification describes the context, scope or method to be used. One of the key features of problem-based learning is the use of scenarios relating to the real life as a point of departure for the learning process [8]. The intention is to get the students associate the scenarios with real-life situations. The scenarios are considered to provide a meaningful context for the concepts and principles that will relate to future knowledge acquisition. Although good teachers will provide with a direction on how tasks should be carried out, and even determine students' activities, different learners may still have their own ways of continuing the activities.

IV. ALGORITMIC THINKING

Algorithmic thinking primarily develops solving various problems that reflect real issues, through in which the application of knowledge from other areas, especially science, mathematics and logical disciplines is necessary. In a broader sense, computational thinking includes many components of problem solving: Formulation and restatement of tasks; Data analysis; Decomposition; Modeling and simulation; Recognition of pattern solution components; Automation of decisions; Efficient use of resources; and Abstraction of decision process [7]. Algorithmic thinking skills are supported and enhanced by a number of dispositions or attitudes, which are essential dimensions of Informatics and digital literacy. The concept of Algorithmic thinking has been present since the 1950s and 1960s, referring specifically to using an ordered and precise sequence of steps to solve problems and (when appropriate) a computer to automate that process [31]. Today, it is often replaced with the term "computational thinking". Wing [33] defined computational thinking as "solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science."

The cognitive aspects of algorithmic thinking involve the use of heuristics, a problem-solving approach that involves the application of a general rule of thumb or strategy that may lead to a solution [33]. This heuristic process involves searching for strategies that generally produce the right solution but do not always guarantee a solution to the problem. For example, "asking for directions in an unfamiliar place" from a local usually leads one to the right place, but one could also end up in a wrong place, depending on one's understanding of local geography [31]. Algorithmic thinking concepts have been used in other disciplines through problem-solving processes so it can be included in primary education. Wing [33] said, "we should add computational thinking to every child's analytical ability alongside to reading, writing, and arithmetic." Embedding computational thinking in teaching and learning junior grades of primary school requires teacher educators to prepare teachers to support students' understanding of algorithmic thinking concepts and their application to the disciplinary knowledge of each subject area. Specifically, teacher educators need to provide teachers with the content, pedagogy, and instructional strategies needed to incorporate computational thinking into their curricula and practice in meaningful ways, enabling their students to use its core concepts and dispositions to solve discipline-specific and interdisciplinary problems and to enhance existing learning outcomes.

When explaining a problem as algorithm, it is breaking down in smaller sections, more familiar, that can be solved using a set of rules (algorithms) to find solutions and using abstractions to generalize those solutions to similar problems" [33]. Algorithms are central to both computer science and computational thinking. Algorithms underlie the most basic tasks everyone engages in, from following a simple cooking recipe to providing complicated driving directions. Due to the fact that there is a general misconception that algorithms are used only to solve mathematical problems and are not applicable in other disciplines, [31] it is important to introduce students to algorithms by first using examples from their daily lives. For example, in early grades, teachers could highlight the steps involved in brushing teeth, while in later grades, students could engage in following steps during a lab experiment. However, according to Shelton [28], the development of algorithmic thinking in children at elementary school does not necessarily require the use of a computer, but can also be achieved with "unplugged" methods, which are not an alternative for using a computer but are to be used as an auxiliary activity in understanding and solving the problem. Understanding algorithms as a set of precise steps provides the basis for understanding the manners of the development of an algorithm that can be implemented in a computing program. Students can be exposed to the computational thinking concept of abstraction by creating models of real life [31]. Teachers can have a new role in the teaching process to assists a student, altering the learning task so the student can solve problems or accomplish tasks that would otherwise be out of reach. The teacher intervenes at the appropriate time for a specific student in the context that increases the student abilities for solving the task. For example, a teacher may help a child in a board game by reminding him/her of the rules or by suggesting strategic steps if the child is stuck [25]. As Karadag [16] points out, Game Based Learning (GBL) is generally effective in primary education because primary school learners are at an age when games are particularly efficient. During this period, they also experience difficulty in learning abstract concepts and procedures, requiring both entertaining methods and an active involvement in learning activities.

Algorithmic thinking can be developed through all school subjects for which appropriate teaching methods are needed either with or without technology. Today, there are many different ways in which young children can learn basic programming concepts e.g., educational computer games [22]. Any learning situation can be improved by incorporating such methods in an appropriate learning scenario.

V. THE GLAT PROJECT

Encouraged by thoughts to enhance the teaching skills of primary junior grade teachers, the Erasmus+ project "Games for Learning Algorithmic Thinking" (GLAT) was developed. The main goal of the project is to encourage the inclusion of coding and algorithmic thinking in teaching different subjects in lower grades of elementary school in a fun and attractive way. This project started on October 2, 2017, and will run until September 1, 2019. The project coordinator is the University of Rijeka - Department of Informatics (leader Nataša Hoić Božić, Ph.D.). The partners in the project are: The Faculty of Teacher Education, University of Rijeka, University of Tallinn (Estonia), The Faculty of Pedagogy of the University of Ljubljana (Slovenia), University of St. Cyril and Methodius in Skopje (Macedonia) and Southwest University "Neofit Rilski" in Blagoevgrad (Bulgaria). The most important activities of the project include the professional development of primary school teachers with various innovative teaching methods using information and communication technology. Special focus will be on using educational strategies of Game Based Learning (GBL) and gamification in order to foster creativity, logical thinking, and problem-solving skills. During the project teachers will be grouped in a focus group to participate in education, formulated according to a mixed e-learning model. The key part will be the three workshops to be held in Croatia while the online part of the education will take place through the e-learning system Moodle. The focus group teachers will use the expertise of the project team to apply new knowledge for the development of learning scenarios, and apply those learning scenarios in schools with their students.

The topic of the first workshop, which will be held on April 5 and 6, is Game- Based Learning (GBL) and unplugged activities. The participants will be introduced to the use of games in different school subjects and the conduction of unplugged activities in classroom. The emphasis is on the examples of learning scenarios and the accompanying materials for the implementation of the activities, while the participants will conceive such activities, create a learning scenario and perform it with their students. For this purpose a Learning Scenario Template was produced as shown at Figure 1.

Games for Learning Algorithmic Thinking

Predložak za izradu scenarija učenja i poučavanja

(Learning Scenario Template)

Naziv scenarija (Learning Scenario Title)		
Nastavni predmet/Razred (Course/ Grade)		
Ishodi učenja (Learning Outcomes)		
Cilj, zadaci i kratki opis aktivnosti (Aim, Tasks and Short Description of Activities)		
Ključni pojmovi (Keywords)		
Korelacija i interdisciplinarnost (Correlation and interdisciplinarity)		
Trajanje aktivnosti (Duration of Activities)		
Metode poučavanja (Teaching Methods)		
Oblici poučavanja (Teaching Forms)		
Potrebni alati (Tools)		
Materijali za nastavnike (Resources/materials for the Teacher)		
Materijali za učenike (Resources/materials for the Students)		
Razrada aktivnosti (Teching summary)	Motivacija – uvod u aktivnost (Motivation /introduction)	Trajanje (Duration)
	Provedba aktivnosti (implementation)	
	Refleksija na provedenu aktivnost (Reflection and evaluation)	
Prilozi (Annexes)		

Figure 1. Learning Scenario template

One such activity can be spatial orientation or moving through the maze. While engaging in this activity as part of the Science lesson dealing with reviewing and practicing the concepts of left and right, up and down and back and forth, students will mark the route by placing appropriate arrows in the maze as shown on Figure 2.

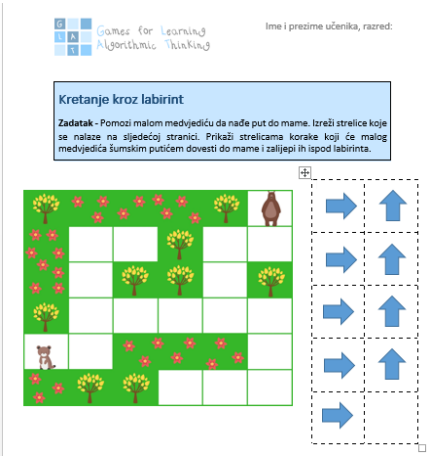

Figure 2. Example of the students' worksheet for unplugged activity "spatial orientation"

Furthermore, students will lead each other from the initial position to the final position in the classroom. Students will also get familiar with the concept of algorithm as a series of commands to be executed for achieving the task - arriving at the assigned location. Besides specifying the learning outcomes, aim, tasks and description of activities, the learning scenario includes a part for teaching summary. In this case, for the motivation part, the teacher can stand next to the door of the classroom and ask the students for help to get to the blackboard. The teacher can write his "path" on the blackboard stating the steps (commands) he has made. Other possible ways of getting from the door to the blackboard can be pointed out in the conversation with students, which brings a conclusion that the same task can be solved in several ways. The term algorithm is explained as a series of actions to be made in order to to accomplish a particular task. The implementation of activities include individual work, i.e. filling the worksheet (Fig.2), and team work in groups of four, where students lead each other in the maze made of desks and chairs in the classroom and write the algorithm of the movement. As a reflection on the conducted activity students are required to provide examples of simple tasks they do every day (getting dressed, washing, preparing school bags ...) and devise an algorithm for solving those tasks. The topic of the second workshop will be Problem Based Learning (PBL), online quizzes and logical tasks, while Games and Tools for Programming will be the topic of the third workshop.

Teacher and student feedback will be used to improve the designed e-learning course, and an improved version of the learning materials and the best examples of learning scenarios will be available as one of the projects results. The aforementioned materials will be published in Croatian and English, so teachers from across Europe can use them together with other Croatian teachers. The general goal of the project is the development of algorithmic thinking of younger students, which will improve students' attitudes towards coding and in the long term contribute to the reduction of the "fear" towards programming. In order to achieve this goal, it is necessary to develop students' digital content creation competence already from the first grade of primary school, and it can only be conducted by the teachers who have been trained for it.

VI. CONLUSION

The need for the introduction of coding and development of algorithmic thinking in schools has been already recognized in Europe. According to "Computing our future - Computer programming and coding - Priorities, School Curricula and Initiatives across Europe", some EU countries integrate coding in their curricula. It is mainly integrated at the secondary level and as a part of a computer science or informatics course or a separate subject but only for some school programmes. There are not enough appropriate subjects in studies for future primary school junior grade teachers, and especially not enough subjects within which the models such as Game Based Learning or the introduction to the elements of creating content and coding into teaching could be implemented. An integration of GBL scenarios in the teaching process can increase teachers' knowledge and skills and enhance their teaching practices.

The GLAT project will try, with contemporary methods and teaching strategies and through different school subjects, to implement the algorithmic way of thinking, problem-solving skills, logic and creativity into the daily learning.

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Educational Computer Games and Gamification in Informatics and Information Technology Education – Teachers' Points of View

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***Abstract* - The Informatics and Information technology (IT) teachers' attitude towards use of educational computer games and gamification is in the focus of our study. Main research questions in the study are: What type of educational computer games (ECG) regarding costs are preferred by the teachers? Which pedagogical purposes of ECG do teachers prefer? Which are the most used types of ECG regarding to game plot? What type of end user devices are used in playing ECG in classes? Which are the information sources for teachers about educational computer games? What is the efficiency of use of educational computer games in different pedagogical activities? Is there a statistically significant difference regarding barriers for use of ECG for teachers who use ECG and who do not ECG?**

Keywords – educational computer game; gamification, teachers; Informatics education; Information technology education; secondary school (key words)

I. INTRODUCTION

Games are a powerful tool for motivating and engaging the learners in the learning process. The latest trend in education is computer game based approach and gamification [5]. One of the factors for effective implementation of ECGs in school practice is teachers' readiness and attitude.

The Informatics and Information technology (IT) teachers' attitude towards use of educational computer games and gamification is in the focus of our study. We conducted survey with 350 teachers in different subjects. 97 of the respondents teach IT and Informatics.

Main research questions in the study are: What type of educational computer games (ECG) regarding costs are preferred by the teachers? Which pedagogical purposes of ECG do teachers prefer? What are the most used types of ECG regarding game plot? What type of end user devices are used in playing ECG in classes? Which are the information sources for teachers about educational computer games? What is the efficiency of use of educational computer games in different pedagogical activities? Is there a statistically significant difference regarding barriers for use of ECG for teachers who use and such who do not use ECG? The state of the art will give directions for future development of ECG's and methodology for their integration in school practice.

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II. RELATED STUDIES

The teachers' attitude towards ECG has been studied from different points of view. In [7] the authors discuss the teachers' role in the implementation of immersive digital games. They conclude that "whilst negative teacher attitudes towards the use of immersive digital games in the classroom persist, the potential impact of immersive digital games in the classroom will not be fully realized".

De Grovea at all [2] argue that "Making teachers and pre-service teachers familiar with using digital games in an educational context can only be successful when adequate content is available." In order for innovative approaches to be involved in education the teachers have to be ready for technological challenges. They summarize the opinion of a lot of researchers "that the use of digital games in a classroom is often looked upon with skepticism by teachers". In [1] the author outlines six factors that hinder teachers' use of games in the classroom: "Inflexibility of curriculum, Negative effects of gaming, Students' lack of readiness, Lack of supporting materials, Fixed class schedules, and Limited budgets.

The 11 studies regarding factors that support or hinder adoption of EVG (educational video games) by the teachers are summarized in [5]. These studies are held in Greece, USA, Turkey, Sweden, Finland, Belgium, France, and Taiwan. Classroom management and possibilities for curriculum integration are outlined as a negative influence on the teachers' acceptance of EVG. As positive influence the following factors are mentioned: gaming experience, environment (technical infrastructure and support), social influence, training on EVG, student related factors, perceived learning opportunities, personal factor (openness, innovativeness…).

Sanches-Mena and Marti-Pareno [6] conducted online structured interview with 16 higher education lecturers regarding adoption of gamification in their courses. Authors point out four main drivers - attention-motivation,

entertainment, interactivity, and easiness to learn; and four main barriers - lack of resources, students' apathy, subject fit, and classroom dynamics.

Some data regarding use of educational computer games as assessment tool in Bulgaria are presented in [9]. The study shows that only 22% of the respondents – teachers in IT and Mathematics, use ECG for assessment.

III. DEFINITIONS AND EXPLORATION OF SCHOOL SUBJECTS INFORMATION TECHNOLOGY AND INFORMATICS

A) Educational Computer Games and Gamification – Definitions

There are several concepts used in the area of application of computer games and gamification in educational process:

Serious games – In the research papers there is a variety of definitions and different points of view about serious games [3]. Zyda [11] describes serious game as a "mental contest, played with computer in accordance with specific rules that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives".

Educational computer games/didactical computer games – We consider them as serious computer games with clear defined educational objectives and outcomes, related to the specific school subject or university course. The educational/didactical computer games are meant for training, learning, or assessment of competences and set of learning objectives.

Gamification - Kapp [4] defines gamification as "using game – based mechanics, aesthetics and game thinking to engage people, motivate action, promote learning and solve problems." Werbach [10] outlines gamification as: "The use of game elements and game thinking in non-game contexts." Generally, gamification can be described as a concept for introducing game mechanics in a variety of processes and areas as business, marketing and education. The aims of gamification are to motivate, engage and attract users. [8]

B) School Subjects Informatics and Information Tehnology in Bulgarian Schools

In Bulgarian schools there are two subjects related to computer science – Information Technology and Informatics. Information technology (IT) is compulsory subject for students from 5th grade till 10th grade. Informatics is compulsory subject for students in 8th grade from 2017/2018 school year on and in 9th and 10th grades up until 2016/2017 school year. The subject Informatics is focused on algorithms and programming languages. The subject Information technology deals with development of digital competences with use of different software. It covers topics like computer system, operating systems, word-processing, computer graphics, spreadsheets, computer presentations, internet communication, networks, internet safety, copyrights etc.

In primary school the subject Information technology is elective and it could be offered in case the school has qualified teachers and is equipped with appropriate hardware and software.

IV. METHODS

A. Description of the Study

For the study we developed a questionnaire with 24 questions, which are spread in 111 variables divided in two main groups and several subgroups:

The first variable divides respondents in two groups – the first one consists of teachers who use educational computer games (ECG) in their practice and the second one consists of teachers who do not use ECG. The data are presented in nominal Yes-No scale.

B. Subgroups of the Variables:

We divided the questions in 17 subgroups. (Table I.)

TABLE I. SUBGROUPS OF VARIABLES

Subgroup	N	Scale
Used type of ECG according to their costs	5	nominal Yes-No scale
Pedagogical purpose of the used ECG	7	5 levels Likert scale
Used type of ECG according to game scenarios	10	5 levels Likert scale
Used type of ECG according to number of players	3	nominal Yes-No scale
Frequency of the use of ECG in classes regarding to taught subject and educational level	7	nominal scale – Every day, One time per week, One time per month, One time per several months, Never
End user devices used	6	nominal Yes-No scale.
Source of information about ECG	6	nominal Yes-No scale
Attitude of the parents and students regarding use of ECG	2	5 level Likert scale (5 – very positive; 1 - very negative)
Efficiency of ECG in different pedagogical activities	10	5 levels Likert scale (5 – high level of efficiency, 1- no efficiency)
Use of gamification according to type of delivering and development	5	5 levels Likert scale (5 – very frequent used, 1- never used).
Efficiency of use of ECG on smartphone in different educational activities	8	5 levels Likert scale (5 – high level of efficiency, 1- no efficiency)
Nessessity of additional training of the teachers to use ECG	1	nominal Yes-No scale.
Barriers in usage of ECG	13	5 levels Likert scale (5 – Definitely Yes, 1- Definitely No)
Impact of the ECG on the achievements and behavior of the students	6	5 levels Likert scale (5 – Definitely Yes, 1- Definitely No)
School policy for the implementation of ECG – nominal scale	1	nominal - Has policy, partial policy, No policy
Profile of the teachers.	15	The variables include questions regarding – Gender, Age, Work experience, level of education in which the thaught subject.
Type of sector of teaching (private, public, NGO etc.)	4	nominal Yes-No scale

The variables from subgroups 1 to 9 are only for the teachers who use ECG in their practice. The rest of the variables subgroups are for all respondents. The main research questions are relevant to the set of variables subgroups.

C. Processing of the Questionnaire

We invited 350 teachers from different parts of the country. The respondents teach different school subjects: informatics, information technology, mathematics, natural sciences etc. at primary and secondary school level. 304 of the invited teachers have responded to the questionnaire.

The Information technology teachers were 97, 40 of them also teach subject Informatics. Only 4 of the Informatics teachers do not teach Information technology. According to this we take into account the respondents from group of Information technology teachers.

For the analysis of the results we use SPSS V.23 and MS Excel 2013.

V. Findings and Results

A) Description of Respondents' Profile

In the survey participated 84% female IT teachers and 16% male IT teachers. The distribution of the respondents regarding the variable Age is presented in the Table II.

About 54% of the respondents teach in the upper secondary school level, 70% in the low secondary level, and 12% in the primary school level. The total percentage is more than 100% because most of IT teachers teach at more than one school level.

The teaching work experience is presented in the Table III.

Regarding the type of town or village the teachers worked in, they are distributed as follows: 5% work in capital city, 50% work in regional city centers, 33% work in municipality centers and 12% work in towns or villages different from above mentioned centers.

The profile of the respondents is typical for the profile of IT teachers in Bulgarian schools – mainly females, older than 40 years with more than 10 years of teaching experience.

B) Users of ECG among IT Sschool Teachers

IT teachers who use ECG in their practice are 46 (47.4%) and teachers who do not use ECG are 50 (52.6%). There is no statistically significant difference in ratios of users and non-users of ECG. We applied Binomial Test for test proportion of 0.50, P=0.685>0.05.

According to school level there is a significant difference between ratio of users of ECG in IT in primary school (92% of teachers use ECG) and in low secondary school teachers (42,64% of IT teachers use ECG), χ^2=9.674, dF=1, P= 0.0019. However, there is no significant difference between ratio of low secondary school teachers and uppers secondary school teachers, χ^2=0.03, dF=1, P= 0.8626. These results are expected because usually people think that games are suitable and typical activity for the small kids.

TABLE II. Distribution of Respondents Regarding to Variable Age

Years	**20-30**	**31-40**	**41-50**	**51-60**	**61+**
Percentage	4%	28%	45%	22%	1%

TABLE III. Distribution of Respondents Regarding to Variable Working Experience as a Techer

Years	**1-5**	**6-10**	**11-15**	**16-20**	**21+**
Percentage	15%	6%	26%	24%	29%

C) Attitudes of the Teachers who Use ECG

RQ1. What type of ECG regarding costs are preferred by the teachers?

The teachers prefer to use free online ECG – 76.1% of them use free online ECG, 66.7% use free ECG delivered by the Ministry of education or by other institutions or organisations, 8.9% use games with single payment, 11.4% use ECG with commercial license access, 9.1% use ECG that have to be payed and require specialized payment for training. The total percentage is more than 100% due to use of different type of ECG all together.

RQ2. Which are the preferred pedagogical purposes?

The answers of the questions regarding the pedagogical purpose are in 5 levels Likert scale (5 – high level of use, 1 – never used).

The descriptive statistics of variables regarding the pedagogical purpose of ECG are presented in the Table IV. The teachers prefer to use ECG mostly for activities related to mastering of knowledge and skills, obtaining new knowledge and skills, propaedeutic of involving new knowledge and skills, and revision of knowledge and skills. Assessment and evaluation however tend to be not as popular.

RQ3. What are the most used types of games regarding game plot?

The teachers use mostly games for attention development, memory games and jigsaw games. A possible reason for this trend is the fact that most of the free online games belong to the above mentioned categories – respondents show preferences towards namely free online games. The descriptive statistics for variables regarding used type of ECG are presented in the Table V.

TABLE IV. Descriptive Statistics Regarding Pedagogical Use of ECG by IT School Teachers.

	Obtaining of new knowledge and skills	**Mastering knowledge and skills**	**Revision of knowledge and skills**	**Propaedeutic of new knowledge and skills**	**Group assessment**	**Assessment and evaluation**	**Self-assessment**	**Self-learning**
N, Valid	42	44	44	41	40	41	40	39
Missing	4	2	2	5	6	5	6	7
Mean	**3.6**	**4.02**	**3.55**	**3.22**	2.64	2.54	3.00	**3.23**
Median	**4.00**	**4.00**	**3.50**	**4.00**	3.00	2.00	3.00	**4.00**
Mode	**5.0**	**5.0**	**3.0**	**4.0**	1.0	1.0	1.0[a]	**5.0**
Std. Dev	1.23	1.02	1.25	1.51	1.50	1.40	1.54	1.68
Variance	1.52	1.05	1.56	2.28	2.24	1.96	2.36	2.81

TABLE V. DESCRIPTIE STATISTICS FOR VARIABLES REGARDING USED TYPE OF ECG

	Storyline game	Games with social elements	Simmulations of sport games	Memory games	Attention development	Motor skills development	Roleplay games	Jigsaw games	Adventure games	Game with Tale storyline
N, Valid	42	44	40	43	42	42	42	44	40	41
Missing	4	2	6	3	4	4	4	2	6	5
Mean	2.98	2.68	1.90	**3.65**	**3.81**	2.91	3.14	**3.48**	2.28	2.59
Median	3.00	3.00	1.00	**4.00**	**4.00**	3.00	3.00	**4.00**	1.00	2.00
Mode	1.0[a]	1.0	1.0	**5.0**	**5.0**	1.0	1.0[a]	**5.0**	1.0	1.0
Std. Dev	1.46	1.49	1.17	1.38	1.25	1.49	1.54	1.53	1.63	1.76
Variance	2.12	2.22	1.37	1.90	1.57	2.24	2.37	2.35	2.67	3.10

About 78% of IT teachers use ECG for individual play.

RQ4. What type of end user devices are used in playing ECG in classes?

The most used device for ECG playing in classes is desktop computer – 95.3%. 34.9% of the IT teachers use laptops, 25% use interactive whiteboard, 20.9% use smartphones, 14% use tablets, and 11.9% use TV screen. These results are seen as an effect from the national strategy of ICT in education. In recent years the schools were equipped with laptops, desktop computers and interactive whiteboards. Also IT classes are held in computer labs.

RQ5. Which are the information sources for IT teachers about ECG?

The three most popular sources for information are colleagues, professional websites and social networks - 73.8% of the respondents mention that they obtain information from colleagues, 60.5% from professional websites, 52.3% from social networks, 44.2% from training provided themselves, 34.9% from trainings provided by employer, 53.3% form conferences, workshops etc.

RQ6. How doparents and students accept use of ECG from the teachers' point of view?

According to half of the respondents both students and parents have positive attitude towards implementation of computer games based education. However, students accept more positive the use of ECG in the educational process. (Fig. 1)

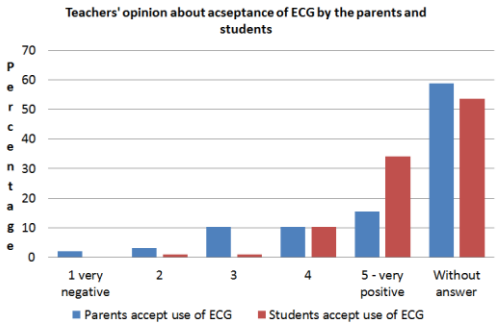

Figure 1. Teachers point of view about students' and parents' adoption of ECG

RQ7. What is the efficiency of use of educational computer games in different pedagogical activities?

The descriptive statistics given in the Table VI, show that according to IT teachers, use of ECG is efficient in all mentioned pedagogical activities.

D) Comparisson of Attitudes towards the ECG of IT Teachers who are Users and Nonusers of ECG

RQ8. Is there a statistically significant difference regarding barriers for use of ECG for users and non-users of ECG?

Every statement is evaluated with 5 levels Likert scale – 5 – Definitely Yes, 1- Definitely No.

Due to ordinal data an Independent Samples Kruskal-Wallis Test is used. The null hypothesis for every variable is: H0: The distribution of independent samples regarding groups of user and non-users of ECG are equal. The results for all variables related to the barriers of use of ECG are presented in the Table VII.

Only for two of the variables (numbered in the table with 2 and 13) there is a statistically significant difference between groups of users of ECG and non-users. The differences in teachers' opinion are regarding high prices of ECG and relevance of ECG to the school level.

The descriptive statistics outline most important barriers for use of ECG by the IT teachers – Too expensive ECG, Lack of time for preparing and becoming familiar with ECG, Lack of games with serious educational elements, Lack of information about where to find ECG with high quality. (Table VIII)

E) Use of smartphone for ECG and their pedagogical efficiency

RQ9. How do teachers adopt pedagogical impact of smartphones for playing ECG?

The level of efficiency for this group of items is evaluated by 5 level Likert scale – from 5- high efficiency till 1- no efficiency. The teachers evaluate positively the pedagogical impact of use of smartphones for playing ECG or gamified elements in all activities (Table IX).

TABLE VI. DESCRIPTIVE STATISTICS OF VARIABLES REGARDING THE PEDAGOGICAL IMPACT OF ECG

	Acquiring knowledge	Acquiring skills	Developing of creativity	Developing decision-making skills	Developing skills for experiments and fails	Developing motivation for learning	Developing critical thinking and problem solving skills	Developing communication skills
N Valid	43	43	40	43	40	41	41	41
Missing	3	3	6	3	6	5	5	5
Mean	4.16	4.23	4.18	4.12	4.08	3.88	4.10	3.56
Median	4.00	4.00	5.00	5.00	4.00	4.00	4.00	4.00
Mode	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Std. Dev.	0.95	0.87	1.13	1.14	1.07	1.12	1.07	1.43
Variance	0.90	0.75	1.27	1.29	1.15	1.26	1.14	2.05

The most meaningful impact is outlined for activities such as self-learning, self-assessment, and revision of knowledge and skills.

TABLE VII. INDEPENDENT SAMPLES KRUSKAL-WALLIS TEST REGARDING BARIERS FOR USE OF ECG

H0: The distributions of variable regarding barriers in using of ECG related with follow reason are equal according to Groups – Users of ECG and Non users of ECG.	**P**
1. I do not have enough time for preparing and becoming familiar with particular ECG. 46.5% of users of ECG agree or strongly agree and 56% of non-users agree or strongly agree with the statement.	0.444
2. The prices of the games are too high. 76.9% of users of ECG agree or strongly agree that ECG are too expensive. 52% of non-users of ECG agree or strongly agree with the statement.	**0.021**
3. Lack of games with serious educational elements. 55% of users of ECG agree or strongly agree and 43% of non-users of ECG agree or strongly agree with the statement.	0.188
4. Lack of information about where to find ECG with high quality. 56 % of users of ECG agree or strongly agree and 46% of non-users of ECG agree or strongly agree with the statement.	0.328
5. I am not so familiar with technologies and cannot use them. 84% of users of ECG disagree or strongly disagree and 69% of non-users of ECG disagree or strongly disagree with the statement.	0.492
6. Lack of ECG relevant to school curricula. 45% of users of ECG agree or strongly agree and 36% of non-users of ECG agree or strongly agree with the statement.	0.697
7. I have no didactical/pedagogical competences to apply ECG. 29% of users of ECG agree or strongly agree and 32 % of non-users of ECG agree or strongly agree with the statement.	0.72
8. It takes a lot of time of the lesson. 37.5 % of users of ECG agree or strongly and 35.4% of non-users of ECG agree or strongly agree with the statement.	0.627
9. Lack of hardware equipment. 37.5 % of users of ECG agree or strongly agree and 34% of non-users of ECG agree or strongly agree with the statement.	0.935
10. I miss support of computer specialist. 20.1 % of users of ECG agree or strongly agree and 15.9% of non-users of ECG agree or strongly agree with the statement.	0.837
11. The parents think that ECG is not useful for the students. 21.6% of users of ECG agree or strongly agree and 23.4% of non-users of ECG agree or strongly agree with the statement.	0.631
12. The use of ECG decreases the added value of my work. 10.8 % of users of ECG agree or strongly agree and 10.6% of non-users of ECG agree or strongly agree with the statement.	0.444
13. Use of ECG is not suitable for the school level that I teach. 78.4% of users of ECG disagree or strongly disagree and 58.7% of non-users of ECG disagree or strongly disagree with the statement.	**0.048**

TABLE VIII. DESCRIPTIVE STATISTICS OF VARIABLES REGARDING BARIERS FOR USE OF ECG

Variables	**Mean**	**Median**	**Mode**
I do have have not enough time for preparing and becoming familiar with particular ECG.	**3.409**	**4**	**5**
The prices of the games are too high	**3.805**	**4**	**5**
Lack of games with serious educational elements.	**3.369**	**3**	**5**
Lack of information about where to find ECG with high quality.	**3.353**	**4**	**5**
I am not so familiar with technologies and cannot use them.	*1.756*	*1*	*1*
Lack of ECG relevant to school curricula.	3.318	3	3
I have no didactical/pedagogical competences to apply ECG.	2.648	3	1
It takes a lot of time of the lesson.	2.966	3	3
Lack of necessity hardware equipment.	2.906	3	1
I miss support of computer specialist.	1.915	1	1
The parents think that ECG is not useful for the students.	2.5	3	1
The use of ECG decreases the added value of my work.	1.762	1	1
Use of ECG is not suitable for the school level that I teach.	1.988	1	1

TABLE IX. DESCRIPTIVE STATISTICS REGARDING PEDAGOGICAL IMPACT OF USE OF ECG BY SMARTPHONES.

	Obtaining of new knowledge and skills	**Mastering knowledge and skills**	**Revision of knowledge and skills**	**Propaedeutic of new knowledge and skills**	**Group assessment**	**Assessment and evaluation**	**Self-assessment**	**Self-learning**
N. Valid	91	90	89	88	88	89	88	89
Missing	6	7	8	9	9	8	9	8
Mean	3.09	3.39	**3.51**	3.11	3.11	3.14	**3.4**	**3.51**
Median	3	4	**4**	3	3	3	**4**	**4**
Mode	4	4	**4**	4	3	3	**5**	**5**
Std. Dev	1.31	1.30	1.31	1.32	1.32	1.4	1.39	1.41
Variance	1.73	1.70	1.71	1.73	1.73	1.96	1.94	1.98

CONLUSION

The conducted study shows that about half of Bulgarian teachers in Information technology and Informatics have experience with use of ECG or gamification. They use ECG mostly for pedagogical activities related to mastering of knowledge and skills, obtaining of new knowledge and skills, propaedeutic of new knowledge and skills, and revision of knowledge and skills. They do not explore the power of ECG or gamification for assessment or self-assessment of the students. Most used hardware for playing of ECG in classrooms in IT and Informatics are desktop computers.

The main barriers for IT and informatics teachers for non-use of ECG are lack of games with serious educational elements, high prices of most of the good games, lack of information about ECG with high quality, the time needed for exploring of ECG.

The teachers need appropriate ECG with high pedagogical impact, relevant to educational objectives of

school subjects Informatics and Information technology. Therefore in our future studies we intend to develop ECG relevant to above outlined teachers' preferences and needs.

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Approaches for integration of educational computer games in e-learning environments

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***Abstract* - The interest of educators in Game-based education and gamification of the educational process has grown rapidly in recent years. The important questions are: What kind of game development tools are to be used and how to use and deliver appropriate educational games in e-learning environments?**

In this paper we propose a framework for analyzing the possibilities for game and gamification integration in e-learning environments. On the basis of this framework we have made an analysis of features of popular free open source e-learning environments like Moodle, ATutor, and ILIAS. In addition, we present examples of integration of educational computer games in e-learning environment Moodle.

***Keywords*: educational computer games, e-learning, Moodle, LMS**

I. INTRODUCTION

The interest of educators towards game-based education and gamification in the educational process has grown rapidly in recent years. A search in Scopus database shows about 224000 papers related to the keyword "game". About 39% of them have been published after 2013. (16.02.2018)

The basic terms in the area of game-based education are serious games, educational games, gamification in education. Different definitions of the terms mentioned above can be found in the research literature. For the purpose of our study we adopt the following definitions:

Serious games – a "mental contest, played with computer in accordance with specific rules that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives" [1].

Educational computer games/didactical computer games – We consider them to be serious computer games with clear defined educational objectives and outcomes, related to the specific school subject or university course. The educational/didactical computer games have the purpose of training, learning, or assessment of competences and fulfilling a set of learning objectives.

Gamification is a relatively new research area and it is applied in a variety of educational areas. [2]. The term appeared in the beginning of 21st century. Discussions have been held about the year and the person who coined the word. According to [3], [4]. the term "gamification" was first introduced in 2002/2003 by Nick Pelling as "game-like interfaces for electronic devices". In S. Deterding [5] gamification is defined as "the use of game design elements in non-game contexts".

The studies on the integration of educational and serious games in e-learning environments and their pedagogical aspects are relatively few, but more than 47% of these studies, indexed in Scopus Database, have been published since 2013. (Table 1.)

The proportion of the papers with the keywords gamification, e-learning, LMS, e-learning environments, published since 2013, is more than 96%. The proportion of papers that discuss gamification and e-learning environments, is less than 2%.

TABLE I. SEARCH IN SCOPUS DATA BASE ACCORDING TO THE KEYWORDS

Keywords	Total number of papers	Number of papers after 2013	Ratio
Game	223998	86590	38.66%
Game +e-learning	2608	1200	46%
Serious game e-learning	830	570	68.67%
Educational game e-learning	1723	950	55.13%
Game + e-Learning +LMS	67	32	47.76%
Gamification	3334	3209	96.25%
Gamification e-learning	765	754	98.56%
Gamification e-learning LMS	29	29	100%
Gamification +"e-learning environment"	67	67	100%

The ever growing usage of e-learning environments on different educational levels determines the need of analyzing the possibilities for integration of educational computer games and gamification in e-learning environments. This integration will ensure the easy tracking of the learners' activities and the assessment of the achieved results in the learning process. The important questions are: What kind of game development tools are

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to be used and how to use and deliver appropriate educational games in e-learning environments?

In this paper we propose a framework for analyzing of possibilities for game and gamification integration in e-learning environments. On the basis of this framework we make an analysis of the features of popular free open source e-learning environments like Moodle [6], aTutor [7], and ILIAS [8]. Also we present an example of the integration of an educational computer game in the e-learning environment Moodle.

II. FRAMEWORK DESCRIPTION

The proposed framework for comparing the possibilities for integration of educational computer games in e-learning environments divides them in three main categories. Generally, we accept that all contemporary e-learning environments (Learning Management Systems, LMS) support responsive interface and/or have mobile apps that can be used instead of the responsive interface in case of using a mobile device. According to this, we exclude support for different end-user devices from our framework. The three main categories are:

- **System integrated** – includes gamification functionalities integrated in standard LMS distributions. By default, LMS does not include any educational games in standard distribution. Basic gamification features include badges, points, levels, and ranking.

Badges are used as part of gamification to mark the achievement and to show the learners' progress.

Points are earned by learners when performing some activities – logging into LMS, reading content, solving task etc.

Levels control access to learning content – the next content becomes available after collecting some points and/or passing a quiz, task etc.

Ranking orders learners according to their current achievement – points, badges, levels etc.

- **System's specific extensions –** possibilities to add gamification functionalities and educational games as extensions (modules, plugins) developed specifically for particular LMS way that cannot be used in another LMS. Later in this paper we will use the term "plugin" for this category of extensions to avoid misunderstanding.

The specifications for development of these plugins are public in case of open-source LMS and anyone can develop their own plugin to extend core functionalities. Also there are sets of plugins (free or commercial) specific for particular LMS to extend basic gamification functionalities and to add educational games. Although this approach is widely used, it suffers from interoperability between different LMS and between major versions of the same LMS.

- **Standard-based extensions –** extensions developed according to SCORM, xAPI, and LTI specifications. These specifications are open and free and anyone can develop their own extension of functionalities of LMS as gamification elements or educational games. By default, this approach grants interoperability of extensions between different LMS if they support these specifications.

SCORM (Sharable Content Object Reference Model) [9] is a specification created and maintained by ADL (Advanced Distributed Learning) Initiative. Learning content developed with respect to this specification is portable and can be used in any SCORM-compatible LMS. Moreover, the learners can "keep" their progress when taking breaks during learning process. Also the test scores achieved by the learners are reported to the LMS. The last SCORM 2004 specification sets the order in which learners may go through the set of learning objects.

xAPI (Experience API) [10], formerly known as Tin Can API, is a specification maintained by ADL (Advanced Distributed Learning) Initiative. The Experience API allows applications to share data about user (learner) performance and in this way lets LMS to collect data about learner's performance in conjunction with associated instructional content. xApi can track a wide variety of micro-behaviors, state, and context like [10] acting with eBook or training video content, activities in a simulation environment or in a mobile app, communication with tutor/mentor, micro-interactions with e-learning content, personal or team performance in a serious game, quiz scores and detailed answer history.

LTI (Learning Tools Interoperability) [11] is a specification, created and maintained by the IMS Global Learning Consortium. Its primary purpose is to connect securely learning platforms (LMS or portals) with external learning applications and tools in a standard way. According to LTI specification there are LTI Consumers (typically LMS) that use the service tool and LTI Tool Provider (it can be LMS or another system). Implementing LTI, LMS can use external content and services, and can receive assignment and grade data between an external assessment tool and a local gradebook. LTI is primarily used to deliver courseware as a service from educational content providers to educational institutions' LMS, and to exchange educational content between educational institutions' LMS.

III. COMPARATIVE STUDY

A. System integrated capabilities

- Moodle

Badges in Moodle may be given according to a variety of criteria and are fully compatible with Mozilla Open Badges [12]. Badges obtained in Moodle can be displayed on a learner's profile or placed in a learner's Open Badges backpack [12]. In addition, the public badges from the learner's backpack may be displayed in the Moodle profile. There are two categories of badges:

Site badges are available to learners on the site level and are obtained from the site level activities, such as passing a set of courses. Awarding can be manual by the tutor, or automatic – in case of completing a set of courses or profile completion.

Course badges are given to learners, enrolled in a particular course, according to the activities performed

during the course. Awarding can be manual by the tutor, or automatic – in case of course completion and/or activity completion.

- ILIAS

As in Moodle, ILIAS badges can be exchanged through the internet from/to the LMS by using Mozilla Open Badges Infrastructure. Badges in ILIAS may be of three types [13]:

Activity Badges are available on site-level and are automatically given by the system if learners fill appropriately their user profile.

Course LP Badges are available on the course level and are automatically given by the system if learners meet some criteria.

Verdienst-Badges are awarded manually by the tutors.

- aTutor

By default, aTutor does not provide any integrated gamification capabilities in the standard distribution.

B. System's specific extensions

- **Moodle**

Moodle has a wide set of developed system specific extensions named plugins grouped internally as blocks and activities. The process of plugins development is public and well documented. The following plugins can be used to implement gamification or educational games in courses delivered through Moodle (only plugins compatible with 3.x versions are considered).

Level Up! plugin allows students to earn points for their actions. Students are able to track their progress from current level to the next level. Also leaderboard is available.

The **Game** plugin allows creation of interactive games using questions, quizzes and glossaries. The following games are included - crossword, cryptex, millionaire, Sudoku, Snakes and Ladders, The hidden picture, Book with questions.

Quizventure is plugin that loads quiz questions from the course it's added to. The learners have to shoot the correct one from the possible answers, which are coming down as space ships.

Stash plugin introduces a block that shows students items that they have picked up through the course.

Mootivated (for schools) and **Motrain** (for corporate training) are mobile apps that encourage student/employee effort for learning in Moodle. Virtual coins are earned for working in Moodle and they can be spent by the learner in the app in example to update the personal avatar or to buy something from virtual store.

Treasure Hunt plugin allows outdoor, indoor and virtual-map treasure-chases with geolocation and QR codes. Using this plugin, educational games can be organized in variety of situations: individual or team playing, moving/desktop-marking, scoring from time, reach position, task completion, etc.

Ranking plugin adds points when learners pass monitored activities with completion criteria, set by the teacher. Daily, weekly and monthly rankings for learners' achievements are also created.

- ILIAS

ILIAS has a very well-structured development environment for system specific extensions, named plugins. Official plugins repository provides two complementary plugins – **Match & Memo Pool** and **Match & Mem,** which together implement a memory cards game.

- aTutor

aTutor provides a well-documented and public system specific extension mechanism for development of plugins – modules in aTutor terminology.

The only module from aTutor repository - GameMe provides a set of gamification functionalities.

Points are earned by the students when an event occurs. According to learners' progress, Event Messages are available to inform them about some particular achievement.

In aTutor **Levels** differ from badges in that they represent a sequence, while badges represent occurrences of some achievements that do not necessarily occur in a particular order.

The **Student Log** provides learners with a running account of all the events they have triggered and are an element of obtaining points, badges and levels reached. It can be enabled and disabled by the instructor.

Leaderboard is used to visualize the ranking of the current learners' achievements in the course.

C. Standard-based extensions

- **Moodle**

Moodle supports usage of SCORM 1.2 learning content as core functionality. Moreover, Moodle is not able to develop or to generate SCORM content, so external tools have to be used for this purpose. In addition, SCORM 2004 content is accessible through SCORM Cloud for Moodle plugin, which is used as client tool for SCORM Cloud service, provided commercially [14].

xAPI is supported in Moodle through xAPI Launch Link plugin. It allows to externally launch xAPI activities from Moodle and to track them on any LRS (Learning Record Store).

Moodle supports LTI 2 as a core functionality in both consumer and provider roles.

- **ILIAS**

ILIAS implements support for SCORM 1.2 and 2004 as a core functionality. Also SCORM online editor is included in core functionalities. In this way ILIAS can be used as a consumer and creator of SCORM-compatible learning content. HTML5 SCORM offline player supports

offline viewing without problems with user progress tracking from LMS.

The current version of ILIAS (5.3) does not support xAPI specification and does not have an official schedule for implementation yet.

LTI 1.1 provider functionality is implemented as a core functionality in ILIAS version 5.3. This allows to share SCORM modules, tests, surveys and courses with another LMSs, playing as LTI Consumer. Access to external LTI 1.1 services as a consumer is supported through External Content plugin.

- **aTutor**

aTutor supports SCORM 1.2 as a system specific plugin SCORM Packages Player. It allows to import and play but not to create and export SCORM content.

Basic LTI 1.0 consumer role is supported as core functionality.

IV. Example Implementations

We have decide to implemented games as SCORM 1.2 packages so as to be compatible with most popular LMS. Although there exist a lot of different tools for computer games development such as SCORM package, we have chosen two tools – one free – e-Adventure, one free web-based LearningApps.org, and one commercial – Adobe Captivate.

The game "Robit" has been developed following a special didactical scenario, designed for primary school pupils. The game is intended to help pupils with elementary math operations. eAdventure was used in the process of scenario implementation and finally, the game was exported as a SCORM package. (Fig.1)

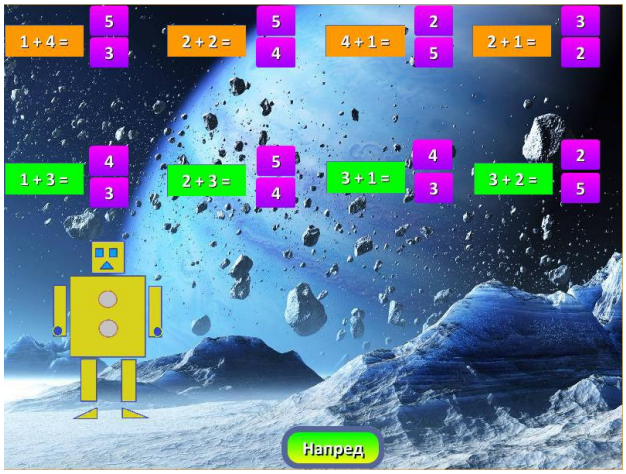

Figure 1. Screenshot from the game Robit, developed with e-Adventure

The game "Safe Internet" involves pupils in lower secondary schools in discovering how to safely use Internet services like e-mail, social networks, message boards, etc. The case-based scenario for this game was developed and Adobe Captivate was used to implement the scenario.

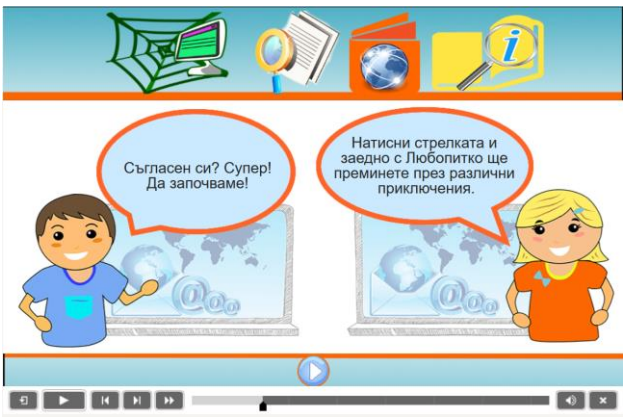

Figure 2. Screenshot from the game Safe Internet, developed with Adobe Captivate

The demo game "Hangman – European Capitals" is created for the purposes of testing. It is developed using on-line web-based tool LearningApps.org [15, 16]. The game can be used as a web link from the development site or exported as SCORM package.

Figure 3. Screenshot from the integrated game from Learningapps.org

All of the three games are tested successfully in Moodle versions 2.9 and 3.4 environments.

V. Conclusion

All of the LMS, discussed above, support at least badges in order to gamify e-learning content. More complex gamification elements like points, levels, leaderboard/ranking are supported as system specific extensions – plugins. Moreover, some simple educational computer games – crosswords, Sudoku, memory cards, treasure hunt etc. are provided as plugins too.

The extensions based on SCORM and LTI specification are supported by all considered LMS and can be used for creation of more complex educational computer games. Moreover, SCORM-based educational computer games can be developed using a wide variety of development tools without a lot of effort. In addition, the xAPI functionality extends learner's tracking to a more detailed level on a wide variety of end-user devices.

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Approaches to learning in a blended learning environment: preliminary results

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***Abstract* - The effectiveness and success of blended learning is an intriguing topic to researchers; the use of technology has transformed the traditional ways of teaching in higher education and has played an important role in achieving a scalable, inclusive, and cost-effective education. In the same time, approaches to learning and the perception of teaching-learning environment have been an interest of authors looking to understand the ways that students go around learning and achieve their study goals. Influenced by multiple factors, students adopt deep, surface, or strategic approach to learning. This research is focused on bringing the two research areas together using an original research instrument, developed to understand the students' approaches to learning in a blended learning environment. The survey has been conducted on a sample of students in two Croatian universities. Relationships between gender, student status, year and area of study, use of MOOCs and/or educational videos, experience with e-learning, learner control, specific use of learning management system, perceptions of teaching-learning environment and the approaches to learning have been explored. This paper covers the instrument's validity and reliability assessment and the preliminary results of the research, along with recommendations for conducting further research in this field.**

***Keywords* - approaches to learning, blended learning, e-learning**

I. INTRODUCTION

Technology has changed teaching and learning, as many other activities in our lives [1]. An example of integration of technology in teaching and learning is blended learning, that can be defined as "thoughtful integration of classroom face-to-face learning experiences with online learning experiences" [2]. Series of authors have researched the effectiveness of blended learning and found generally positive experiences of students on different levels [3]–[7]. With advantages such as easy content delivery, studying (and teaching) anytime, anywhere, personalized learning plans, and general convenience and support in achieving learning outcomes, it comes as no wonder that blended learning is well accepted in higher education systems. [8] sum it well: "one of the main outcomes of the increased uptake of e-learning, particularly in predominately campus based universities, is the creation of student learning experiences that flow back and forth between face to face and online (or at least technologically supported) situations." Naturally, there are reasons why new technologies might not be fully embedded into a traditionally taught course: cultural challenges, lack of time, resources, knowledge or inclination from a teacher, or infrastructure not being ready to support the technologies [8]. Similarly, challenges can come from the students' side, where understanding the motivation of students is important for personalising their education, which is a challenging task in online and blended learning environments [9]. With that, the idea of expanding research on student learning in blended learning environment comes naturally. One of the theories on student learning is the one on approaches to learning. Approaches to learning have been the subject of work of Ference Marton and Roger Säljö [10], [11], Entwistle and Ramsden [12], Biggs [13], [14], and many other authors who have published their findings. Authors have identified three main approaches to learning: deep, surface, and strategic. Deep approach is characterized by an intention to understand ideas and by seeking meaning by relating ideas to previous knowledge and experience, while surface approach is characterized by the intention to cope with course requirements and reproducing knowledge by treating the course as unrelated bits of knowledge [15, p. 36]. Finally, strategic approach is related with activities of students who are focused on achieving the highest possible grade [16]. Some research highlights organised approach as an alternative to strategic approach [17], [18]. A student can adopt a different approach to learning and it is important to know what factors influence approaches to learning. There has been a number of findings in this area, and some of the factors that influence adopted approach to learning are learning environment factors (such as teaching, workload, assessment and choice in learning) [19], motivation and anxiety, emotions [20], social identity [21], teacher approach to teaching [22] [23]. With the above in mind, the question arises: what approaches to learning do students adopt in blended learning environment, how can we evaluate them, and what is the connection between embedding technology in teaching and learning and adopted approaches to learning?

A. MOOCs and use of educational videos

There have been multiple studies addressing a blended learning environment that includes Massive Open Online Courses (MOOCs) [4], [24]–[29]. Although there are challenges with leveraging this type of content, the potential that MOOCs have is indisputable. Constructive alignment is needed to create a sustainable learning environment [24]. Educational videos have been used to complement traditional teaching either through a well-known flipped classroom model where students watch the videos as a pre-assignment, or the videos are watched together during classroom teaching time. Students favor

self-learning as well as offering flexibility while supplementing traditional methodologies with video [30]. To embed an educational video created specifically to enrich a certain course unit, teachers have to invest a certain amount of time in planning and delivering the product. Benefits include targeted content, verified narrative, and good connection to course content and expected course outcomes.

B. Experience with e-learning

To evaluate the component of e-learning in the learner experience, the author decided to use a subscale from the research of [31], who were developing a scale for "determining the quality of the student e-learning experience at the degree level when the student learning context is predominately a campus-based experience." With the idea of evaluating blended learning environment created around traditionally taught courses, this approach was logical. Interestingly, [31] have written about the limitations of their research, also mentioning that future studies might take approaches to studying in consideration. The author argues that the experience with e-learning is related to the adopted approaches to learning

C. Learner control

The on-demand nature of blended learning is often mentioned as its advantage and the ability to go back to content they need is even highlighted by students as one of the key elements they appreciate about having an e-resource in addition to the traditional teaching-learning time. Still, learning online is different than learning from traditional textbooks. [32] developed a scale for evaluating learner readiness for online learning, a subscale of which is learner control; the authors have highlighted the importance of learner control and the ability of students to direct their learning progress. The ability for each learner to keep the control of their learning when it comes to the online element is an important part of the success of blended learning environment; control might be connected with the approach to learning that students may adopt in these environments.

D. Use of Learning Management System

Using a learning management system (LMS) to facilitate teaching and learning, as well as organizing a course is very common. In the groups of students where this questionnaire was planned to be distributed, LMS is used in specific parts of the teaching processes, leveraging various functionalities of the system. In Croatia, where the research was conducted, there has been a classification of blended learning courses, categorizing them in basic, middle, or advanced level, also based on technologies used. In this research, the author is looking to establish a relationship between the use of the system in particular parts of classes, such as for communication or discussion and approaches to learning, as well as between the use of specific functionalities with the approaches.

E. Approaches to learning and teaching

Teaching affects approaches to learning. However, it is "the students' perceptions of the teaching and assessment procedures, rather than the methods themselves, that affect student learning most directly" [33]. Based on this, the ground for this research is Shortened Experiences of Teaching and Learning Questionnaire (SETLQ), one of the results of the project "*Enhancing Teaching-Learning Environments in Undergraduate Courses"*. In one of the project reports, a concept map of some influences on student understanding was published; the concept map included influences on personal understanding from student's perspective (for example current knowledge, perception of the learning environment, comperehension of topics and target, motivation and approach to studying) and teacher's influences (for example type of formative assessment used, choice of teaching method, choice of topics and learning materials) on student's understanding [33]. The perceptions of teaching-learning environment cover the experience of, among others, aims, teaching and learning, set work and feedback, all of which are relevant in constructing a blended learning environment. The purpose of this paper is to present the preliminary results of the study on the approaches to learning in a blended learning environment. This is a pilot research, with the aim of developing and verifying a questionnaire and observing potential improvements for the main research. Only a part of the results is included in this paper.

Main research questions in this paper therefore are:

RQ1: Can the developed questionnaire be used to evaluate approaches to learning in a blended learning environment?

RQ2: Is there a difference in adopted approaches to learning based on gender, course unit, experience with e-learning, and the use of LMS?

RQ3: Are gender, course unit, use of MOOCs, use of instructional videos, experience with e-learning and use of LMS correlated with approaches to learning?

II. METHOD

A. Sample

The data was collected at two Croatian faculties. At one of them, the data was collected at two courses, one in undergraduate and one in vocational programme. At the other faculty, the data was collected at a graduate course. Only complete set of responses to all scale items were included in analysis. The final sample comprised 392 students, 126 male and 266 female. 59.7% respondents came from the undergraduate course, 15.1% from the graduate course, and 25.3% from the vocational course.

B. Instrument

The instrument used in this research was based on an existing questionnaire, the Shortened Experiences of Teaching and Learning [18], specifically sections three and four: approaches to learning and experiences with teaching-learning environment. These were expanded by adding concepts through which the use of online learning is studied in the blended learning environment: use of MOOCs and educational videos, experience with e-learning, learner control, use of LMS as well as gender and student status. The final questionnaire consisted of 6 sections. The first section included general characteristic

questions: gender and student status (full-time/part-time). Different response collectors were used for each of the three course units, so students were not asked to share the name of the course unit they are participating in; the author added this information after finalizing the collection of responses. It is important to note that participating in a specific course, also means a different year of study. In this section, experience with using videos was also evaluated through yes and no questions on: previous use of MOOCs, impact of MOOCs to student's final grade, and use of custom educational videos in class. The second section included five items that evaluated students' experience with e-learning, based on the work of the e-Learning scale (E-LS) measuring experience with e-learning. The second section consisted of five items, which were adapted to fit this research, particularly by removing the reference to the specific university the authors were doing their study at [31]. Overall satisfaction with the course unit was also evaluated in this section. The third section consisted of 17 items based on the third section of the SETLQ questionnaire; the approaches to learning and studying. The fourth section consisted of 26 items based on the fourth section of the SETLQ questionnaire, covering experiences with teaching and learning [33]. The fifth section covered learner control in 3 items, based on earlier research [32]. The sixth section evaluated the use of learning management system, questioning whether LMS was used in particular parts of teaching and learning, as per classification in [34], as well as which particular functionalities of the LMS were used. All faculties included in this study use Moodle as their LMS. Questions from all sections, apart from the first one and part of the sixth one when the use of functionalities was reported on a yes/no basis, were graded on a 5-point Likert scale: "Strongly Disagree", "Disagree", "Neutral", "Agree" and "Strongly Agree" or "Never", "Rarely", "Sometimes", "Often", "Almost always" in the use of LMS scale.

C. *Procedure and data analysis*

The chosen elements of the SETLQ questionnaire and the added sections were translated from English by the author. The translation was reviewed by a translator and amendments were made so that the translated questionnaire fits Croatian language well. The questionnaire was created using the tool SurveyMonkey and the link to it was distributed via Moodle. Students at the undergraduate and vocational courses filled the questionnaire during classroom time and students at the graduate course did it on their own time. Participation was on a voluntary basis and students were assured that their data is confidential and anonymous. Descriptive statistics and Cronbach alpha for each scale were reviewed at the very beginning to help screen the data. For every scale, the scale total was produced by creating a new variable by summing the items [18]. Factor analysis followed. Several studies on approaches to learning have included factor analysis to analyze the types of learning the students adopted [16], [35]–[37]. In this study, as in [35], factor analysis was used to "test the theoretical structure of the instrument and assure that the items are associated with the respective scales". In extracting the factors, principal component method and direct oblimin rotation were used. Data was analyzed in SPSS 23.

III. RESULTS AND DISCUSSION

Table 1 shows scales (number of items in the scale in brackets), mean, standard deviation, skewness and kurtosis, as well as Cronbach alpha, compared, where available, with the result in the original research (in brackets). Cronbach alpha was calculated to test the internal reliability of the scales. The alpha values for the main scales range from 0.704 and 0.891, showing high level of internal consistency. One scale that showed alpha smaller than 0.7 is learner control (0.59). The reason for lower alpha can be smaller number of items (3).

TABLE I. DESCRIPTIVE STATISTICS AND CRONBACH ALPHA FOR SCALES

Scale (items)	Mean	SD	Skew-ness	Kurto-sis	Cronbach alpha (in original research)
Deep approach (9) [18]	30.09	5.45	0.282	0.347	0.84 (0.75)
Surface approach (4) [18]	12.37	3.08	0.204	-0.003	0.70 (0.67)
Organised approach (4) [18]	13.90	2.98	-0.303	0.194	0.77 (0.75)
Aims and congruence (5) [18]	18.47	3.79	-0.299	0.169	0.88 (0.75)
Choice allowed (2) [18]	7.05	1.85	-0.505	0.154	0.76 (0.60)
Teaching for understanding (5) [18]	16.62	3.98	0.037	0.092	0.89 (0.74)
Set work and feedback (5) [18]	17.20	4.10	-0.236	0.226	0.89 (0.79)
Assessing understanding (2) [18]	7.19	1.71	-0.486	0.450	0.74 (0.55)
Staff enthusiasm and support (2) [18]	7.18	1.74	-0.440	0.323	0.79 (0.66)
Student support (2) [18]	7.50	1.75	-0.378	-0.096	0.81 (0.73)
Interest and enjoyment (2) [18]	6.69	1.94	-0.314	-0.072	0.83 (0.83)
Learner control (3) [32]	10.68	2.11	-0.043	-0.012	0.59
Use of LMS in class (7) [34]	24.58	4.96	0.298	-0.236	0.80
Exper. with e-learning (5) [31]	19.20	3.60	-0.676	0.968	0.83 (0.81)

TABLE II. PATTERN MATRIX ITEMS DESCRIBING APPROACHES TO LEARNING

Items	Component		
	1	2	3
When I've been communicating ideas, I've thought over how well I've got my points	0.830		

across.			
I've looked at evidence carefully to reach my own conclusion about what I'm studying.	0.803		
Ideas I've come across in my academic reading often set me off on long chains of thought.	0.778		
It has been important for me to follow the argument, or to see the reasons behind things.	0.604		
If I've not understood things well enough when studying, I've tried a different approach.	0.602		
In making sense of new ideas, I have often related them to practical or real life contexts.	0.545		
I've been over the work I've done to check my reasoning and see that it makes sense.	0.505		
I've tried to find better ways of tracking down relevant information in this subject	0.496		
In reading for this course, I've tried to find out for myself exactly what the author means.	0.454		
Much of what I've learned seems no more than lots of unrelated bits and pieces in my mind.		0.830	
I've often had trouble in making sense of the things I have to remember.		0.768	
I've just been going through the motions of studying without seeing where I'm going.		0.764	
I've tended to take what we've been taught at face value without questioning it much.		0.501	
I have generally put a lot of effort into my studying.			-0.864
I've organised my study time carefully to make the best use of it.			-0.819
On the whole, I've been quite systematic and organised in my studying.			-0.668
Concentration has not usually been a problem for me, unless I've been really tired.			-0.435

Exploratory factor analysis was performed to explore the factorial structure of the sample. It is justifiable to assume that "items describing approaches to learning and perceptions of the teaching–learning environment correlate with each other [17], [38]." For approaches to learning, Bartlett test value was significant, and the Kaiser-Meyer-Olkin value was 0.857, meaning that the data is suitable for factor analysis. For principal component analysis, Kaiser criterion was taken into consideration, as well as the scree plot. The initial factor structure consisted of four components with eigenvalue above 1. The scree plot though showed inflexion after the third component. Four factors using SETLQ were also extracted in [17]. The first three factors were deep, surface, and organized approach to learning. In addition to these three factors, expected from previous research, the fourth factor loaded and consisted of three items describing deep approach to learning and one describing surface approach. According to expectations based on previous research, the author decided to move forward with the three factor structure, i.e. to extract a fixed number of factors, three. It was expected that the items from the fourth factor will load on one of the three expected factors. The results are shown in Table 2. The final structure explained 51.498% variance and the three factors are theoretically expected and can be defined as deep, surface, and organised approach to learning. Small coefficients of items were suppressed and only absolute values above 0.30 were included in the interpretation. Correlations between factors were also aligned with theoretical assumptions, with deep and surface approach being negatively correlated and with a moderate correlation between deep and organised approach.

TABLE III. COMPONENT CORRELATION MATRIX

Component	1	2	3
1	1.000	0.109	-0.504
2	0.109	1.000	-0.124
3	-0.504	-0.124	1.000

The same procedure was followed to evaluate the factorial structure of scales evaluating teaching-learning environment, with Bartlett test value being significant and Kaiser-Meyer-Olkin value of 0.944, finally resulting in eight factors, aligned with theoretical expectations: aims and congruence, choice allowed, teaching for understanding, set work and feedback, assessing understanding, staff enthusiasm and support, student support, and interest and enjoyment.

To determine whether to use parametric or non-parametric tests for analyzing differences in adopted approaches to learning (RQ2), normality of distribution was tested. This was done using the Kolmogorov-Smirnov and Shapiro-Wilk tests. Both tests confirmed that the distribution is not normal ($p=0.05$) meaning that non-parametric tests should be used. To evaluate whether there are significant differences between groups of students and their approaches to learning, based on specific factors, Kruskal-Wallis test was performed. Table 4 summarizes the results of this test. Based on the analysis, there was no statistically significant difference in adopted approaches to learning between male and female students; however, there was a statistically significant difference in the adopted approaches to learning (deep and surface) based on the course unit the students were participating in. To analyze the difference in approaches to learning based on experience with e-learning and particular use of LMS, the two variables were recoded to three level variables. The findings show that there is a statistically significant difference in deep and organised approach to learning based on experience with e-learning. The outcomes are the same when observing deep and organised approach with the specific use of LMS; the difference is statistically significant.

TABLE IV. DISTRIBUTION OF RESULTS ACROSS GENDER AND SCHOOL, SHOWING SIGNIFICANT DIFFERENCES BETWEEN GROUPS

Scale	Course unit	Use of LMS	Experience with e-learning
Deep approach (9) [18]	0.023	0.000	0.000
Surface approach (4) [18]	0.000		
Organised approach (4) [18]		0.000	0.000

To determine the details of the differences in distributions between samples, a non-parametric version of a post-hoc test was used. Table 5 shows means of approaches to learning in different groups (course unit, use of LMS, and experience with e-learning). Pairwise comparisons between groups were used to determine where the statistical difference between groups is coming from. The pairs between which there is a significant difference in means are marked with "*" in table 5.

TABLE V. COMPARING MEANS BETWEEN GROUPS

		Deep approach (9) [18]	Surface approach (4) [18]	Organised approach (4) [18]
Course unit	Undergraduate	29.12	10.90	-
	Graduate	30.68*	12.62*	-
	Vocational	29.27*	12.65*	-
Use of LMS	Low	23.82*	-	9.82*
	Medium	28.66*	-	13.25*
	High	32.82*	-	15.23*
Experience with e-learning	Bad	28.00	-	13.8
	Average	26.84*	-	12.39*
	Good	31.04*	-	14.33*

To explore the correlation between scales (RQ3), Spearman's coefficient of correlation was used, since the distribution is not normal. Table 6 shows the correlations between the selected scales and approaches to learning. Statistically significant correlations at the 0.01 level are marked with "*". Findings show that there is a small, statistically significant positive correlation between surface approach and course unit as well as the use of educational videos. This could be because the educational videos were only used in one course unit. Statistically significant, medium positive correlation is observed between deep approach and use of LMS and experience with e-learning, as well as between organised approach and experience with e-learning [39].

TABLE VI. CORRELATIONS BETWEEN APPROACHES TO LEARNING AND SELECTED SCALES

Scale (items)	Deep approach	Surface approach	Organised approach
Gender	-0.046	0.002	-0.012
	0.368	0.969	0.818
Course unit (school)	-0.042	0.161*	-0.060
	0.405	0.001	0.234
Use of MOOCs	0.075	0.038	0.018
	0.136	0.448	0.716
Use of educational videos	0.070	0.152*	0.042
	0.167	0.003	0.406
Use of LMS in class (7) [34]	0.465*	0.081	0.410
	0.000	0.108	0.000
Experience with e-learning (5) [31]	0.430*	-0.087	0.356*
	0.000	0.084	0.000

IV. DISCUSSION

The aim of this study was to explore approaches to learning in a blended learning environment and evaluate the new instrument created for the purpose of the research. Research questions have been answered:

RQ1: Can the developed questionnaire be used to evaluate approaches to learning in a blended learning environment?

Based on the validity and reliability analysis, the questionnaire can be used to evaluate approaches to learning in a blended learning environment.

RQ2: Is there a difference in adopted approaches to learning based on gender, course unit, experience with e-learning, and the use of LMS?

Based on the findings, there is no significant difference in adopted approaches to learning based on gender. There is a significant difference in adopted approaches to learning between students with different experience with e-learning and different use of LMS. Students with good experience with e-learning have higher scores on the deep and organized approach scales, i.e. they adopt a deeper and a more organised approach to learning than students with average experience with e-learning. Similarly, students with high use of LMS in specific parts of class, scored higher on deep and organised approach scales, than the students who had low use of LMS in specific parts of class. Finally, students from the graduate program demonstrated higher scores on both deep and surface approach scales than students in vocational programe.

RQ3: Are gender, course unit, use of MOOCs, use of instructional videos, experience with e-learning and use of LMS correlated with approaches to learning?

The results indicate that there is a positive correlation between deep approach and use of LMS in class and experience with e-learning. Surface approach is positively correlated with course unit and use of educational videos. Finally, organised approach is positively correlated with experience with e-learning. The results indicate that the correlation between scales related to the use of LMS and experience with e-learning with deep (and partially organised) approach to learning might be a valuable insight into how blended learning environment could be structured to support deep approach to learning.

This is a pilot research; there are several areas in which improvements can be made. The distribution of the data is not normal; given the sample structure and size, it is expected that some responses are skewed [35]. However, normal distribution would ensure the use of parametric tests for additional valuable insights. Cronbach alpha of the construct "learner control" was 0.59. For the main research, learner control construct should be expanded by adding more items to ensure higher alpha (preferably above 0.7). This will ensure that learner control can be studied in relation to approaches to learning in a blended learning environment. This study resulted in a new, reliable and valid instrument for evaluating approaches to learning in a blended learning environment. Although there are limitations that need to be addresses in further research, the author believes that this is a step forward in understanding students' learning and creating successful blended learning environments.

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Influence of gamification on student motivation in the educational process in courses of different fields

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***Abstract* - The rapid development of Information and Communication Technologies (ICT) offers great possibilities of improvement of the educational process in higher education. It is very important to motivate students to actively participate in classes, regardless of a classical classroom education or e-learning style of teaching. Gamification is one of the methods that motivates students to actively participate in class, learn through entertainment by playing with their colleagues and emphasize on the positive competition and also, to make learning fun. In this paper, some of the methods used by Zagreb School of Economics and Management (ZSEM) will be described and analyzed through student engagement and motivation in different courses – courses that are related to technologies and courses that are related to legal discipline. The research shows that students are very pleased with the introduction of gamification as part of the educational process - no matter which course it is, they feel that gamification has helped them to get motivated to study and they have expressed their wish to have it as part of any course they are attending.**

Keywords – Gamification, motivation, education, information and communication technologies

I. INTRODUCTION

The rapid development of new technologies has influenced the traditional educational process and also changed the role of students and professors today. As students are exposed to information overload every day, it is getting more challenging to sit through the entire period and focus on the professors' lectures. This classical and traditional way of the educational process has become tedious for the new generations. On the other hand, it is known that gamers can sit for hours without losing a big amount of interest and energy, as playing is very dynamical and fun [1]. One of the methods that may aid this situation is gamification [2]-[6]. Gamification can be used in either a classical class, or even as a part of e-learning. [7, 8]

In the paper „Influence of Gamification on Student Engagement in Education" [9], authors have shown that there is no correlation between games that are played during the semester, which means, if a student has an excellent result in one game, it is not necessary to conclude that the next game will also be completed with excellent results. This is promising since students are still motivated in playing a new game without any reflections on the previous results and standings. Also, students that have better final grades such as 4 or 5, usually have better results in gamification than other students.

The aim of this paper is to show how gamification was used in courses that are of different discipline – between new technologies and law. Gamification was a part of Information and Communication Technologies (ICT) course which is taught in the first semester, as well as of Legal business environment (LBE) which is taught in the fifth semester at Zagreb School of Economics and Management (ZSEM). In both of the courses, gamification tool Kahoot [10] was used for checking the students' knowledge, as well as to motivate students to be more active in class by playing and competing together. [11]-[13]

II. GAMIFICATION IN CLASS ON ZSEM

The acts regulating the higher education sector in the Republic of Croatia are: the Act on Scientific Activity and Higher Education[1], Act on Quality Assurance in Science and Higher Education[2], the Ordinance on the Content of a Licence and on the Conditions for Issuing the Licence for Performing Higher Education Activities, the Implementation of the Study Programme and Re-accreditation of Higher Education Institutions[3], as well as

[1] Act on Scientific Activity and Higher Education (in Croatian: Zakon o znanstvenoj djelatnosti i visokom obrazovanju, Official Gazette 123/03, 198/03, 105/04, 174/04, 02/07, 46/07, 45/09, 63/11, 94/13, 139/13, 101/14, 60/15, 131/17)

[2] Act on Quality Assurance in Science and Higher Education (in Croatian: Zakon o osiguravanju kvalitete u znanosti i visokom obrazovanju, Official Gazette 45/09.

[3] Ordinance on Conditions for Issuing a Licence for Performing Scientific Activity, on Conditions for Re-accreditation of

the Ordinance on Conditions for Issuing a Licence for Performing Scientific Activity, on Conditions for Re-accreditation of Scientific Organisations and on the Content of the Licence[4], and finally the Institutions Act[5].

Zagreb School of Economics and Management (ZSEM) started 16 years ago, and since that time it has been able to implement best practices involving processes in quality management, standardization [14] and also, new technologies in the education [15, 16]. During the practical teaching of a course, The Statute of the Zagreb School of Economics and Management, which is the governing act enacted by the School and aligned with the aforementioned acts, encourages faculty to encompass laboratory work, study visits, internships, field work and other forms of teaching which enable students to acquire the necessary knowledge and skills for each course.[6]

At the beginning of 2018, a research was conducted among ZSEM professors regarding gamification. 50% of the lecturers participated in the research, out of whom 42% has used some sort of a gamification in their lectures and it is present in every department in at least one course. Over 90% showed satisfaction in using gamification and consider it as a contribution to the students' motivation and engagement in class. 63% of the professors analyse all the student answers, while the rest only analyse top five students.

Some of the professors started with gamification already in 2011, but it has been implemented into even more courses since 2016. In the open answer professors confirmed that using gamification positively motivates students to learn, provides an opportunity to innovate the course and also they would recommend it to other colleagues. All of ZSEM students have a chance to experience Kahoot or other gamification tools on every year enrolled.

A. *Gamification on ICT course*

ICT course aims to teach students how to use new technologies and how to adapt to changes at the appropriate time. The course has a very developed e-learning component so students are adjusted to using new technologies, either in class or in the form of asynchronous distance learning [17].

Kahoot is used for repetitive learning and for exam preparations. The quiz is assembled from 7-10 questions, and for the each question a student has 20 seconds to answer. Kahoot counts accuracy, as well as speed of an answer. Activity in gamification is not a necessary part to form a grade, but it provides extra percentage which depends on students' Kahoot placement order. In Table I, it is visible that the first place is awarded with 1.5%, and students that were from 2nd – 5th place are awarded with 1%. The rest of the students get a symbolic award of 0.5% for participating in the Kahoot game.

TABLE I. KAHOOT AWAED SYSTEM ON ICT

Kahoot placement	**Extra percentage award system**
1st place	1.5%
2nd – 5th place	1%
Symbolics activity award	0.5%

The example of a Kahoot question can be seen on Figure 1.

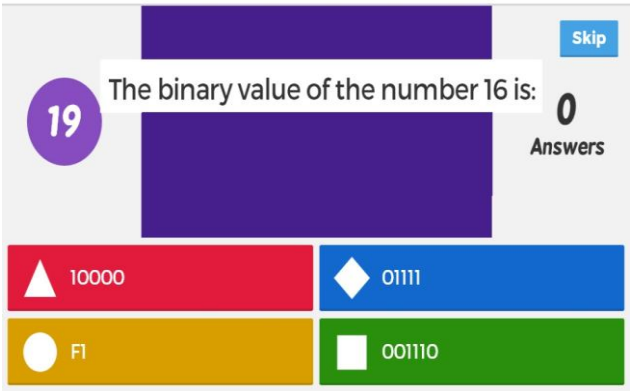

Figure 1. Kahoot question [1]

In the academic year 17/18, 100 students participated in the gamification in ICT. Table II shows student engagement regarding the gamification process throughout the whole semester. Out of all 9 games of Kahoot, 23% of the students participated in all of the games, 30% only missed one game with only 15% of them who participated in less than five Kahoot games.

TABLE II. ICT – STUDENT ENGAGEMENT ON KAHOOT

Number of participated Kahoots	***Student %***
9	23%
8	30%
7	11%
6	12%
5	9%
< 5	15%

Scientific Organisations and on the Content of the Licence (in Croatian: Pravilnik o sadržaju dopusnice te uvjetima za izdavanje dopusnice za obavljanje djelatnosti visokog obrazovanja, izvođenje studijskog programa i reakreditaciju visokih učilišta), Official Gazette 83/10.

[4] Ordinance on the Content of a Licence and on the Conditions for Issuing the Licence for Performing Higher Education Activities, Implementation of the Study Programme and Re-accreditation of Higher Education Institutions (in Croatian: Pravilnik o uvjetima za izdavanje dopusnice za obavljanje znanstvene djelatnosti, uvjetima za reakreditaciju znanstvenih organizacija i sadržaju dopusnice), Official Gazette 24/10.

[5] Institutions Act (in Croatian: Zakon o ustanovama), Offical Gazette 76/93, 29/97, 47/99 and 35/08.

[6] Article 53, Statute of the Zagreb School of Economics and Management, 2014.

B. Gamification on LBE course

The Legal business environment is an obligatory course for third-year students in the Economics and Management undergraduate study program at the Zagreb School of Economics and Management. The course is taught within one 15-week semester. Students attend the course for three hours per week: two-hour lectures and one-hour of practical teaching.

The course is a part of the curricula since knowledge of the legal environment of business is of the utmost importance for any manager or other person who works in the economy. Within the "classic" legal subjects in the economics schools and colleges, knowledge is acquired in the field of contract law, company law, international trade law, and other courses. However, important legal aspects of business operations remain outside the scope of these legal subjects. Also, there is a need for connecting knowledge acquired from different areas of the law with the case-law in business operations. Therefore, there is a need for a special legal course that focuses on different segments of the legal environment of business.

The main objective of the course is to raise students' awareness of the impact of legal rules and their importance for the daily operations of entrepreneurs and companies. Special emphasis is placed on the fact that the legal system within which they operate their businesses makes up the macroeconomic environment and as such has a direct effect on the business process and results of operations. That is why students should be familiar with the everyday rules and legal requirements which they will meet in their future work and possible issues that can occur related to them, as well as offer them a perspective on how to fix them.

The next goal is closely related to the previous one, which is to build students' awareness of the need for action and operating in accordance with the regulatory framework. The knowledge gained will help students in their future work in the market and increase the safety of their business operations, avoid unnecessary additional costs and damages arising from improper and illegal operations and adopt the basic principles of ethical and socially responsible behavior within the company and on the market.

The lecturer used Kahoot during the practical teaching in order to measure the knowledge of students on a specific course-related topic discussed that week and award points for additional activities. Student could earn as much as six percent of the total grade via their success in Kahoot [7]. The grade elements are provided in Table III.

TABLE III. LEGAL BUSINESS ENVIRONMENT GRADE ELEMENTS

Legal business environment grade elements	*Percentage in grade total*
Class attendance	4%
Activity	6%
Mid-term exam	40%
Final exam	40%
Term paper or presentation	10%
Total	100%

During each Kahoot session, only the top half of participating students were rewarded one percentage point for activity points, while the winner was awarded two percentages for activity points. The rules about using Kahoot and how they could earn activities percentage points were stated to the students before each Kahoot. Participation in the Kahoot quizzes was not obligatory for students. Students participated in Kahoots individually.

In total, there were five Kahoots during the 15 weeks of course provision. 85 students participated in at least one Kahoot quiz. Kahoot quizzes had from 10 to 13 questions, and students could provide an answer within 30 seconds to most questions (questions with correct/incorrect answers were limited to 20 seconds for providing an answer). The number of questions for each Kahoot is provided in Table IV.

TABLE IV. NUMBER OF QUESTIONS ON KAHOOT

Kahoot	*Number of questions*
First Kahoot	10
Second Kahoot	12
Third Kahoot	13
Fourth Kahoot	12
Fifth Kahoot	12
Total	59

III. RESEARCH RESULTS

In gamification in ICT course there were almost all of the students of first semester, making a sample of 100 students (N = 100), and on LBE there were 85 students (N = 85). At the end of the semester, after all the played Kahoot games, students were involved in a research about motivation and engagement in using gamification. In ICT, there were 70% of students who filled the survey, while in LBE it was around 40%. Even though students played Kahoot in both the courses, they also have experience with lots of other different gamification tools such as MineCraft, Millioner, Sokrative, etc. They strongly recommend to implement gamification in courses that are still not involved in it. To underline this thesis, we are going to analyze some of the results.

[7] Students could also earn acitivity points by attending guest lecturers and visiting course-relevant institutions.

A. *Satisfaction*

In both courses, even though they are of different field, students are very satisfied regarding gamification in class. Over 95% of students gave the grade 4 or 5 in the survey – in ICT 96% (Figure 2), and in LBE 98% (Figure 3). To get the best insight of this analysis, we used couple of functions in order to get different indices. The average of students' satisfaction in ICT is 4.67, but with median and mode function the result was a clear 5. In LBE, students' average score was 4.73 with also highest median and mode – 5.

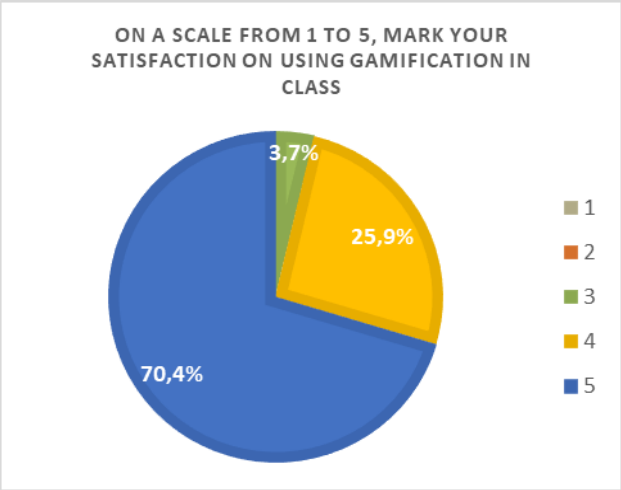

Figure 2. ICT student satisfaction

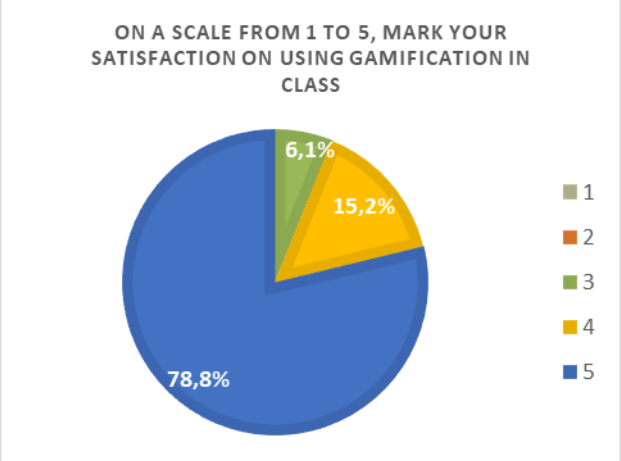

Figure 3. LBE student satisfaction

B. *Motivation*

When trying to assess students' motivation, we asked them to rate how much gamification is helping them towards better motivation, where we got similar results to their satisfaction rating. 91% of the students marked with either 4 or 5 in believing that gamification helps their motivation, with an average of 4.47 in ICT and 4.48 in LBE. With median and mode ratings of 5, it is easy to see that students have a high opinion of Kahoot and gamification in general. ICT motivation rating is presented in Figure 4 and for LBE is on Figure 5.

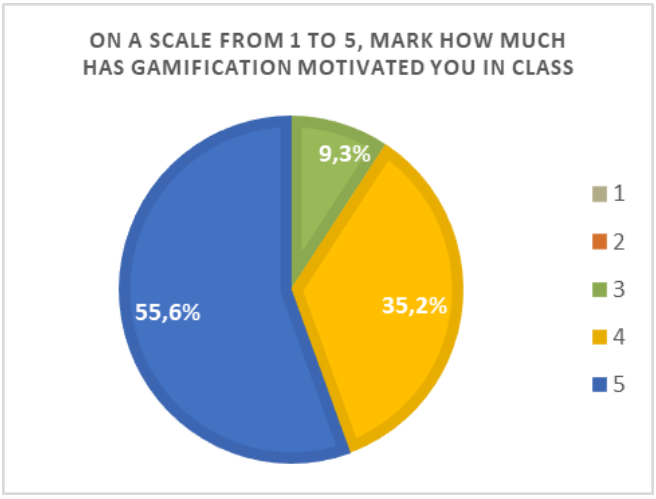

Figure 4. ICT student motivation

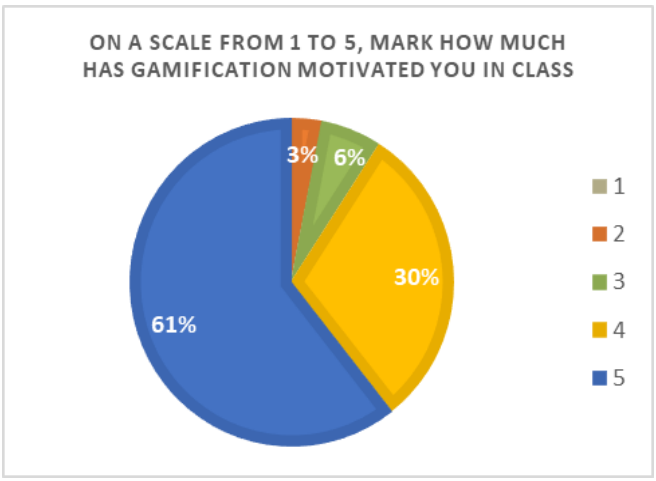

Figure 5. LBE student motivation

C. *Intrinsic and extrinsic motivation*

Even though gamification is closely related to Intrinsic motivation and it presents 4th motive on Glasser's list of motives [18, 19], students are more likely to play and compete if there is some kind of a symbolic award in the end, such as extra percentage or other. This is the only point where there is a correlative difference between the evaluated two courses – ICT and LBE. In ICT course, average of students' ratings regarding awards for playing Kahoot is a high 4.56, with a median and mode of 5, representing the high value of this element towards motivation. But, in LBE, the average rating is 3.64 with a median 4, and mode 3. The assumption is that a greater discrepancy arises primarily because of the difference in intrinsic motivation of students in the third year of studies than those in the first year. The influence of different grading systems is also likely to be a factor for intrinsic motivation.

IV. CONCLUSION

This paper shows gamification usage on courses from different fields: new technologies and law. Research has shown that students are very satisfied with using gamification in class regardless of the course's nature and would like to use various types of gamification

applications on all of the courses. In future research it would be interesting to follow the same group of students on different courses to see if there is any correlation in student motivation and engagement regarding their enrolled study year and courses taken. It would also be interesting to observe the proportion of intrinsic motivation on each year of their studies.

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Analysis of correlations between indicators influencing successful deployment of ePortfolios

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***Abstract* - This paper brings the selected results of the research focused on measuring the success of an ePortfolio system deployment at the individual level. Further, it explores the structural model based on the DeLone & McLean's IS success model by investigating the relationships between the Use, User Satisfaction and Net Benefits as the main constructs of the model. The analysis involved 186 students from 10 different institutions worldwide. The descriptive statistics is used to identify and explain the correlations between main constructs, as well as to explain the correlations between indicators that are direct benefits of using ePortfolios. The results confirmed the previous research implications and found the modest correlation between the Use and Net Benefits, as well as a moderate correlation between the User Satisfaction and Net Benefits.**

Keywords – ePortfolio system; DeLone & McLean's IS success model; ePortfolio benefits; use; user satisfaction

I. INTRODUCTION

This research presents an extension to the previous work focused on measuring the success of an ePortfolio system deployment at the individual level [10] based on the well-known Delone & McLean's Information System Success Model (hereinafter D&M Model). For that purpose, the ePortfolio success measurement model and the structural model were developed to study and explain the relationships between the following six dimensions of the proposed model: System Quality, Information Quality, Service Quality, Use, User Satisfaction and Net Benefits.

Among other findings, the previous work showed that the higher User Satisfaction will lead to the higher Net Benefits that will, in turn, affect the User Satisfaction. Moreover, the proposed ePortfolio success model clearly shows that the Use and User Satisfaction dimensions are very tightly connected. This means that the Use affects the User Satisfaction and vice versa. Such relationships are in accordance with the argument that six dimensions are interrelated, showing not only the process flows but causality flows as well [20]. The same tight connection was found between the Net Benefits and User Satisfaction dimensions.

Further, this research explores the nature of connections between the three constructs, as well as the relationships between indicators in the Net benefits due to the fact that this construct was not previously explored. Therefore, this paper reveals the basic terminology, research background and research rationale. Beyond defining research aims, all three research constructs are operationalized in order to explain their nature and their prospective indicators. The data analysis explained below is focused on the relationships between constructs and also between indicators within Net benefits. The paper ends with the discussion based on the results and implications for ePortfolio researchers and practitioners.

II. RESEARCH BACKGROUND

An electronic Portfolio, or ePortfolio, constitutes an extension to the e-learning and was, therefore, strongly popularized in the recent years. An excellent definition of the ePortfolio was offered by [6], who described the Portfolio as "a meaningful collection of student work that demonstrates progress and/or mastery guided by standards and includes evidence of student self-reflection".

Regarding the fact that the ePortfolio is an Information System [9], a whole set of Information System techniques and methods can be applied in order to analyse the successful implementation or deployment of an ePortfolio system. Therefore, in our previous work [10] we used the D&M Model [20] (see Figure 1) as the most widely accepted model for measuring IS success [17] to develop the ePortfolio Success Model that explains the relationships between the dimensions of ePortfolio success. Along with the Model, we also developed a corresponding ePortfolio success instrument for assessing ePortfolio success based on the indicators and constructs of the Model. However, that research revealed the relationships on general levels (i.e., between the main constructs) and neither did it focus on the relationships between indicators within the constructs, nor did it further explain the relationships between indicators from different constructs.

However, [20] indicate that the Use, which captures the recipient's consumption of the system's capabilities, precedes the User Satisfaction, that captures the recipient's response to the use of the output of an ePortfolio system, in a process sense. Moreover, the greater User Satisfaction will also lead to an increased Use, which refers to a causal relationship. Therefore, those two constructs are mutually tightly related and depend on the first three constructs, as well as on the Net Benefits, that captures the balance of the positive and negative impacts on consumers, organizations, industries, economies and even on our societies.

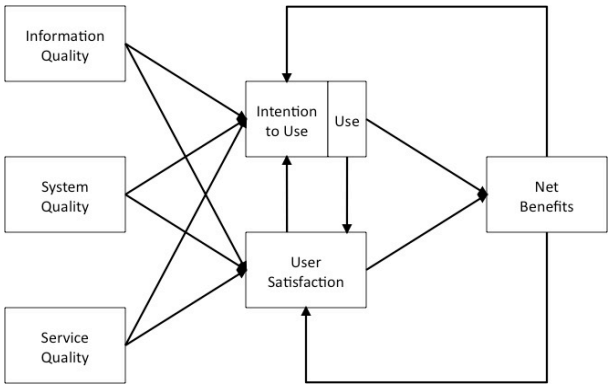

Figure 1. DeLone & McLean's IS Success Model

They also stress that the Net Benefits depend directly on the Use and User Satisfaction, which means that every change in the Net Benefits will be reflected on Use and User Satisfaction. Such claims are also supported by [15] who researched the effect of student learning on ePortfolios, reporting a strong positive impact of use on students' opinions and on enhancing their learning as part of net benefits. References [17] and [1] indicate the existence of the relationship between the Use and Net benefits. The success measure of the Web-based IS [4] showed that the User Satisfaction directly and positively influences Net Benefits. Reference [17] found a very strong positive relationship between the User Satisfaction and Net Benefits. In their analysis, all 14 papers reported positive relationship between the two constructs. Reference [17] also provided evidence for the existence of a very strong positive relationship between the Net Benefits and User Satisfaction, noting that all 11 papers included in their analysis confirmed the existence of such relationship.

With that in mind, this paper further explores our previous work [10] by focusing on the analysis of the relationships between the three constructs of the D&M Model (Use, User Satisfaction and Net Benefits), as well as on the analysis of relationships within the Net benefits in order to get deeper insight into the nature of relationships between such "the most important success measures", as the D&M Model refers to them [20].

III. OPERATIONALIZATION OF RESEARCH CONSTRUCTS

In this section, we analyse the research constructs and define the main indicators in order to assess them according to the criteria found in the literature.

A. Use

In most cases the system usage is an appropriate measure of success. It is a complex variable and researchers must also consider the nature, extent, quality and appropriateness of the system use [20]. Reference [17] claims that the empirical studies brought out many measures of the IS use, e.g. intention to use, frequency of use, self-reported use and actual use. Besides, it is important to note that the self-reported usage can be poor indicator for actual use of a system because some research found a significant difference between self-reported use and actual use [5]. In addition, [17] emphasises the suggestion of [8] that more use is not always better, so the frequency of use may not be the best way to measure the IS use. Therefore, they developed an instrument to measure the system usage based on the effects of use and not on the frequency of duration. Furthermore, [18] found out that there is a significant relationship between an intention to use and the actual use, concluding that the intention to use can be a good indicator for the system usage.

In the ePortfolio context: This construct assesses the degree and the manner in which an individual uses the ePortfolio application and realizes its potential and usage for the lifelong learning. In terms of ePortfolio, it measures the system's functionalities such as: features for organizing the ePortfolio content, joining groups, artefacts tagging as well as facilitating conditions that are present during the use of ePortfolio. Table 1 contains items for the construct Use.

TABLE I. ITEMS OF CONSTRUCT USE

USE		
	Items	***Ref.***
USE1	While using the ePortfolio, I used available features for organizing my content.	[11]
USE2	While using the ePortfolio, I collaborated with my peers in organizing ePortfolio content.	
USE3	While using the ePortfolio, I used features that helped me to join the groups.	
USE4	While using the ePortfolio, I used features that helped me to set view permissions for different views (ePortfolios).	
USE5	I have the knowledge necessary to use the system.	[19]
USE6	I was able to complete a task using the system even if there was no one around to tell me what to do as I go.	

B. User Satisfaction

The construct User Satisfaction is strongly connected to the construct Use. As [20] claims, "use must precede user satisfaction in a process sense" which means that one must first use a system and based on the experience express the level of satisfaction. Accordingly, a positive experience will lead to greater satisfaction in a causal sense. The most popular user satisfaction instruments according to [17] are EUCS – End-User Computing Support instrument [21], and UIS – User Information Satisfaction instrument [2]. Both contain items linked to the system, information and service quality, so they are used to measure beyond the overall user satisfaction with the system.

In the ePortfolio context: This construct assesses the user satisfaction with an ePortfolio application and the information produced by that application. The User's satisfaction with views, artefacts and received feedback will probably lead to a greater use of the ePortfolio as an application and a concept. The attitude towards using the system and its usefulness are considered to be two of the most important elements of the User Satisfaction in the ePortfolio context. Therefore, this construct measures whether the ePortfolio system makes work more interesting, whether all the necessary user requirements are met in order to use the ePortfolio, whether an individual has the necessary knowledge to work with the ePortfolio, etc. Items for the construct User Satisfaction are shown in Table 2.

TABLE II. ITEMS OF CONSTRUCT USER SATISFACTION

USER SATISFACTION		
	Items	***Ref.***
USAT1	I like working with the system.	[19]
USAT2	The system makes work more interesting.	
USAT3	Using the system is a good idea.	
USAT4	I find the system useful in learning.	
USAT5	The degree of freedom for expressing one's own individuality and personal strengths is satisfactory.	[11]
USAT6	The ePortfolio presentation capabilities (e.g. quick upload, format and presentation of personal information) are satisfactory.	

C. Net Benefits

Net Benefits result from the constructs Use and User Satisfaction, and they are the most important success measures capturing the balance of positive and negative impacts on consumers, organizations, industries, economies and even on our societies. Besides, the Net Benefits can't be analysed and understood without the constructs System Quality and Information Quality [20]. This construct is very case-specific which means that it depends entirely on the type of the IS. Sequentially, there are many methods to measure net benefits. The perceived usefulness, job impact and the profitability measurements being the most common measures [17].

In the ePortfolio context: This is the most comprehensive and delicate construct because it is specific for every context. It needs to be tailor made for each type of the IS because it captures the contribution of a specific type of the IS to different target groups. This construct measures the extent to which ePortfolio enhances the lifelong learning. One of the key aspects of the Net Benefits concerning an individual is enhanced learning through developing a positive attitude towards the lifelong learning, fulfilling the learning outcomes, increasing evaluation transparency, enhancing the communication between student and teacher etc. The other important aspect of the Net Benefits for an individual can be seen through personal growth and development in terms of evaluating one's progress towards the achievement of personal goals, the ability to choose co-workers, benchmarking, etc. At the same time, based on the information from an ePortfolio, institutions can show their particular strengths and advantages or regroup their employees into project teams based on their interests, skills and work experience so to advance the work efficiency. Moreover, employers can benefit from an ePortfolio in the recruitment process by, for instance, narrowing the list of potential employees based on the information provided in their ePortfolios. Students can also benefit in that respect by enhancing their learning and managing or tracking their own growth and development. Table 3 contains items for the construct Net Benefits.

TABLE III. ITEMS OF CONSTRUCT NET BENEFITS

NET BENEFITS		
	Items	***Ref.***
NB1	The ePortfolio encouraged me to develop a positive attitude to lifelong learning.	[11]
NB2	The ePortfolio helps me to make connections between formal (i.e. structured learning within the school or faculty) and informal (i.e. unstructured learning occurring in everyday life) learning experiences.	
NB3	The ePortfolio helps me to fulfil learning outcomes.	
NB4	Using ePortfolio led to increased transparency in evaluation.	
NB5	The enhanced communication between me and educators enhances the chances for my success.	
NB6	I am able to evaluate progress towards achievement of my personal goals.	
NB7	I am able to choose my co-workers among peers according to various criteria (interests) presented in ePortfolio.	
NB8	I am able to compare myself with others.	
NB9	I am able to show my personal growth and development over time.	
NB10	Writing reflections enable me to develop decision-making skills.	
NB11	Potential employers can view my showcase Portfolio with the benefit of contextual clues from the institution, assessment criteria, and my personal descriptions of achievements.	

IV. DATA ANALYSIS AND RESULTS

For the purpose of data collection, a questionnaire-based method was used. All items were measured using a five-point Likert-type scale from 1 (I don't agree/totally incorrect) to 5 (I totally agree/totally correct). Again, the developed questionnaire undergone a rigorous test for content validity, construct validity and reliability of the scales as indicated in our previous work [10].

A. Sample

In total, 186 valid responses were recorded from 10 different institutions worldwide. The respondents were 55,4% female students and 44,6% male students, a balanced gender sample. Most students (80,6%) fell into the 18–23 age range, the most common university student population. The targeted population was comprised of students that used ePortfolio within at least two courses or for a minimum period of six months. Additionally, students used different ePortfolio software (in most cases they used Mahara and custom made ePortfolios), which was very important. When all students use the same ePortfolio software, it is difficult to determine the relationships between the System Quality construct and other constructs. Additionally, a very large number of respondents (94,6%) reported having from a few up to 20 artefacts in their ePortfolios. Most respondents (38,7%) had between 5 and 10 artefacts stored in ePortfolio. Most of them had their CVs in the form of a single artefact. Most respondents (69,4%) used ePortfolio within only two courses.

B. Scale reliability

In order to proceed with the data analysis, the scales were examined for internal consistency using Cronbach Alpha coefficient. After calculations, all scales showed

satisfactory consistency: Use (0,79), User Satisfaction (0,89) and Net Benefits (0,91).

With this respect, we proceeded to the analysis of the results. Since each item was evaluated with a version of Likert-type scale (with ordinal variables), the Spearman's correlation coefficient was used to evaluate the relationships between single items from each construct.

C. Relationship between constructs

Firstly, we analysed the correlations between the constructs Use and Net Benefits and between the constructs User Satisfaction and Net Benefits. In this paper, the focus will be on the correlation coefficients above 0,40 following the recommendations from [13].

Table 4 shows the correlation matrix between the constructs Use and Net Benefits. The bolded values in the Table represent the correlations which are taken into further consideration.

TABLE IV. SPEARMAN'S RHO FOR CONSTRUCTS USE AND NET BENEFTIS

Indic	USE1	USE2	USE3	USE4	USE5	USE6
NB1	0,261**	0,235**	0,173*	0,106	0,211**	0,086
NB2	0,288**	0,305**	0,212**	0,136	0,280**	0,095
NB3	0,160*	0,199**	0,097	0,064	0,242**	0,110
NB4	0,214**	0,114	0,230**	0,231**	0,257**	0,166*
NB5	0,346**	0,258**	0,232**	0,197**	0,203**	0,056
NB6	**0,419****	0,280**	**0,417****	**0,401****	0,293**	0,168*
NB7	0,343**	0,385**	**0,481****	**0,475****	0,332**	0,188*
NB8	0,378**	0,306**	**0,464****	**0,425****	0,380**	0,307**
NB9	0,262**	0,243**	0,254**	0,293**	0,351**	0,200**
NB10	0,328**	0,224**	0,323**	0,330**	0,292**	0,187*
NB11	**0,451****	0,308**	0,331**	0,317**	0,333**	0,266**
**. Correlation is significant at the 0,01 level (2-tailed).						
*. Correlation is significant at the 0,05 level (2-tailed).						

Accordingly, there is a weak correlation between the item USE1 and item NB6. This means that using the available features for organizing content in ePortfolio affects the users' ability to evaluate progress toward achievement of personal goals ($rs = 0,419$; $p < 0,01$). Furthermore, the item USE1 correlates with the item NB11 which means that using available features for organizing the content in ePortfolio also correlates with the ability of potential employers to view the users' showcase Portfolio within the context of the institution's requirements, assessment criteria, and personal descriptions of achievements ($rs = 0,451$; $p < 0,01$). This shows that the user of ePortfolio is motivated to organize his content within the ePortfolio, so he could be more appealing for the potential employers. It is important to note that the item USE3 correlates with the items NB6, NB7 and NB8 from the construct Net Benefits ($rs = 0,417$; $rs = 0,481$; $rs = 0,464$; $p < 0,01$) and that the item USE4 also correlates with the previously mentioned items from the construct Net Benefits ($rs = 0,401$; $rs = 0,475$; $rs = 0,425$; $p < 0,01$). This means that if a user uses the features to join the groups and to set different view permissions (ePortfolios) it might help him to evaluate progress toward achievement of his personal goals, to choose his co-workers among peers according to various criteria (interests) presented in ePortfolio and to compare himself with others.

Table 5 shows the correlation matrix of the constructs User Satisfaction and Net Benefits. As in the previous table, the bolded values represent the correlations taken into further consideration.

TABLE V. SPEARMAN'S RHO FOR CONSTRUCTS USER SATISFACTION AND NET BENEFITS

Indic.	USAT1	USAT2	USAT3	USAT4	USAT5	USAT6
NB1	0,449**	0,451**	0,470**	**0,595****	**0,528****	**0,518****
NB2	0,405**	0,439**	0,370**	0,431**	0,478**	0,386**
NB3	0,450**	0,495**	0,311**	**0,543****	0,386**	0,326**
NB4	0,402**	0,418**	0,445**	**0,535****	0,466**	0,372**
NB5	0,383**	0,366**	0,418**	0,469**	0,479**	0,353**
NB6	**0,506****	0,382**	**0,504****	0,384**	**0,538****	0,470**
NB7	0,423**	0,349**	0,466**	0,372**	**0,510****	0,366**
NB8	0,387**	0,311**	0,337**	0,370**	0,439**	0,367**
NB9	0,474**	0,318**	0,422**	0,345**	0,421**	0,423**
NB10	0,438**	0,409**	0,471**	**0,523****	0,494**	0,408**
NB11	0,389**	0,306**	0,457**	0,318**	**0,515****	0,496**
**. Correlation is significant at the 0,01 level (2-tailed).						
*. Correlation is significant at the 0,05 level (2-tailed).						

All bolded correlation coefficients are above 0,50 and there are no coefficients under 0,30 so it can be concluded that there are moderate to good correlations between the constructs User Satisfaction and Net Benefits. The items USAT1 and USAT3 moderately correlate with the item NB6 from the construct Net Benefits ($rs = 0,506$; $rs = 0,504$; $p < 0,01$), which means that the user likes to work with the system and the system makes work for him more interesting because he is able to evaluate progress toward achievement of his personal goals. Furthermore, the item USAT4 from the construct User Satisfaction correlates well with the items NB1, NB3, NB4 and NB10 ($rs = 0,595$; $rs = 0,543$; $rs = 0,535$; $rs = 0,523$; $p < 0,01$). This means that the user is able to see the benefits of using the ePortfolio in learning. In other words, ePortfolio is useful for the user in learning because it encourages him to develop a positive attitude towards lifelong learning, it helps to fulfil the learning outcomes of the user, it increases the transparency of evaluation and it helps the user to develop decision-making skills through writing reflections. It is also important to note that the item USAT5 moderately correlates with items NB1, NB6, NB7 and NB11 from the construct Net Benefits ($rs = 0,528$; $rs = 0,538$; $rs = 0,510$; $rs = 0,515$; $p < 0,01$). Based on that, one can say that the user considers the degree of freedom for expressing own individuality in the ePortfolio satisfactory because through ePortfolio one can develop a positive attitude to lifelong learning, evaluate his own progress, choose his own co-workers according to various criteria and make his showcase Portfolio available to potential employers. The item USAT6 also correlates with the item NB1 ($rs = 0,518$; $p < 0,01$), which means that if a user is satisfied with the ePortfolio presentation capabilities (which include quick upload, format and presentation of personal information) it will encourage him to develop a positive attitude to lifelong learning.

D. Relationships between indicators in Net Benefits

Since the construct Net Benefits is new, unexplored and therefore not previously analysed like the constructs Use and User Satisfaction, an analysis was made to see to what extent do the items within the construct Net Benefits correlate and to find out whether there are some indicators that significantly determine the benefits of ePortfolios. Accordingly, Table 6 shows the correlation matrix for the items within the construct Net Benefits. As above, the bolded values represent the correlations which are taken into further consideration. All bolded correlation coefficients are above 0,50 and there are no coefficients under 0,25 so it can be concluded that there is a correlation between all items in the construct, and between some items, even a moderate to good correlation. The highest correlations are between items NB1 and NB2 (rs = 0,633; $p < 0,01$), NB6 and NB7 (rs = 0,658; $p < 0,01$) and NB7 and NB8 (rs = 0,619; $p < 0,01$). This means that, in the ePortfolio context, developing a positive attitude to lifelong learning correlates with making a connection between formal and informal learning experiences. In other words, the user of an ePortfolio can make a better connection between structured learning within a school or a faculty and the unstructured learning in everyday life, which results with a positive attitude towards lifelong learning. Beside the above mentioned, the ePortfolio encourages the user to develop a positive attitude to lifelong learning through a higher level of transparency in evaluation (NB1 and NB4, rs = 0,556; $p < 0,01$), enhanced communication between the user and educators which enhances the changes for the user's success (NB1 and NB5, rs = 0,519; $p < 0,01$) and through writing reflections which enables the user to improve decision-making skills (NB1 and NB10, rs = 0,522; $p < 0,01$).

Further, the ability to evaluate the progress toward achievement of the user's personal goals has a moderate to good correlation with the ability to choose co-workers among peers, according to various criteria presented in an ePortfolio (NB6 and NB7). Moreover, the ability to evaluate the progress toward achievement of the user's personal goals also has an impact on the ability of the user to show his personal growth and development over time (NB6 and NB9, rs =0,558; $p < 0,01$), but it also affects the user's ability to write down reflections, which in turn enables the development of decision-making skills (NB6 and NB10, rs = 0,518; $p < 0,01$), and enhances the change of the user's success through enhanced communication with the educators (NB6 and NB5, rs = 0,518; $p < 0,01$). The last correlation between items over 0,60 is between items NB7 and NB8, which means that the ability to choose co-workers among peers according to various criteria in an ePortfolio allows the user to compare himself with others. For the correlations around 0,50, it is important to note that the ePortfolio allows the user to show his personal growth through comparison with others (NB8 and NB9, rs = 0,537; $p < 0,01$).

Furthermore, fulfilling the learning outcomes by using an ePortfolio increases the transparency in evaluation (NB3 and NB4, rs = 0,540; $p < 0,01$). Finally, the ePortfolio allows better communication between the user and his educators, the user is able to enhance the chance for his success, and this is connected to the user's ability to evaluate progress toward achievement of his personal goals (NB5 and NB6, rs = 0,508; $p < 0,01$).

TABLE VI. SPEARMAN'S RHO FOR ITEMS WITHIN THE CONSTRUCT NET BENEFITS

Indicators	NB1	NB2	NB3	NB4	NB5	NB6	NB7	NB8	NB9	NB10	NB11
NB1		**0,633****	0,492**	**0,556****	**0,519****	0,438**	0,312**	0,259**	0,403**	**0,522****	0,375**
NB2			0,492**	0,492**	0,491**	0,379**	0,373**	0,250**	0,314**	**0,505****	0,388**
NB3				**0,540****	0,406**	0,332**	0,346**	0,357**	0,396**	0,378**	0,339**
NB4					**0,520****	0,386**	0,364**	0,310**	0,339**	0,452**	0,354**
NB5						**0,508****	0,465**	0,391**	0,441**	0,496**	0,402**
NB6							**0,658****	0,463**	**0,558****	**0,518****	0,463**
NB7								**0,619****	0,467**	**0,548****	0,497**
NB8									**0,537****	0,448**	0,490**
NB9										0,485**	0,473**
NB10											0,498**
NB11											
**. Correlation is significant at the 0,01 level (2-tailed).											
*. Correlation is significant at the 0,05 level (2-tailed).											

V. DISCUSSION

While analysing the relationships between constructs, a weak correlation was noted between the Use and Net Benefits. Fifty percent of the indicators in the Use construct do not correlate with the Net Benefits. In overall, it was noted that the "ease of use" and the collaboration features do not affect the impact of the ePortfolios on target groups. However, two indicators, USE3 and USE4, that relate to joining the groups and managing ePortfolio viewing permissions, showed the highest number of correlations with the Net Benefits which implies that those could be the "triggers" for more successful implementation of ePortfolios.

The second analysis revealed 11 indicators between the User Satisfaction and the Net Benefits that are strongly correlated while others are moderately to good correlated. This indicates better correlation than between the Use and Net Benefits, which is in line with the theoretical background. In this case, we note 2 indicators that correlate with 4 indicators in the Net Benefits - USAT4 and USAT5, which reflect usefulness of an ePortfolio in learning and the level of freedom to express one's own individuality and personal strength. Those two indicators significantly determine the user's perception of the ePortfolio benefits.

In the domain of Net Benefits, there are no coefficients under 0,25 which means that all indicators are interrelated to some extent. By examining the indicators and their correlations, one can note that the indicator NB10 has an effect on the largest number of other indicators in the domain. Since the NB10 is related to using reflections, it was confirmed once again that the reflections are indeed a very important feature of the ePortfolio thus playing an important role in the learning process. Another indicator that has large number of correlations with others is the NB1 which indicates that the ePortfolio can help students to develop a positive attitude towards lifelong learning, which is also indicated in numerous known definitions of the ePortfolio. A notable overall impact of the ePortfolios is also recorded in NB6 that reflects the ability to evaluate progress towards achievement of students' personal goals. Again, this is in-line with the general definitions and explanations of the ePortfolios, as a tool for managing personal growth and development.

In overall, the results of previous researches are confirmed by this study in terms of relationships between the Use, User Satisfaction and Net Benefits. It means that almost every change in the constructs Use and User Satisfaction will be reflected in the Net Benefits. All these findings should be taken into consideration by future researchers and practitioners dealing with successful implementation of ePortfolios.

VI. CONCLUSION

This study confirmed that the greatest impact on Net Benefits has the User Satisfaction while the lowest has the Use as it was already reported in previous researches. In causal sense, the positive experience of using the ePortfolio will lead to greater user satisfaction. There are some key indicators in order to increase the benefits of ePortfolios. A user must see the benefits of using an ePortfolio in learning like fulfilling the learning outcomes, making personal growth, achieving personal goals, developing decision-making skills, etc. All of these will also lead to user's positive attitude towards lifelong learning. The relationship between the Use and the Net Benefits is not negligible. It stresses that the available ePortfolio features enable users to organize their content in order to be more visible for potential employers, as the ability to join different groups and to work with the peers, set different view permission etc. Each institution with the implemented ePortfolio system should periodically conduct a questionnaire about the user satisfaction and their use in order to identify possible gaps and plan activities to improve the benefits from using ePortfolios.

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Calibration of source-code similarity detection tools for objective comparisons

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***Abstract* - Today there are many source-code similarity detection tools. These tools are used for many purposes and one of them is plagiarism detection, in which context this paper is written. Every time a new tool is developed authors want to show that it is better than existing ones, and so they perform comparisons. Often these comparisons tend to be unfair towards the existing tools, for which there can be multiple reasons, such as the lack of calibration of existing tools. Almost all tools have configuration parameters, but often they are not calibrated before the comparison. The paper presents a way of calibrating the tools to keep the comparison more objective.**

Keywords* - *source-code, plagiarsim, similarity detection, calibration

I. INTRODUCTION

Similarity detection is a process of finding similarities in a set of documents. These documents can be pure text, source-code, binary files, etc. There are different reasons for using similarity detection, and the process, techniques, and similarities differ depending on the contexts. But whatever the context, to speed up the detection similarity detection tools (short: tools) are built to analyse the files and generate a report.

For each context, multiple tools exist, which then lead to many comparisons. Researchers compare the tools to find out which exhibit improved performance focusing on a single property of the tool, such as speed of execution, allocation of memory, precision of task execution, or some combination of two of more of those properties, depending on the tools and the context.

For comparisons to be valid and useful they need to be objective and not biased. One factor that influences the comparisons is the configuration of the tools being compared. Similarity detection tools mostly have some kind of configuration parameters (short: parameters), which enable the user to modify the different aspects of the detection to get better results.

Sometimes the best configuration for a particular context is known, but often it is not. To have an objective comparison the tools need to be used with their best configuration, and this raises a question: "Is it possible to have an objective comparison of similarity detection tools when there is no knowledge of the best configuration for a tool involved?"

In this article a method is proposed that enables a more objective comparison when the best configuration is now known for one or more tools involved. Although the tools are built for a specific purpose and all perform similarity detection, they may be quite different, and so only tools in the same context can be compared.

To demonstrate the method we need to set up the context in which similarity detection is used, and in this article we focus on source-code plagiarism detection in student programming assignments.

The rest of the article is structured as follows. Section 2 describes the related work. Section 3 and Section 4 describe the tool calibration method and the metric needed to do it. Section 5 demonstrates the use of the method on real examples with two tools, and Section 6 discusses the result of the example. Section 7 describes possible future work and Section 8 concludes.

II. RELATED WORK

Source-code plagiarism detection is not new. Already in 1981 Donaldson et al. [1] built a plagiarism detection system which could be used for programs written in FORTRAN, COBOL or Basic. Since then over 100 similarity detection tools have been built mainly for the purpose of plagiarism detection, examples of which include MOSS [2], JPlag [3], YAP3 [4], Sherlock [5], SIM [6].

Most of these tools were built for specific programming languages so when deciding which tool to use it is important to know if the chosen tool supports the target programming language. Also not all tools can be used offline, and not all tools are free. For help one can consult review articles like [7], [8] which compare the tools by their features and list such information for selected tools.

Every time a new tool is developed it is usually compared by the authors. Sometimes authors make feature comparisons [9] and sometimes they use experiments [10], but comparisons are also performed by others (like [11], [12]) not just the authors who have developed a tool.

Many experimental comparisons have already been performed, each one with some parameter configurations of the tools involved, however, it is often unknown what the specific configuration was [13]. Sometimes it is not directly specified, such as in [14] where the authors simply write they are using JPlag and the SOCO dataset, and from this one can look up (for example) [15] and find out that the parameter configuration is the default configuration.

When the configuration is not specified one can assume that the tool was then used with the default parameter configuration (if there is one), but cannot know for sure. Also, since the datasets and/or tools are not often available, it is impossible to repeat the experiment to identify the parameters.

The problems for not publishing the configuration parameters are obvious: authors could have manipulated them so that a tool appears better, the data used in different studies cannot be compared, and future users do not know how to set up the tool for best performance.

Sometimes it is also a problem if two tools have the same name. For example there is Sherlock from the University of Warwick [5] and Sherlock from the University of Sydney [16], or SIM from Grune [6] and SIM from Gitchell and Tran [17]. In such cases it may happen that a comparison is accidentally made to the wrong tool, or worse, authors cite one tool and use the other.

Another problem is that even if published research states the parameters, one could ask what the best configuration is. Ragkhitwetsagul et al. [11] tried to solve this by searching for the optimal configurations for 30 tools, among which are four plagiarism detection tools. The results of this research can now be used when comparing tool, but one then needs to be careful that the results depend on the datasets used during the comparisons. It could be that for a different dataset a different configuration would be better, and thus it is preferable to refer to an "optimal" configuration rather than a "best" configuration.

III. TOOL CALIBRATION METHOD

From [11] we now know the optimal parameters for some tools, but many tools are not covered in [11] and in some instances the parameters may not yield satisfactory results for the current dataset. How can two tools in such circumstances be compared objectively?

We propose calibrating the tools, for which there are two approaches. The first approach is to take a dataset for which the similarities between files are known, and to try various combinations of parameters and find the most suitable. With this approach one could – in principle – find the optimal parameter configurations.

The problem with this approach is that the similarities need to be known for each pair and this is not really possible unless it is an exact copy. One could ask experts to evaluate the source-code and quantify the similarity – this may be possible with programs with (say) ten lines but infeasible for programs with 100 or more lines, for which it would be unreasonable to expect to get an accurate number from an expert. Also, we would then need to establish *how many* experts would be needed, *who* the experts should be, and whether *sufficiently many* of them can be found. Also, this approach with experts is used when we just want to evaluate whether something is or is not a plagiarism [15], rather than quantifying precisely the degree of similarity for each pair.

TABLE I. THEORETICAL CALIBRATION EXAMPLE

Tool	Case 1	Case 2
Base tool	50%	60%
Calibrated tool – Configuration 1	50%	55%
Calibrated tool – Configuration 2	30%	60%

The second approach is a calibration method, performed using the tools themselves to calibrate each other. There is no need to know the similarities in advance, instead one tool (the *base* tool) is used to calculate the similarities, and other tool (the *calibrated* tool) is used to get as close as possible on the same dataset (the *calibration dataset* – CD). The base tool should ideally be a tool for which the optimal parameter configuration is already known, and is similar to the jury concept [18].This approach has a potential problem, illustrated by the following example. Suppose there are two cases (c_i) in the calibration dataset, where a case is a set of two files which are compared. Formula 1 defines CD as a set of n cases of pairs. Let say that similarity calculated using the base tool is 50% similarity for the first case and 60% similarity for the second case. A tool that needs to be calibrated is run and the results are the following. For the first case with 50% similarity, one configuration is optimal, but for the second case with 60% similarity a totally different configuration is optimal.

$$CD = \{c_i, i = 1 \dots n\} \quad (1)$$

This problem we have solved by using a metric that we called Calibration Difference Sum (CDS).

IV. CALIBRATION DIFFERENCE SUM

Calibration Difference Sum (CDS) is a metric invented to solve the problem of the second approach. The idea is to sum up the differences for each case with each configuration and then see which parameter configuration comes closest for both cases. Formula 2 defines a difference of case (c_i) as absolute difference of similarity for tool A with parameter a (t_a^A) and similarity for tool B and with parameter b (t_b^B), where "a" and "b" are sets of allowed parameter values in tools which have only one configuration parameter.

$$\text{diff}\,(c_i, t_a^A, t_b^B) = |sim(c_i, t_a^A) - sim(c_i, t_b^B)| \quad (2)$$

$$a = \{p_{A1} \dots p_{An}\}, b = \{p_{B1} \dots p_{Bn}\}$$

In Table I a theoretical calibration example is given (using the two cases introduced above). The two cases prefer different configurations but configuration 1 misses case 2 only for 5% while configuration 2 misses case 1 for 20%, and therefore configuration 1 is better.

The sum of differences for all cases between the base tool and one configuration of the calibrated tool is what we refer to as the *Calibration Difference Sum*. Formula 3 defines CDS value for tool A with parameter a calibrating

tool B with parameter b as a sum of differenced for all cases.

$$CDS_{ab}^{AB} = \sum_{i=1}^{n} \text{diff}\,(c_i, t_a^A, t_b^B), \quad (3)$$

$$a = \{p_{A1} \dots p_{An}\}, b = \{p_{B1} \dots p_{Bn}\}$$

The benefit of using CDS is that it can be used with two or more base tools. In the above scenario of two base tools, the CDS values for the first base tool are calculated, the CDS values for the second base tool are calculated, and then the CDS values for the same configuration are summed (we called that *Total CDS*). Finally, a configuration with the lowest Total CDS value is selected.

Another possibility is when there are multiple tools that need to be calibrated. In this scenario the suggestion is to calibrate the tools one by one, and then use each calibrated tool as a base tool to calibrate the next. For example, there are three tools where first is the base tool and others need to be calibrated. The second tool is calibrated with the first tool, and the third tool is calibrated with the first tool and the second tool.

All scenarios require a base tool, but what if there is no base tool, for example when the optimal parameters are not known for any of the tools involved? The answer is *mutual calibration*. The idea this time is to set one tool as base tool, set one configuration (one parameter value), and then calibrate the other tool and calculate CDS (Formula 3).

The configuration (parameter value) of the base tool is then changed, and the other tool re-calibrated and a new CDS values calculated (Formula 3), and this process repeated that for as many configurations as necessary. To be able to terminate the process one should experiment with the parameters to find out what range of values give meaningful results. Often above some parameter value tool marks most cases in the dataset with equal values for similarity, for example everything is marked close to 100% similarity or 0% similarity.

The roles are then switched (the base tool becomes the calibrated tool, and vice versa) and the whole process repeated. Formula 4 defines CDS value for tool B with parameter b calibrating tool A with parameter a as a sum of differences for all cases.

$$CDS_{ba}^{BA} = \sum_{i=1}^{n} \text{diff}\,(c_i, t_b^B, t_a^A), \quad (4)$$

$$b = \{p_{B1} \dots p_{Bn}\}, a = \{p_{A1} \dots p_{An}\}$$

Once all CDS values are known the minimum CDS in both iterations can be found. If the minimal CDS values are achieved with the same parameters we are getting the so called optimal CDS (CDS_{opt}) as defined in Formula 5.

$$CDS_{opt} = \min\left(CDS_{a_1 b_1}^{AB}\right), \min(CDS_{a_2 b_2}^{BA}), \quad (5)$$

$$a_1 = a_2, b_1 = b_2$$

To better explain the last scenario and to demonstrate the calibration approach, in the next Section two tools will be calibrated this way: SIM (from Dick Grune) and JPlag. These tools were selected since both tools have been evaluated in [11] and give us the possibility to compare how different our results will be from the optimal parameter values reported in [11].

V. MUTUAL CALIBRATION OF SIM AND JPLAG

To demonstrate tool calibration, SIM and JPlag are used. The programming assignments used are all written in Java since both tools can work with the Java programming language. Both tools enable textual comparison and Java comparison. The main difference between the comparison approaches is that Java comparison uses tokens instead of the original text. Tokens are created so that instead of using a real value for some variable, the value is replaced by a name (such as "value") or the real type (such as "int" or "float") is just replaced by a name (such as "type"). In this way modifications like variable renaming have no influence on finding similarities.

Since Java comparisons are specific for programs written in Java it is natural to use the Java version, and this is assumed for the rest of this paper.

Both SIM and JPlag have one parameter to influence the comparison mechanism. SIM has the parameter *minimum run length* (*r*) and JPlag has the parameter *minimum token match* (*t*). In both cases the lower the value the more sensitive the tool is to similarities, which means it is more probable that a false similarity is reported.

In [11] it is reported that the optimal values for SIM are r=22 and for JPlag t=3, which differ from the default values for JPlag, which is t=9, and for SIM, which has default value r=24. This already confirms that default configuration is not always optimal. These values will serve us as guides and help us see how different the calibration will be from the reported values and from the default values.

A. Calibration dataset

The programming assignments we have used are written in Java, and the dataset contains a total of 18 cases. One case contains one pair of files which are compared to each other. Two kinds of cases are present, the first are manually created, and the second are cases created from the SOurce COde Reuse (SOCO) PAN track from the FIRE competition dataset. A detailed description of the SOCO dataset can be found in [15].

For the calibration from the SOCO dataset the cases from the training collection have been used where the cases were labelled manually by three experts as plagiarized and non-plagiarized. Ten SOCO cases were constructed by selecting two files for each case whereby three cases are made of plagiarized files and seven are made of non-plagiarized files.

The eight manually created cases were made in three versions. The first two cases contain two files where the similarity should be 0%. They are different as much as possible, although similarities can occur in a programming language just because of the syntax. The next three manual cases contain two files which are direct copies, but different changes (so called obfuscation) are made on two out of three cases. The obfuscations are simple replacements and insertion of dummy lines with the idea to confuse the detectors. The two modified cases have different obfuscations. The last three cases are cases which have around 50% similarity. Again two out of each three statements have been modified with different obfuscations.

Of course, for none of the 18 cases we *actually* do not know the exact similarity, but for the manually created cases we at least know approximately what can be expected, for example for the 100% cases it is not expected to get a similarity of 10%.

B. Test of the optimal calibration

Before the actual experiment a simple test was performed with the optimal values for each tool reported in [11]. The idea was to find out how JPlag and SIM differ in similarities on individual cases.

For all manually created cases both tools gave quite similar results, the maximum difference being 11%. In SOCO cases they reported more different similarities. For example, in one case JPlag reported 50% and SIM reported 0% similarity, and an analysis has established that JPlag was wrong since the two source files are completely different. The full reason for the 50% similarity reported by JPlag is beyond the scope of this article, but a simple answer is that the t value is too small and therefore JPlag was too sensitive and reported parts as similar which are not semantically similar but because of the syntax they were found similar.

It is of no surprise that SIM performed better since in [11] it was ranked much higher than JPlag. In the next section we shall see if calibration will generate more similar results.

C. Calibration of SIM using JPlag

As a first step of mutual calibration, SIM is calibrated using JPlag. In the simplest case one can use t=3 which we know is optimal [11] and find out which value of r will give the lowest CDS. The lowest CDS in this case was with r=9.

TABLE II. CALIBRATION RESULTS OF SIM (BASE TOOL JPLAG)

JPlag (t)	SIM (optimal – r)	CDS
3	9	158,7
6	14	106,0
7	21	105,5
8	22	93,5
9	22	84,1
10	26	89,8
11	26	95,4
12	26	112,6

TABLE III. CALIBRATION RESULTS OF JPLAG (BASE TOOL SIM)

SIM (r)	JPlag (optimal – t)	CDS
8	3	159,0
19	9	106,5
20	9	102,1
21	9	94,6
22	9	84,1
23	9	86,4
24	9	86,4
25	9	86,4

However, in order to find out whether a lesser CDS is possible, t was set to 1 and then the optimal parameter value for SIM was calculated. SIM's parameter r was tested in the range [1-30], and for every r value the CDS metric was calculated. The r value which caused the lowest CDS is taken and it is presented in Table II. This is repeated for every t value in the range of [1-30]. In Table II all the optimal values of r (with the lowest CDS value) for different parameter values of t are presented and only the most interesting parameter values of t that were used to calibrate SIM are presented. It is evident from Table II that the lowest CDS was with t=9 and r=22.

D. Calibration of JPlag using SIM

We could stop with the calibration if JPlag would be our base tool. But in our case we do not want to use JPlag or SIM as the base tool so the next step is to calibrate JPlag using SIM.

The test was exactly the same as it was when SIM was calibrated. The only difference is that now for every value of SIM's parameter r in the range of [1-30] the lowest CDS for JPlag's t value was searched. The tested t values for every r value were again in the range of [1-30].

Table III presents the results. Again the most interesting r values used to calibrate JPlag with the lowest CDS are presented, and it is evident that the lowest CDS value is for t=9 and r=22.

VI. DISCUSSION OF THE RESULTS

From Table II and Table III one can see that the optimal results reported in [11] are equal for SIM but different for JPlag.

In this mutual calibration a "perfect" result has been achieved since calibrations in both directions have produced the same result. In such a case one can trust the results. The result of this calibration (that the parameter value r of SIM is 22) is the same as reported elsewhere, and this fact gives us extra confidence that the chosen configuration is as optimal as possible.

It would be foolish to believe that every time mutual calibration is used, both calibrations yield the same results. If that happens one should have a plan how to objectively decide which configuration to use. In our case the plan was that since we know SIM ranked better than JPlag in [11] we would chose SIM as the base tool rather

than JPlag. Another reasoning that one could chose is that JPlag is much more used than SIM so it would be acceptable to use JPlag as base tool. Also, there is maybe a possibility to use a third tool to arbitrate.

Even though calibration is not perfect, it is still more objective than simply using default values. From our demonstration, if one would use the default values for SIM (r=24) and JPlag (t=9), the result would not be as optimal as with r=22 and t=9 (although – at least for SIM and JPlag – the difference would not be substantial). However in the case presented in [11] the difference from the defaults would be much greater.

The execution time in the cases of SIM and JPlag, and with a dataset of 18 cases, was around 3 minutes. But the execution time depends on the tool used and on the dataset used. The impact of the dataset is twofold. First there is the number of cases in the dataset and the length of each file. In the 18 cases used in the experiment there were files that contained from 50 up to 750 lines of code.

One could argue how the parameter values gotten from the calibration are valid to be used for real detection. We have done some simple validation (Table IV) on four cases which came from real student assignments where we knew what the approximate similarity was. The cases consist of files from 1200 up to 2500 lines of code.

It is impossible to know the exact similarity as a percentage since it depends on an expert (a teacher for example) to confirm it. In our case we performed a similarity check using a tool Sherlock [5] and a process described in [12] in 2016. The cases were analysed by teachers on the course. The first two cases were plagiarized and the students were accused of plagiarism and admitted doing it. The second two were cases which were not plagiarized.

The last case is the most interesting one, since it has 50 percent similarity but it is not a plagiarized case. This happened because template code was used and a lot of code was generated by the NetBeans IDE for web services and Object Relational Mappings, ORM. Actually, in all four cases some similarity comes from using template code and using some generation functions of the NetBeans IDE but this was not relevant for calibration.

TABLE IV. VALIDATION OF CALIBRATED PARAMETERS

	JPlag	SIM	Expected
Case 1	83.0	86.0	90.0
Case 2	77.2	78.5	75.0
Case 3	25.7	26.0	25.0
Case 4	47.7	50.5	50.0

From Table IV one can conclude that the similarities calculated using the calibrated parameters are good for SIM and JPlag. There are some differences, such as for case 1, but similarities gotten from both tools are very close to each other and also to the expected result.

However, it needs to be noted that both tools are known to be very good tools for plagiarism detection, so good results were expected. Suppose that a very bad tool were to be calibrated and which gives a combination of bad results. In such situation, the calibration would not improve the bad results, but the results would be more comparable than in a case where the calibration is not used. Also, if a bad tool is calibrated with a very good tool than the calibrated parameters for the bad tool would probably be the best parameters that one can get when comparing such a tool to the very good tool. The similarity calculated by the tools is then not relevant because the important thing is the equality for comparison.

At this point, it is useful to remind the reader that the intention of the calibration technique presented in this article is to put two or more tools in a more equal position for comparisons. It is *not* the intention of the calibration to find the best parameters for one tool, and it is possible that with different parameters some other tool would perform better.

VII. FUTURE WORK

One could spent a large amount of time calibrating tools and using a variety of datasets, and this would be valuable research helping us understand the detailed performance issues for the individual tools and the algorithms they use.

But the goal is often different, and calibrating (synchronizing) tools may be a precursor to performing an experiment, and be sufficient to ensure objectivity of the real experiment (insofar this is feasible).

Both SIM and JPlag had one parameter for configuration. Another problem arises when a tool has multiple configuration parameters (such as Sherlock, from the University of Warwick, which has 8 parameters). In such cases one needs to learn how the different parameters affect the results, and how to limit the number of combinations of the parameters. The limitation is needed to be able to finish the calibration in a practical amount of time. In future work we plan to experiment with Sherlock and other tools that have multiple configuration parameters.

VIII. CONCLUSION

The research question stated at the beginning was: “Is it possible to have an objective comparison of similarity detection tools when there is no knowledge of the best configuration for a tool involved?”

As was presented in Section 5, using mutual calibration one can get optimal parameter configuration in cases when there is no knowledge of the best configuration for a tool. By using calibration one can get a more objective comparison by putting both tools in an equal starting position, although it will probably never be 100% fair. Although it is possible that the approach will still favor one tool, it will surely be more objective than using just the default parameter configurations for both tools, except when there is proof that the default configuration is the optimal.

To be able to perform the tool calibration method, a metric is needed which enables comparison of parameter results on multiple calibration cases. For this reason we have created the metric called Calibration Difference Sum (CDS), which we seek to minimize.

It is possible that the parameter configuration differs for different datasets, and that in some cases there is no best parameter configuration. For that reason we justify our comment in the Introduction that we should refer to a calibration giving an optimal configuration rather than a best configuration.

In situations when there is knowledge of the optimal configurations for some similarity detection tool that was used in a published experiment, one should question if the parameter configuration is also optimal for some new experiment. In case of doubt, if the configuration for one tool can then be fixed, a calibration can then be performed and can yield insights into the problem. The calibration method gives an easy way of checking the applicably of parameters from existing research in new experiments.

The new calibration method described in this article is a new way of ensuring more objective comparisons by using a simple CDS metric. Besides the textual description, formulas are given as the formal presentation of the method.

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Designing an educational music game for digital game based learning: a Lithuanian case study

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***Abstract* - We describe the development and evaluation of the educational musical computer game for preschool children that offers a first experience with music education. The game is used as a case study to demonstrate, evaluate and discuss the principles of game design for digital game based learning. We describe the game's scenario along with the explanation of the logics and mechanics of this game, and present its evaluation from the educational point of view. The game fills the niche of the Lithuanian educational musical games, while the study results show that preschool children show great interest in exploration and creation of musical sounds thus ensuring the enrichment of educational game-based process with elements of creativity and emotional learning.**

Keywords - digital game based learning, emotional learning, musical learning, children, games, STEAM.

I. INTRODUCTION

Today preschool children are already digitally engaged and are acquainted with handheld computers (smartphones, tablets) at a very young age [1]. Especially, computer games attract children with immersive game worlds, capturing game stories, and rich multimedia experience. The games can also contribute towards children's discovery of the world and provide motivation for learning new knowledge. The pedagogical use of digital games has been recently a subject of an increased attention from researchers [2]. There is a need to associate and explore gaming activities that could be useful when applying for educational purposes [3]. An example of such game is the game designed for adult seafarers as well as undergraduate maritime students of maritime academies/institutions presented in [4], where the knowledge in navigational safety training was delivered using a multimodal game framework that included images, words, sounds, music, and movement.

Contemporary neuro-didactics [5] emphasizes the importance of passive (e.g., music listening) and active (e.g., singing, playing, dancing) child's musical involvement of music into children education [6]. Music is important for children's holistic development, especially in the socio-affective domain. The study [7] showed that children in the early and preschool age are very interested in music-related activities such as sound exploration, which encourages childrens' creativity and enhances their emotional intellect. Digital music games are increasingly being developed for educational purposes, like learning to sing, play the piano or read musical notes. Gradually, these games are being recognized as active learning environments, which can reinforce learning-oriented motivation of players and allow to sustain interest in learning while playing [8]. Moreover, music is effective in developing working areas such as auditory memory [9].

The use of Information and Communication Technologies (ICT) in combination with arts (including music) is relevant in the context of Science, Technology, Engineering, Arts and Mathematics (STEAM) education. Introducing young people to hybrid works of art and technology and by offering digital games as an educational art tool opens new opportunities to mix technology/engineering with artistic/creative process and design thinking, and keep young people attracted to the fields of Science, Technology, Engineering and Mathematics (STEM). For example, robotic music has been employed to help children enhance their educational motivation and effects [10].

The structure of the remaining parts of the paper is as follows. Section II describes the theoretical framework. Section III describes the development of the game. Section IV evaluates the game, and Section V presents the conclusions.

II. THEORETICAL FRAMEWORK

The pedagogical backgrounds of our research are Digital Game Based Learning (DGBL), self-determination theory (SDT), immersive learning and Technological Pedagogical Content Knowledge (TPACK).

Digital games can instill learning experiences in different learning fields, as these can respond to the intrinsic motivation of learners, when the tasks are interesting and fit the learners' abilities [11]. DGBL is related to the constructivist principles of active learning, in which understanding and knowledge of the world is constructed through personal experience and reflection on those experiences. This is also relevant to music education, as pupils need to not only recognize, but also

experience essential music elements; i.e., duration, pitch, tone color, dynamics and structure of music.

We also use the TPACK framework [12]. TPACK integrates technological (TK), pedagogical (PK), content (CK), pedagogical content (PCK), technological pedagogical (TPK), and technological content knowledge (TCK). Here CK is knowledge about the subject matter to be learned or taught. PK is knowledge about the methods, processes and practices of teaching. PCK is knowledge to develop and deliver effective content-specific instruction. TK is knowledge of basic ICT. TCK is knowledge of how the content can be represented by and researched with technology. TPK is knowledge of using technology to implement teaching methods, and the ICT tools fitting for achieving learning aims and implementing [13].

Immersive learning [14] focuses on learning design through achieving immersive experiences rather than conventionally transferring formal sets of knowledge between a teacher and a learner. Games provide a tool for achieving immersive learning in virtual spaces to provide the gamers with complex skills and information they need to become successful [15]. In line with SDT [16], games can be intrinsically motivating, when they make players feel competent, autonomous and provide psychological relatedness.

The main motivation for gamification is to increase player motivation to perform some kind of a task (e.g., to learn, in our case) or to increase and retain addiction to some process (such as learning) or a product (such as learning environment) using a game as a tool. Fogg Behavior Model (FBM) [17] explains gamification in terms of converging motivation and ability to perform until the desired behavior occurs. Motivation must be continuously supported and reinforced by game mechanics and player incentives so that the player is kept on the desired path in the game flow and his interest to continue playing is maintained [18]. For gamification to be effective, however, the elements (layers, actors, tools) of the game must be linked to learning outcomes [19].

III. DEVELOPMENT OF A GAME

A. Prerequisites

Hereinafter we describe the development of an educational musical play called "Happy piano sounds" (original title: "Pianinas linksmieji garsai"), which can be played on any Android smartphone or tablet, and is available to download from the GooglePlay store at play.google.com/store/apps/details?id=com.erfe.gtegw. The game was downloaded nearly 500 times from 2016 until April of 2018, and its average evaluation rate is 4.9 stars.

In designing the game, we followed the principles formulated by Chung et al. [20] as follows: (1) age-appropriate game content; (2) multi-touch applications to support interaction, and problem-solving; (3) game design with creative functions and recorded audio files to encourage meaningful repetition; (4) no prerequisite musical knowledge and skills; and (5) the potential to expand gameplay to a higher level of symbolic knowledge.

B. Design considerations

For the first time in the game, it may be difficult for the player, especially for a preschool child, to understand what the purpose of the game is, what needs to be done in a particular case. To help solve this problem, the game should provide an assistance tailored to be understandable for target user audience. Such assistance is presented in different (multimodal) ways - written, visual or audio. Considering that in the games for young children, the help provided by the text is difficult to understand, because most of the preschool age children still can not read. For this reason, the help provided by elderly (e.g., a parent, older brothers or sisters) is essential for playing. To create a game that small children can play on their own, needs to create visual or audio help. Monotony should be avoided in order to create a game that is playful, fun and interesting for children. For this reason, there is an option to choose, which sound (animal, instrument, or other object) will be propagated when the player clicks on the corresponding key/button.

The piano keyboard simulator is a necessary part of the game aimed at teaching the meaning of the piano keys and associated musical notes. Usually, 7 to 8 keys (one octave) are used from the start. The number can be explained by the Miller's Magical Number Seven Law, which claims that the number of objects an average human can hold in his/her working memory is 7 ± 2 [21].

The selection of colors used is another important issue to consider. While the real-world piano keys are black and white, the black color is usually associated with negative concepts such as fear, anger, death, evil, aggression [22]. Black color has been shown to make children unhappy [23]. Vivid colors rather than black & white have been shown to increase emotional attachment, attention, and memory [24], thus facilitating the learning process. While black keys are necessary to learn the piano keyboard correctly, but on the other hand, there is some difficulty of learning with the help of black keys. Therefore, the piano keys have been painted in different colors to induce positive emotions from children and encourage playing.

When developing an educational game, its main purpose is to train. The entertainment side of the game is only to sustain the attention of the player. This functionality is especially important in order to create a game that is not only fun to play, but also can fulfil its main goal – to teach. Creating a game that is tailor-made for everyone is very complicated, because the needs of each player are different. Individual settings, which the player can adjust themselves, helps to meet his/her needs more easily. Vast majority of children music education games do not have any settings. Such a solution adopted by game developers may be due to the fact that a child does not inadvertently turn off or turn off the features he likes. To make settings, but to prevent unintentional changes to them, the proper solution would be to make the settings button tailored for the elderly.

We added the non-binding functionality to the playful musical game - songs already recorded in the game that can be selected and played back. Although the game has aimed for diversity, it is not an essential function for an educational game. A good atmosphere in the game helps

to create background music and background sounds. Background music has been noted to increase overall user satisfaction, support immersion, prevent from boredom, and provide more pleasure and higher perceived social richness in terms of personality, liveliness, and emotionality [25]. The main features of background music are playfulness, childhood and integrity. When some object appears on the screen or when some object is clicked, its name or relevant information is displayed. In this way, the player learns more about music and piano.

Each level of the game features a specific animal (sheep, dog, cat or cow), which provides a narrative and helps the child to learn. Pets provide children with positive experiences and feelings thus facilitating communication, fostering imagination, and supporting learning [26]. Companion animals, even if only virtual ones, are powerful motivators for learning, due to children learning and retaining more about subjects with whom they develop emotional attachment [27].

Creativity is one of the characteristics, which is important to promote from an early age. The most creative way to promote the child's creativity is in the form of a game. Creative mode can facilitate the user can create music, record and play the music. This functionality teaches children to learn the piano keys better, and to accept them in a creative way.

C. *Interface models and metaphors*

The development of the game interface is based on the interface metaphors of fuzzification, gamification and metaphorization.

Fuzzification is the reduction of information load by presenting data to a person in a more understandable and acceptable form [28]. The essence of the fuzzification is the information provided to the consumer using abstract but acceptable and naturally understandable concepts.

Gaming is the integration of game elements into the interface [29]. Gameplay increases the attractiveness of the user interface, instructs the user to perform certain routine but necessary actions, encourages the user to come back and make the process of communication with the system enjoyable. Gamification is introduced through gamification patterns [30], which capture the reoccurring templates of game interfaces.

Metaphorization is used to represent abstract concepts, to use real-world objects that the user directly or intuitively relates to these concepts [31]. The essence of metaphorization is to illustrate an unknown concept (object or process) by using a well-known and understandable symbol that does not directly relate to an illustrative concept, but intuitively associates with an illustrative concept. Metaphors in user interfaces increase interface visibility, usability, help the user to create a mental model of the system, and contributes to enhancing connectivity.

Figure 1. The main menu environment

D. *Description of Game World*

The action at each level takes place in different environments:

First environment (main menu, see Figure 1) - in the menu environment, there are five zones painted in different colors, depicting animals or human silhouette, surrounded by four musical notes. At the bottom of each colored box is the line of the same color, but a brighter tone. At the bottom of the image is a part of the settings icon, which, by clicking, will open the entire settings window, and the image will be dimmed for it. The entire center of the image, in the oval zone, depicts a landscape with two different houses, sky, and meadow. There are two cows in the meadow. The oval area also features clouds, a smiling sun, a rainbow, trees, and flowers.

Second environment (sheep level, see Figure 2) - piano keys (5 black and 7 colored) are shown at the bottom of this environment. Above each colored key stands the sheep. Each colored key has a gray background. In the left corner, a gray, translucent button with an arrow to the left is depicted, symbolizing the action - back. In the upper right corner are two gray transparent buttons: one button is with an arrow rotating round, and the other one has a question mark. The landscape above the piano keys features a rotating mill, a blazing river and a light rainbow. There is also a meadow, and a sky showed in the

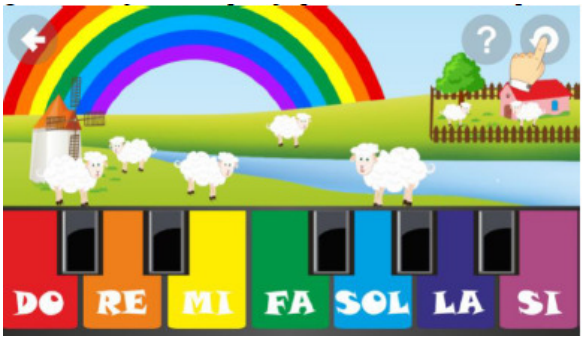

Figure 2. Sheep level environment

Figure 3. Dog level environment

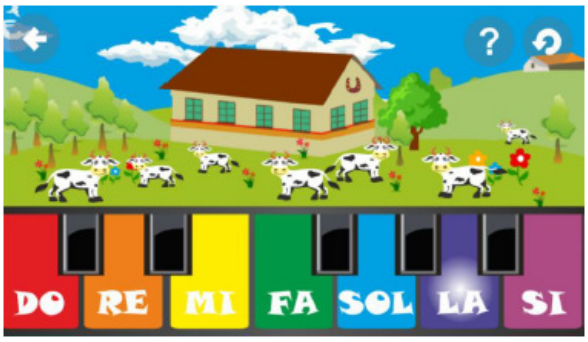

Figure 4. Cow level environment

level. On the right side of the image there is a fence with a house and a tree.

Third environment (dog level, see Figure 3) has five black and seven colorful piano keys in the bottom of the environment, as in all levels. Above each key stands the dog. The left corner of the level is a gray, translucent button with an arrow to the left, indicating the back key. Above the piano keys, there is the moon depicted, with changing phases, a starry sky, a meadow, trees, stones, and a dog hut.

Fourth environment (cow level, see Figure 4) presents a landscape view of the farm. At the bottom of the screen, as in the other levels, the piano keys are displayed. Above each keypad, a cow figure stands. Also, as in the abovementioned levels, there are three gray transparent buttons in the upper left corner and in the upper right corner. At the level above the piano keys there is a farm, a silhouette of the house, in the distance one can see trees, flowers, grass, heaven, and sky-high clouds.

Fifth environment (cat level, see Figure 5). At this level, the action takes place in the living room. As in the above levels, there are piano keys above which there are seven cat figures on this level. There are also three gray, translucent control buttons in this level. Above the piano keys there is a sofa in which the color changes when clicked. The colors of the sofa are seven, the same as the number of the piano keys, thus providing a meaningful association. The floor also features a wall decorated with geometrical shapes and flowers. On the wall there is a picture hanging that features a bird that looks up on a branch of a flowering tree. In the room there is also a table, a cake with seven burning candles, a cat's bed, and a cat bowl.

Figure 5. Cat level environment

Figure 6. Creative level environment

Sixth environment (creative level, see Figure 6) - as in the above cases, it shows the piano keys and the control buttons. This environment imitates a children's play piano with two speakers in its upper corners. Above the piano keys there are five buttons featuring the images of animals and pianos. At the top, in the middle, there are three more buttons with recording, playback and silence icons. The background for all buttons is moving from one color to another. From the speakers, white semi-transparent lines, which give rise to light imitation, shine. Also there are stars, which flash in different colors one by one.

E. Game mechanics

When a player enters the first level of any animal, first of all a sound is played that tells you what to do to get the player to level. At the same time, a picture of the hand is displayed on the screen, indicating the selection of the button. At the end of the helping stage, sounds are played that the player will have to repeat. When other levels (second, third, fourth) are triggered, the melody that a child needs to repeat will be heard immediately. When playing each sound, the piano key that corresponds to the sound flashes. Piano keyboard keys are inactive until a ringtone sounds to be played complete. When the ringtone ends, the piano keys become active.

Pressing one of the piano keys sounds its sound, launches the animation of the animal up-front of the button, and checks whether this key should have been pressed to repeat the melody. When a child presses the wrong key, an error sound is played, and the button, with the circle pointing arrow, starts to spin around its axis. The player can press the rotary button to hear a ringtone to repeat, and the level starts again. One after another, when pressing the correct keys, at one of the levels no. 1, 2 or 3, the animation of the balloons appears on the screen and the greetings are heard thus providing an encouragement and gratification for a child, acknowledging his/her successful effort. After the balloon animation, the player moves to the next level. After pressing the correct keys and at one of the levels no. 4, the animation of the balloons appears on the screen, the greetings are heard, the buttons that were previously turned on are inactive, and the 2 buttons appear on the screen - a button with a circle leading arrow and a button with a depiction of the home image.

Once the player clicks the arrow button (level button #1), the level is repeated again, and once the player clicks the button with the home image, it returns to the main menu.

At the user level and clicking on one of the animals, the sound of an animal is played corresponding to the note, which is indicated by the key under the corresponding animal.

There are educational objects, which, once clicked, have certain functions performed when the learning sounds are activated. For example, when clicking on sofa, it changes its the color to one of seven colors (red, orange, yellow, green, blue, blue, violet) and the name of that color is given. Clicking on the moon shows its name and it changes to another image depicting one of the four moon phases (new moon, first quarter, full moon, third quarter).

By pressing one of the sound buttons, with the pictured animal or piano, the piano key sounds are replaced by the sound of the animal shown on that button, or the piano's sound. These sounds are of a different pitch, adapted to each piano key.

IV. Evaluation of Pedagogical Usability

Considering that most of preschool children can not read, it is difficult to evaluate the pedagogical usability of the game using the traditional survey based approach. According to [32], usability is a characteristic related, among others, to the use of the product, user experiences or user expectations. Here we evaluate the pedagogical usability of the educational game in terms of the usability attributes, which are measured through subjective effectiveness of the pedagogical aspects of digital learning material [33]. However, since the target of the game are preschool children, complex questionnaires such as 56-item Pedagogically Meaningful Learning Questionnaire (PMLQ), which relate the learning experience to formal teaching programs, do not fit here [34].

Here we use the Child-Initiated Pretend Play Assessment (ChIPPA) [35], which has been created to assess children of 4-7 years of age. Three play items are measured on the ChIPPA: the elaborateness of child's play action (Percentage of Elaborate Pretend Play Actions (PEPA) score), the ability of the child to substitute objects during playing (Number of Object Substitutions (NOS) score), and child's imitation of the examiner's modelled actions (Number of Imitated Actions (NIA) score). PEPA measures both the complexity and level of self-organization of a child's play ability [36], and is calculated as the number of elaborate (i.e., meaningful) play actions divided by the total number of actions performed by the child during each 15-minute session of the ChIPPA, multiplied by 100. The ChIPPA assessment consists of three 5-minute long sessions of conventional play followed by three 5-minute long sessions of play with the educational game.

The summary of ChIPPA sessions is presented in Table 1. The sample comprised 9 preschool children ages 4 to 7 years old (6 boys and 3 girls) years old. The assessment was made by their parents, who are also the authors of this paper. The bias of the study was limited, since the assessment was performed by four different examiners. The ethical procedures were adhered to.

We have observed the reactions of the Lithuanian children to the play materials to check if they have understood the purpose of the play and responded to the actions of the game in a meaningful way. For example in the conventional game play, the children can imagine that the toy animals are alive and they can take animals to walk outside of the farm in the fields. In the musical game, the children imagined that the cows sing and produced musical sounds. The results of the assessment were as follows: PEPA (conventional game) = 85.55, and PEPA (digital game) = 84.46. The results indicate that the children interaction with the musical game was meaningful.

TABLE I. Summary of ChIPPA sessions

ChIPPA play session	**Appearance**
Conventional imaginative play session (play materials: animal figures from PLAYMOBIL Farm Set)	
First 5 minutes	Present the toys (cow figure is withheld). No play directions are given.
Second 5 minutes	Examiner produces the cow figure and models five play actions (go to house, go to fields, eat, sing, say hello).
Third 5 minutes	No instructions are given. The child is encouraged to play
Digital game play session (play materials: electronic educational game)	
First 5 minutes	Present the digital game (the "cow" level is not shown). No play directions are given.
Second 5 minutes	Examines shows the cow level and encourages playing.
Third 5 minutes	No instructions are given. The child is encouraged to play

V. Conlusion

In this paper, we have described the development of the educational music game for preschool children aiming to motivate their learning abilities. The game targets Lithuanian preschool children, which do not speak English. The game belongs to the memory type games and helps children to learn the basic knowledge about the piano keys and the associated musical notes. The game was developed based on the principles of Digital Game Based Learning (DGBL), self-determination theory (SDT), immersive learning and TPACK (Technological Pedagogical Content Knowledge), and employed the gamification patterns for motivation reinforcement. The game was evaluated by preschool children using the Child-Initiated Pretend Play Assessment (ChiPPA) assessment, and the results were good.

Considering the availability and wide-spread use of digital technologies even among young children there should be a reconceptualisation of young children learning in early childhood settings as children under six years of age are actively engaging with digital technologies in playing and learning at home and this cannot be missed by preschool education system. Preschool educators should re-examine the way children learn. The developed educational musical game presented in this paper and associated study is a step in this direction.

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Measurement of the effects of e-learning courses gamification on motivation and satisfaction of students

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***Abstract* - In this paper, we present the results of a study which was conducted in two stages. The first part of the paper contains literature search findings and analyzes the existing self-assessment scales for measuring motivation and satisfaction of students that were developed by other authors. In the second part of our study we created a battery of self-assessment measures for collecting data for an overarching set of gamification-related constructs/variables selected in accordance to those that are reported in literature). These scales were constructed by (a) adaptation and improvement of items from existing measures and (b) creation of novel items for measures of constructs that were found to be important in research articles on gamification and educational games. The initial empirical evaluation of this new questionnaire (battery of assessment scales) was performed on a large convenience sample of students (N=201) who attended a hybrid course on computer programming. These respondents were divided into an experimental group, which used gamified e-learning course material, and a control group, which used a parallel (non-gamified) version of the e-learning course with equal theoretical content. For each self-assessment scale of the questionnaire Cronbach alpha coefficients were calculated and the scales were slightly corrected to improve their internal consistency. We report the results concerning the effects of gamification on motivation and satisfaction, which were measured by respective assessment scales.**

Key words - e-learning, gamification, motivation, satisfaction with e-learning, game elements, self-assessment, questionnaire

I. INTRODUCTION

Gamification is a popular construct which denotes the introduction of elements that are characteristic of game playing (points, rules, competition, levels, progress monitoring, community, ranking of players, reward systems, etc.) to areas that are not games (or originally did not include game playing) for the purpose of making a specific activity more interesting, motivating, and engaging for participants. As in many other areas (marketing, health promotion, work productivity, finance, government) a serious potential for the use of gamification in education, in particular in e-learning, has been recognized. It must be emphasized that since 2011 the interest in the use of gamification in e-learning has been growing rapidly.

A brief analysis of scholarly literature with the use of the Google Scholar search engine indicates that in the 2011-2017 period there was a greater than tenfold increase in the interest in the use of gamification in e-learning (see Figure 1).

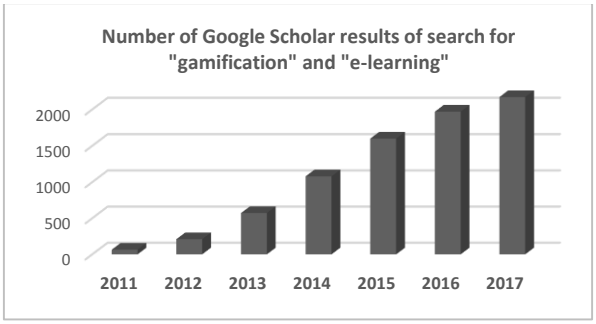

Figure 1. The results of using Google Scholar and key words "gamification" and "e-learning" in academic literature search (February 2018)

A. Review studies and meta-studies on gamification

A review performed by Dicheva et al. [1] on the application of gamification in e-learning revealed that most of the analyzed studies were related to courses on (a) *Computer Science* or (b) *Information Technology*. They found that the benefits of gamification that were reported in literature were mostly associated with higher engagement of students in learning activities, increased attendance and participation, increased quantity of students' contributions/answers (without a reduction in quality), and an increased percentage of passing students. However, the authors of that study concluded that the majority of reviewed publications only described specific mechanisms and dynamics of gamification and/or discussed their possible use in the educational context, while the effectiveness of gamification regarding learning outcomes was dealt with in only few quality empirical studies.

In a recent and more detailed inspection of methodological issues and outcomes of studies related to the use of gamification in education Dichev and Dicheva [2] established that, beyond its proven potential to enhance learning environments, there was not enough evidence that gamification produces long-lasting educational outcomes and yields better performance than traditional educational models. However, these authors emphasized that most of the studies (79%) in their analysis were related to affective, behavioral and/or cognitive outcomes, which highlights the importance of adequate measurement of the related sets of constructs.

Clark et al. [3] pointed out the very demanding nature of the assessment of complex variables in the related field of serious games and also stated that "higher order cognitive, intrapersonal, and interpersonal processes and skills prove

more challenging to measure accurately and reliably than do lower order cognitive skills and rote knowledge."

B. Motivation in educational games and gamification

Recent research on the motivational effects of specific gamification elements has advocated the need for differential analyses of the effects of particular gamification elements on the functioning of individuals instead of searching for the general effect of gamification *per se* [4]. For instance, in a study by Suh et al. [5] the authors adapted a set of measurement scales related to motivation and needs satisfaction constructs. Their recommendation was not only to assess the effects of points, leaderboard and badges in analyses of gamification outcomes, but also to investigate psychological constructs like self-expression, competition, and altruism, as well as their effects on needs satisfaction.

The importance of motivational variables was also indicated by an intriguing study by Hanus and Fox [6], who found that over time the students in the *gamified* course showed *less* motivation, satisfaction, and empowerment in comparison to the students in the equivalent *non-gamified* course.

An interesting literature review by Peixoto and Silva [7] listed more than 200 gamification requirements for educational software. Some of the requirements were related to players' personality traits, while those related to objectives of gamification implementation were aimed at increasing and facilitating engagement, motivation, involvement, proactive attitude, interaction, participation, collaboration, satisfaction, etc. It must be noted that, in order to measure the fulfillment of those requirements in a gamified course, specific response scales need to be constructed.

Despite the growing popularity of practical application of gamification, several meta-studies have failed to produce unquestionable evidence of its effectiveness. In their meta-study Hamari et al. [8] found that, according to the results of several studies, the effect of gamification may not be long-term and could be associated with the novelty effect. However, most of the studies that they reviewed *reported positive effects of gamification on some aspect of motivation*.

II. Assessment of Motivation Related Variables in Serious Games and Gamification Studies

Diverse constructs have been used by various authors to create scales to measure the effects of e-learning courses, gamification of instruction, educational games and video games on users/students. These constructs can be grouped into the following categories: (1) general course evaluation, (2) perceptions of the learning system/environment, (3) evaluation of user interface and flow, and (4) learners' motivation variables. Some of the investigated constructs and related authors are listed here in chronological order (including the year of publication):

- Impact of self-determination theory on motivation in e-learning (Sørebø et al., 2009 [9]);
- Learners' enjoyment of e-learning games (Fu et al., 2009 [10]);
- Impact of media richness and flow on e-learning technology acceptance (Liu et al., 2009 [11);
- Users' experience of video games (Parnell et al., 2009 [12]);
- Core elements of gaming experience (Calvillo-Gámez, 2010 [13]);
- Facets of students' expectations and experiences related to perceived learning achievements and course satisfaction (Paechter et al., 2010 [14]);
- Students' satisfaction with hybrid learning regarding preconceived and informed expectations (Pinto and Anderson, 2013 [15]);
- Students' flow experiences in an online learning environment (Esteban-Millat et al., 2014 [16]);
- Dispositional flow in education (Hamari and Koivisto, 2014 [17]);
- Determinants of satisfaction and continuous use intention in e-learning services (Pereira et al., 2015 [18]);
- User experience video game satisfaction (Phan et al., 2016 [19])
- Antecedents and consequences of flow in e-learning (Rodríguez-Ardura and Meseguer-Artola, 2017 [20]).

Much of the research on gamification is related to and preceded by investigation of video games and serious (educational) games. For instance, Parnell et al. [12] developed a scale for prediction of game appeal and another scale for assessing game quality with the following four subscales: Affective Experience; Focus; Playability Barriers; Usability Barriers. In a similar study Fu et al. [10] designed a 42-item scale for the measurement of learners' enjoyment in e-learning games with the following 8 subscales: Concentration; Goal Clarity; Feedback; Challenge; Control; Immersion; Social Interaction; and Knowledge Improvement. In a more general study related to e-learning Paechter et al. [14] investigated students' expectations, experiences and course satisfaction using a questionnaire with the items related to course design, interaction with the instructor, interaction with peer students, individual learning processes, and learning achievements or course outcomes. Finally, Calvillo-Gámez et al. [13] introduced an instrument for measuring gaming experience with the following 10 scales: Enjoyment, Frustration, Core Elements of the Gaming Experience, Puppetry, Video-game, Control, Facilitators, Ownership, Game-play, and Environment.

For the purpose of the study that is presented in this paper the scales and specific items that were created by the previously mentioned researchers were combined and reformulated to create a set of measures of constructs that are more specifically associated with gamification of e-learning courses.

III. Method

A. Research questions

The application of gamification in e-learning is attracting great interest despite the lack of quality experimental studies

examining its effectiveness (see: [1]). Furthermore, a study by Peixoto and Silva [7] indicated the need for the development of measurement instruments that could be used to evaluate numerous gamification requirements and objectives for using gamification.

In accordance with the theoretical issues previously outlined in the introduction section, two main research questions (RQ) were defined for our study:

RQ1: Is it possible to develop a set of assessment scales to measure distinct constructs related to the process of using a gamified e-learning course, learners' experience and satisfaction, as well as their evaluation of the course.

RQ2: Does the use of a *gamified* e-learning course module (in the *experimental* group) in comparison to the use of a *non-gamified* e-learning course module (in the *control* group) have an effect on learner' evaluation of the process of using a gamified e-learning course, their experience and satisfaction, as well as their evaluation of the course in general.

B. Subjects

The subjects in our study were students of the second year of the undergraduate study of information systems at a Central European university who were enrolled in a hybrid Programming course. The total number of respondents who volunteered for the study was 201. Out of the total number of respondents, 44 (or 21.9%) were female and 157 (or 78.1%) male. The average age of respondents was 20 years. However, the survey questionnaire was correctly completed by 182 students. Among those 182 students, 87 were assigned to the *experimental* and 95 to the *control* group.

C. Instruments

The main instruments in our study were a *pre-test* and *post-test* of knowledge of a specific programming topic ("Batch and Stack"), as well as a *survey* with demographic questions and carefully chosen scales for the assessment of gamification related processes, experiences and perceptions of the e-learning course. It should be noted that for the purpose of the study two parallel e-learning course modules with identical teaching materials were designed on the "Batch and Stack" topic.

The ***pre-test*** consisted of 30 items with 25 closed and 5 open-ended questions related to the general topic of programming. The *pre-test* was applied on the initial group of 201 students. Based on the results of the pre-test the subjects were divided in the experimental and control group. The ***post-test*** consisted of 32 items with 26 closed and 6 open-ended questions related to the content of the e-learning course module "Batch and Stack". The *post-test* was applied on 192 students (96 from the *experimental* and 96 from the *control* group).

The ***survey*** consisted of demographic questions and items related to the use of internet technology (in the *first* part), scales for the assessment of the process of gamification and students' evaluation of the e-learning course attributes (in the *second* part), as well as of items related to students' perception of specific gamification elements (in the *third* part). The labels for the scales in the second part of the survey and sample items from each scale are listed in *Table 1*.

TABLE 1. SCALE LABELS AND SAMPLE ITEMS FOR EACH SCALE IN THE SECOND PART OF THE SURVEY

Scale label	**Sample item**
Satisfaction with e-course	"I thought that the e-course was fun."
Navigation / overview of the e-course	"I always knew where to go in the e-course."
Feedback within the e-course	„I received sufficient feedback about my results during my use of the e-course."
Enjoyment / preoccupation with e-course	"I was focused on the tasks of the e-course."
Instructions for use / menus, settings, help	"The instructions for menus and other functionalities were clear and detailed enough."
Adequate difficulty of e-course	"The level of difficulty of the e-course was right for me."
Motivational incentives	"I used the e-course well because it was motivating for me."
Interaction with other learners	"The cooperation with other participants in the e-course was helpful for my learning."
Learning achievement	"The e-course motivated the player to integrate the knowledge taught."
Self-paced and flexible learning	"The e-course enabled me to use my own choice of strategy and pace of learning."
Personal experience with e-course	"I liked the way the e-course looked."
Evaluation of e-course	"I think that working with this e-course was important for my knowledge."

The ***e-learning course*** module which was used by the *experimental group* of subjects included numerous gamification elements based on the model developed according to the *Octalysis Gamification Framework* [http://yukaichou.com/gamification-examples/octalysis-complete-gamification-framework/]. These gamification elements were added as plugins in the Moodle learning management system.

The gamification elements included in the e-course "Batch and Stack" for the *experimental* group included a simplified graphic user interface, dynamic graphic interface, story as an introduction to the e-course, links to social networks, tasks and challenges, visual display of tasks/duties, collecting points, progression through the e-course, badges, status of e-course completion, collaboration, leaderboard, elements of surprise, countdown or remaining time, feedback, educational games, etc. However, the e-learning course that was used by the *control group* of subjects used only a traditional non-gamified online course with equal course related learning content in the Moodle system. This traditional non-gamified version of the course "Batch and Stack" had only three gamification-related elements: profile and avatar area, use of forums, and nonlinear access to educational materials.

D. Procedure

The subjects in our study were full-time students enrolled in an undergraduate hybrid Programming course. That means that they regularly attended classroom lectures and exercises in the computer laboratory but also had access to online course material that was placed in the Moodle learning management system. For the purpose of our study a separate Moodle course material was developed on the "Batch and Stack" topic in the Programming course. In fact, a gamified and a more traditional non-gamified parallel version of this module were placed.

Before implementing the e-learning course "Batch and Stack", the students were assessed with the *pre-test* to ensure that there would be no difference in prior knowledge between the experimental and control group. Then both the *experimental* and the *control* group used the e-learning course for 2 weeks. Finally, a *post-test* and a *survey* were applied.

IV. RESULTS

A. Internal consistencies (Cronbach alpha) of scales related to learners' experience and satisfaction

A pilot study was conducted to test the gamification related elements of the e-learning course module "Batch and Stack" and an initial version of the survey. However, due to limitations of space in this paper it is not possible to describe it in detail. The scales of the survey for the measurement of distinct constructs related to the process of using a gamified e-learning course, learners' experience and satisfaction, as well as their evaluation of the course were once more investigated after the application of the survey on the 182 subjects in the study described in this paper. After the items of several scales of this survey had been excluded due to their low item-total correlation, the final Cronbach alpha for all the scales was calculated (see *Table 2*).

As can be concluded from the data presented in *Table 1*, all of the scales that were used in our study manifested a satisfactory level of internal consistency measured by the Cronbach alpha coefficient (i.e. ranging from .767 to .931). It must be noted that the items of those scales originated from various sources, as well as that the original items of the scales were articulated in the context of video games or educational/ serious game and therefore had to be rephrased to the context of gamification of e-learning courses.

To verify that each of the scales measures a separate construct, a *confirmatory factor analysis* was performed with *varimax* rotation and a fixed number of factors which corresponded to the number of scales. The results of this factor analysis indicated that each of the scales has the largest projection on a unique/separate factor, which makes it sufficiently specific regarding the respective construct and different in terms of the object of measurement in comparison to other scales.

The value of Cronbach alpha coefficients that are presented in *Table 2*, as well as the previously mentioned results of the confirmatory factor analysis permit the following conclusion regarding the first research question ***(RQ1)**: It is possible to develop a set of assessment scales to measure distinct constructs related to the process of using a gamified e-learning course, learners' experience and satisfaction, as well as their evaluation of the course.*

TABLE 2. SCALE LABELS, NUMBER OF ITEMS PER SCALE, CRONBACH ALPHA COEFFICIENTS AND SOURCE OF ITEMS IN SCALE

Scale label	Number of items	Cronbach alpha	Initial versions of items [source]
Satisfaction with e-course	9	.858	[12]
Navigation / overview of the e-course	11	.903	[12], authors
Feedback within the e-course	4	.904	[10]
Enjoyment / preoccupation with e-course	12	.856	[12], [10]
Instructions for use / menus, settings, help	6	.767	[12], [10], authors
Adequate difficulty of e-course	7	.782	[12], authors, [10]
Motivational incentives	4	.835	[14], [12], authors
Interaction with other learners	9	.919	[10], [14], [12]
Learning achievement	9	.867	[10], [14], authors
Self-paced and flexible learning	7	.859	[14], authors
Personal experience with e-course	9	.810	[13]
Evaluation of e-course	24	.931	[21]

B. The effect of gamification on students' achievement in an e-learning course

To examine the effects of gamification on students' learning of the content of the e-learning course module on the topic "Batch and Stack", a *t-test* was performed on the results of the *post-test* of the *experimental* and *control* group of subjects. The data in *Table 3* confirms that the students in the *experimental* group, which used a *gamified* version of this e-learning course module, had a statistically significantly *greater average score* in the *post-test* in comparison with the *control* group, which used a *non-gamified* parallel e-learning course module with only several gamification related elements (profile and avatar area, use of forums, and nonlinear access to educational materials).

TABLE 3. STATISTICAL SIGNIFICANCE OF DIFFERENCE IN *POST-TEST* KNOWLEDGE BETWEEN EXPERIMENTAL (NE=96) AND CONTROL (NC=96) GROUP OF SUBJECTS WHO TOOK THE POST-TEST

Group	N	Mean	σ	t	p
Experimental	96	13.89	5.42	2.68	0.0079
Control	96	12.03	4.05		

It must be noted that the average test score in the *post-test* is greater for the *experimental* group than the average test score for the *control* group and the difference is statistically significant at the level of $p<0.01$. However, the *actual difference* in the average score is less than 2 points (out of possible 32 points in the post-test). Therefore, despite the great additional effort to gamify the e-learning course module "Batch and Stack", the real and measurable effects of gamification in form of greater learning achievement, although positive, are not impressive and do not demonstrate a proportional return regarding the investment in technology innovation and time for preparation and implementation of this rather demanding teaching activity.

C. Comparison of evaluation of learners' experience and satisfaction with e-course in relation to gamification

The previously presented results of gamification on learning achievement in the experimental group are not the only measurable positive effect. Other effects of gamification can be related to satisfaction with the e-learning course, greater level of enjoyment and preoccupation with learning activities, more positive personal experience, and better evaluation of the gamified e-learning course in comparison to more traditional design of e-learning courses. The data presented in *Table 4* illustrates the observed differences between the experimental and control group regarding the evaluation of various attributes of the gamified and non-gamified versions of the e-learning course "Batch and Stack", as well as perceptions of satisfaction, enjoyment, and learning achievement.

As can be concluded from the data presented in *Table 4*, the gamified version of the e-learning course was on average much better evaluated regarding the variables measured by the scales "Feedback within the e-course" and "Self-paced and flexible learning", as well as in relation to the construct measured by the scale "Interaction with others". Also, the gamified version of the e-learning course was on average slightly better evaluated (with statistical significance) in relation to variables measured by the scales "Motivational incentives", "Satisfaction with e-course" and "Enjoyment /preoccupation with e-course", as well as "Personal experience with e-course" and "Evaluation of e-course". Finally, in case of the average scores for the scales "Instructions for use/menus, settings, help" and "Learning achievement", the gamified version of the e-learning course also received higher evaluation.

On the basis of the results presented in *Table 4* a conclusion can be made regarding the second research question (*RQ2):* The use of a *gamified* e-learning course (in the *experimental* group) in comparison to the use of a *non-gamified* e-learning course (in the *control* group) had a predominantly positive effect on learners' perceptions and evaluation of various variables related to the process of using a gamified e-learning course, experience and satisfaction with this course, as well as the general evaluation of the gamified e-learning course.

TABLE 4. STATISTICAL SIGNIFICANCE OF DIFFERENCE IN AVERAGE SCORES OF ASSESSMENT SCALES RELATED TO EVALUATION OF COURSE ELEMENTS, MOTIVATION, ENJOYMENT AND SATISFACTION BETWEEN THE EXPERIMENTAL (N_E=87) AND CONTROL (N_C=95) GROUP OF SUBJECTS WHO CORRECTLY FILLED OUT THE SURVEY

Scale label	M_E	M_C	σ_E	σ_C	t	p
Satisfaction with e-course	3.05	2.86	1.14	1.05	**3.59**	**0.00**
Navigation / overview of the e-course	3.19	3.09	1.23	1.19	~~1.76~~	~~0.08~~
Feedback within the e-course	3.98	2.89	0.84	1.17	**14.26**	**0.00**
Enjoyment / preoccupation with e-course	2.97	2.67	1.07	1.11	**6.36**	**0.00**
Instructions for use / menus, settings, help	3.54	3.20	1.13	1.16	**4.92**	**0.00**
Adequate difficulty of e-course	3.16	3.10	1.19	1.14	~~1.03~~	~~0.30~~
Motivational incentives	3.54	3.02	0.97	1.02	**6.98**	**0.00**
Interaction with other learners	3.31	2.75	1.00	1.16	**10.37**	**0.00**
Learning achievement	3.64	3.34	0.83	1.00	**6.52**	**0.00**
Self-paced and flexible learning	3.90	3.00	0.91	1.12	**15.64**	**0.00**
Personal experience with e-course	3.42	3.21	1.16	1.05	**3.80**	**0.00**
Evaluation of e-course	3.29	3.01	1.13	1.10	**8.98**	**0.00**

* M – arithmetic mean; σ – standard deviation; t – t-test value; p – level of statistical significance of t-test; E – experimental group; C – control group; statistically significant differences are written in boldface

V. CONCLUSION

The main goal of the research presented in this paper was to investigate various effects of gamification of e-learning courses on students. For this purpose a collection of assessment scales was required and, after literature search, a number of scales was developed by combining the (a) adaptation of items from scales of other authors and (b) creation of new items. The scales were first tested in a *pilot study* and then applied once more on 182 subjects who were enrolled in a Programming undergraduate university course. All of the evaluated scales manifested good internal consistency (Cronbach alpha) and can be used for similar research topics (see *Table 2*).

The subjects in our study were divided in an *experimental* group, which used a *gamified* version of an e-learning course module "Batch and Stack", and a *control* group, which used a

non-gamified version of the same e-learning course module. Both groups used this course module for a period of two weeks. The *post-test* indicated that the e*xperimental* group achieved slightly higher average scores in comparison to the *control* group (see *Table 3*). In addition, the *experimental* group valued most attributes of the gamified e-learning course module more favorably in comparison to the evaluations of the non-gamified course by the control group (see *Table 4*). Also, the experimental group which used the gamified version of the e-learning course module "Batch and Stack" reported a higher level of satisfaction with the e-course, greater enjoyment and engagement with the e-course, and greater learning achievement.

It can be concluded that the effects of gamification should not be measured only by the difference in learning effectiveness, but also with regard to the experience of learners with the online courses, their level of motivation and satisfaction. The gamification of e-learning courses has the potential to create a more interesting, motivating, engaging, enjoying and collaborative virtual environment, which may compensate for the occurrences when the learning effectiveness of an e-course is in disparity with the investment of instructors' time, effort and engagement in technological innovation.

With numerous elements that can be used in gamification it is necessary to evaluate their respective influence on learning outcomes and learners' experience (see [22]). Moreover, in each practical application of gamification the potentially negative effects must be studied despite the commonly positive general expectations of instructors (for example, see: [23]).

As was discussed in the "Results" section of our paper, the measurable effects of gamification in form of greater learning achievement were not impressive in comparison to the time and effort for the preparation and implementation of this type of online course. Iosup and Epema [24] had a similar observation regarding their research on the effects of gamification of two computer science university courses. They found that it may present a challenge for instructors who need advanced skills for the use of gamification pedagogy and technology. Furthermore, large-enrollment courses may need computer-assisted management of bonuses and explanation of gamification is needed for new students. Finally, there could be some organizational inertia in acceptance and limited university support for successful implementation of gamification. It must also be noted that for a variety of reasons the attitudes of teachers toward game based learning may not necessarily be positive [25].

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Searching for the reasons why ICT is not adequately used in schools

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Abstract - Government have invested into the educational institutions' ICT equipment and expected multiple favourable outcomes. Schools are equipped with ICT hardware, educational materials are available for all study subjects, teachers were trained to use them but the surveys have shown that the ICT is not properly used. An ongoing national investigation project have started to find the reasons for inadequate ICT usage in education among students of educational study programs. The outcome of the project will be the handbook of principles of application of ICT in education for all teachers to use it.

The research question for inadequate use of ICT in education we are going to test are:

1. **Students are overconfident in the assessment of their ICT competences and they feel no need for improvements.**
2. **Students are opportunist by nature and they do not want to change their perceived cycle of education. If it worked for them, it will work for next generations too.**
3. **Students do not have enough good examples how to use ICT in education in their study programs.**

These three researcg questions are not the only influences for inadequate use od ICT in education but they are most promising for the testing purposes.

Keywords: education, ICT, didactics, competences, challenges

I. INTRODUCTION

Ever since we know, the software development is in crisis [1] [2]. Software production cannot satisfy demands and this drives evolution of software development tools and techniques. The same can be seen in the computer education and all corresponding educational activities. The analysis have shown that the problem lies in the digital competences of teachers [3]. Teachers often lag behind students in the ICT area.

The education cycle starts with the kindergarten, continues to primary and secondary schools and finishes with the educational studies for different disciplines. The outcome of this cycle is competent teacher [3] [4]. However, teachers also need continuous update of their competences because of the new curricula and advancement in the ICT [5]. Constant changes of educational system is therefore here to stay [6]. Nevertheless, changes are generally slow and outcomes can be seen years after the paradigm shifts. We still have not adopt the revised Bloom's taxonomy of the learning outcomes which have been available for more than two decades [7]

Many countries have seen the problem in the ICT and CS (Computer Science) education and prepare new curriculum to correct this negative influence to other educational topics [8] [9]. In many cases, CS is mistaken for ICT and teaching algorithms and coding are not part of general education in primary and secondary schools. Many more success can be seen in other subjects' didactics than in the CS and ICT didactics [10]. Even the ICT specialists have made researches outside ICT itself. [6] [11]

In general, the governments want optimal outcomes for the money they spend. During last two decades, the ministries responsible for education have spent a lot of money for ICT in schools. Money was spent on: ICT equipment, internet infrastructure, teacher's education and e-learning materials production [12] [13] [14] [15]. Most of the money comes from the European Social Funds but the outcomes should be visible in the country and among people.

It was long known that schools particularly primary and secondary are very good equipped with ICT (except with tablets). They have interactive boards, computers and projectors in almost every classrooms. It was repeatedly proven that technology works well if used appropriately [16]. The further education courses for teachers, where they would learn how to use the ICT equipment, were prepared and implemented. Educational institution for teachers' education have courses to enhance teachers' digital competences and jet we got rumours that ICT equipment was not adequately used. When these rumours become widespread the Ministry of Education, Science and Sport decided to find the background of the rumours and enhance teachers' competences to correct the possible drawbacks.

The project named "Innovative and flexible forms of teaching and learning in educational study programs" started in 2017. This was all national project, involving three universities of Slovenia, to get better insight to the use of ICT in education. Between March 2017 and October 2018, we have to perform different phases of the project:

- Analysis of knowledge, competencies and skills of using ICT
- Creation of a group of higher education teachers who will adapt the exercises and lectures

- Adapting the methods and approaches to carrying out lectures and exercises
- Implementation of a pilot project with student groups
- Creation of professional basis for didactic use of ICT
- Evaluation of project implementation
- Preparation of recommendations for the equipment of schools
- Dissemination and promotion of results

The Ministry of Education, Science and Sport had prepared the document with the title "Recommendations on standards and norms: Program for Computer Literacy and Informatics for the years 2016 and 2017" where a brief overview about the topics that concerns project scope are described:

- Identification of computer equipment over the premises of the institution
- Who are the users of computer equipment at the educational institution?
- Computer equipment at the institute
- Local computer networks, connection to the Internet and network services

At the beginning, we need to coordinate the actions and content between different faculties that educate teachers for primary and secondary schools. At the University of Maribor there are three faculties that educate teachers: Faculty of Arts, Faculty of Education, Faculty of natural sciences and mathematics. The division of topics by faculties are best seen on figure (Figure 1)

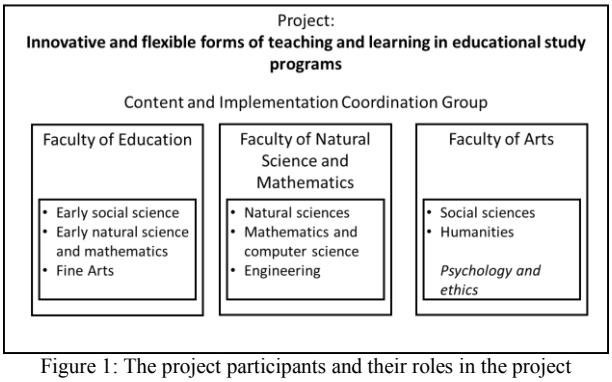

Figure 1: The project participants and their roles in the project

The psychology and ethics are not educational study programs but the experts from Faculty of Arts were involved into the project to cover deep understanding, research methodology and border areas of the project. The ethics expert is necessary to remind us and help us with the ethical problems of dealing with the young students and possibilities of misuse of ICT in education.

In the article we are going to focus to the Faculty of Arts who prepares teaches for social sciences and humanities. We have decided to cover topics of language learning (Slovene, English, and German), general pedagogy studies, and geography.

II. DEVELOPMENT OF PROJECT METRICS

It is mandatory to measure the outcomes of the project. Reports are good but we need results that are more tangible. We needed to find the right metrics to quantify the results of our experimental work and outcomes of the project. We discovered the suitable questionnaire in the Master Theses that we could use for further improvement [17]. Upon thorough review, we modified the questionnaire and prepared two slightly different questionnaires – one for pre-test and one for post-test (with some additional questions).

There were some constraints involved with the questionnaires and we had to find answers to the questions:

1. Could one student fill the same questionnaire more than once?
2. Do we want anonymous results of the questionnaires?
3. Do we need to match pre-test with post-test questionnaire?

Ad 1: If we wanted to get consistent data, we do not want to get multiple feedback from single students. Only one for pre-test and one for post-test are required. This constraint dismissed most of free public web questionnaires system since they are made for anonymous data gathering. We have to prepare questionnaire in our LMS (Learning Management System). The LMS Moodle do not have questionnaire by default but it is possible to install it as component. Most studying programs are two major study disciplines for educational study programmes at our faculty (Faculty of Arts). The same is true for Faculty of Natural Sciences and Mathematics but not for Faculty of Education. Therefore, we could not copied questionnaires to the courses in the winter semester of study year 2017-2018 because some student would be require to fulfil questionnaire multiple times. We create one course for project and every students were able to enter this course which have only questionnaires (pre- and post-test) and question forums for information of our students.

Ad 2: It is possible to set different modes of questionnaire in settings (anonymous or full-name settings). With the psychology expert, we have discussed positive and negative aspect of both settings. In the anonymous mode, we may get better results but we would lose the connection between pre- and post-test. All students were informed about the project and explained why we do the survey and how the outcomes are going to be used.

The decision was made to make questionnaire in full-name mode. The questionnaire (pre- and post-test) would be available to students twice in the same study year in each start of the semester (winter and summer semester) the pre-test and at the end of the semesters the post-test.

Ad 3: For deeper understanding, the connection between pre- and post-test is vital, especially when we do not have very large sample. We have expected to receive more answers in the pre-test than in the post-test because we have no meaning to force students to fill the questionnaire.

The questionnaire consist of 13 questions where some of them are further structured. First five questions are for the

classification (gender, age, study program, level of study, and study type) the rest of the questions are mostly five level Likert scale questions about students' opinion about different statements or questions of ICT in education.

III. ACQUIRED DATA

The questionnaire (pre-test) was sent to the students in October 2017, at the beginning of the semester. Upon the period of two week (questionnaire was closed afterwards), 92 students (14 male, 78 female) answered the questionnaire. The age of students involved are between 18 and 29 years, with the peak of 23 years. Most of the students are from the second level study and 20 students were from first level of study (1st Bologna study).

The post-test questionnaire was sent to the same students, who participated in the pre-test, in the January 2018, in the last week of the winter semester. During the post-testing time, we received 58 responses. We expected the drop of responses because of different reasons. In the pre-test student were more motivated to fill questionnaire, in the post-test most of them have focused to the exam period. Despite we got less data we still have 63% of answers and could do some basic analysis. The differences between answers were expected to be minimal.

We have speculated that students would change their score just for one grade and the calculation we made shows that score change for 0.1 require 10% of student to choose different grade then in pre-test. The change in grades about 0.2 or higher are worth examining for our case.

TABLE 1: How often do you perform specific activities related to the use of ICT in the average working week?

	pre-test	post-test
(1) Playing games	2.0	2.0
(2) Quizzes	1.8	1.8
(3) Using social networks, forums, blogs (eg Facebook, Twitter)	4.5	4.6
(4) Communication via e-mail, Skypa, Messenger	4.4	4.4
(5) Reading daily newspapers and news on portals	3.4	3.5
(6) Watch videos (eg YouTube)	4.0	4.0
(7) Reading e-books and professional articles	**2.5**	**3.0**
(8) Working with office tools (MS Office, Open Office)	**3.2**	**3.5**
(9) Finding information online	4.4	4.4
(10) Use of online study materials and textbooks	3.2	3.3
(11) Programming	1.3	1.2
(12) Use of online maps (eg Google Maps, Google Earth)	**3.0**	**2.7**
(13) Website design	1.2	1.2
(14) Visit library libraries (eg COBISS)	3.0	3.1
(15) Preparation of seminar and project tasks	**3.3**	**3.6**
(16) Creating and editing picture material	2.3	2.4
(17) Editing and processing of video or animations	**1.4**	**1.6**

The TABLE 1 shows one interesting change in the subsection 7. Students were using e-books and professional article more often than at the beginning. Though it may be interesting, it is expected and even statistical test show the significant differences between two consecutive questionnaires responses (χ^2=13.11, p=0.011). The same differences can be seen in subsection 8 (*using office tools*) and 15 (*preparation of seminar and project tasks*) but neither were significantly different (χ^2=5.15, p=0.272; χ^2=3.70, p=0,296). Explanation is simple. Before the beginning of the winter semester, the students have holiday hence lower grades in the pre-test. The interesting change of score is the subsection 17 (*editing and procession of video or animations*). Despite here are no significant differences between consecutive questionnaires (χ^2=7.74, p=0.101) a tendency can be seen. A larger sample could explain this topic more thoroughly. This activity have positive change but it is still very low. We know that video editing is time and resource consuming task and people generally do not perform it unless they have to or it is their hobby. The Table 3 may give some insight. Most students use notebooks that are generally not suitable for video editing.

The drop in subsection 12 (*use of online maps*) may sound alarm but it is reasonably expected. In the summer semester they have more free time and they could plan some vacations but during the semester they have other preoccupation and hence the change. But statistical test show no significant difference between two consecutive samples (χ^2=4.08, p=0.396). The rest of the results are practically unchanged and the high usage of social network and communication was expected.

The area that we could improve is the use of the quizzes. Students of the educational disciplines could use them in their professional work at schools. A simple enough authoring tools are freely available and there are no reason not to use them.

TABLE 2: How often do you use ICT equipment that you own or own? Do you have access to it?

	pre-test	post-test
(1) Smartphone	4.9	4.9
(2) Notebook	4.1	4.5
(3) Stationary computer	2.0	1.8
(4) Tablet	1.4	1.9

The use of tablets (TABLE 2) are low in both test but the change for the positive is huge. It may show that tablets are good for some peoples but generally not for our students. They need to prepare the content and creation of the content on a tablet is too frustrating. The drop of stationary computers and increase use of notebook were expected - students are migrants and notebooks are the primary choice for work. There are no statistical differences between students groups in pre- and post-test questionnaires; a tendency might be detected in notebook and tablets (where χ^2=6.58, p=0.160 and χ^2=6.59, p=0.159).

TABLE 3: How confident do you feel about the different situations that involve working on the World Wide Web?

I feel confident ...	pre-test	post-test
(1) because I know that I can find any information online without foreign aid.	4.1	4.2
(2) because I know that in case of problems I can join the online discussion group.	3.4	3.3
(3) when it is necessary to present your own findings and opinions to others on the web.	3.3	3.2
(4) when it is necessary to learn new skills to work with new programs.	3.4	3.5
(5) when participating in forums and online communities with professional-scientific content.	3.1	3.1
(6) in communication on web and social networks.	4.2	4.1
(7) in solving problems that may arise when working with the Internet.	3.4	3.4
(8) using search strategies to find information online with search engines such as Google, Yahoo, Bing, etc.	4.2	4.1
(9) using search strategies for searching for Slovenian library databases such as COBISS, the University Digital Library, and so on.	**4.0**	**4.2**
(10) using search strategies for searching for foreign databases, such as Web of Science, Scopus, Google Scholar, etc.	2.8	2.9

Changes seen in TABLE 3 shows just little fluctuations in the opinion of our students. In general, all changes are easily explained with the increase involvement in the TLS (Teaching Studying Learning) activities. Very favourable result is seen in the use of online digital libraries (not statistically significant χ^2=6.37, p=0.173). At least we know that the money we pay for access of the articles in the foreign databases is well spent.

TABLE 4: The following are some of the factors for the use of ICT in the higher education pedagogical process.

	pre-test	post-test
(1) Professors and assistants encourage me to integrate ICT into learning and future teaching.	3.4	3.4
(2) Teachers at elementary and / or secondary schools encourage me to integrate ICT into learning and future teaching.	3.1	3.0
(3) With other students, we often exchange ideas about the integration of ICT into learning and teaching.	2.9	2.9
(4) Other students use ICT in learning and preparing for teaching.	**3.4**	**3.2**
(5) In lectures and exercises, we often discuss the integration of ICT in teaching.	2.9	3.0
(6) Students at my faculty are well informed about the importance and value of ICT in learning and preparing for teaching.	**3.0**	**3.2**
(7) We have a variety of software at the faculty.	2.9	3.0
(8) Technical support for lectures and exercises at the faculty is appropriate.	3.1	3.0
(9) At the faculty, we have the right ICT instructors available to us.	**2.7**	**2.4**
(10) Technical infrastructure (eg equipment in lecture rooms, Wi-Fi) at our faculty is appropriate.	**2.6**	**2.8**

TABLE 4 shows the interesting drop of score in subsection 4. This would mean that students produce less learning materials for other students and share less. Despite the almost alarming drop, it not a significant change and was observed even before the ICT becomes primary factor in education. Only few students made good notes and the rest copied from them. This could explain the drop of the grade.

We were pleased with the result in the subsection 6 (*Students at my faculty are well informed about the importance and value of ICT in learning and preparing for teaching*). The grade is not great but the improvements shows us that we are on the right way. The improvements are shown even in subsection 10 (*Technical infrastructure at our faculty is appropriate*) but as before the lack of funds prevents to improve this topic even further.

Students have discovered the haunting truth. The subsection 9 (*At the faculty, we have the right ICT instructors available to us*.) just proves that we lack of ICT experts not just for students but even for the employees. Once upon the time, when less ICT was used in work, it was specified that around 4% of employees should be for IT. We barely get to 1%. The differences between two consecutive questionnaire results are statistically significant (χ^2=13.26, p=0.010)

The TABLE 5 shows much more changes between two consecutive questionnaires. The subsection 2 (*That would do for your own good*) (χ^2=2.32, p=0.678) and 3 (*Because this should have been done*) (χ^2=6.50, p=0.165) are interconnected and not statistically significant. They bring smile to the face because students perceive ICT as a necessary "benevolent" evil that takes time and effort but gives something in return. Some just go with the flow - subsection 2 (*It probably makes sense to do this, even if I do not see it myself*) (χ^2=7.31, p=0.120). The more problematic is the subsection 8 (*I would include it, but I'm not sure if it would be worth it*) (χ^2=1.46, p=0.834) subsection 11 (*Since I would have no other choice*) (χ^2=4.53, p=0.339) and 12 (*I do not know what I would have of it*) (χ^2=4.49, p=0.344). Students do not see the obvious benefits of the use of ICT in the education. The grades to these subsections (8, 11, and 12) are bellow middle but the drop in subsection 10 (*I would involve it on a voluntary basis*) shows some statistical trends (χ^2=8.65, p=0.070) and 15 (*I feel that I should include it*) (χ^2=2.89, p=0.577) are more interesting. Are these the results of the ethical dilemmas, pragmatics approach cost-benefit analysis, or awareness of the constraints of ICT it is still up to us to find.

TABLE 5: Why should I include ICT in my teaching when I am going to be a teacher?

	pre-test	post-test
(1) I think that work with ICT is interesting.	4.1	4.0
(2) That would do for your own good.	**3.5**	**3.7**
(3) Because this should have been done.	**2.7**	**3.0**
(4) It probably makes sense to do this, even if I do not see it myself.	**2.0**	**2.2**
(5) Because ICT work is enjoyable.	3.6	3.5
(6) I believe that ICT integration is good for me.	3.6	3.6
(7) Since this is something that should be done.	2.8	2.9
(8) I would include it, but I'm not sure if it would be worth it.	**2.2**	**2.4**
(9) Because it would be fun.	3.8	3.8
(10) I would involve it on a voluntary basis.	**4.2**	**3.9**
(11) Since I would have no other choice.	**2.0**	**2.3**
(12) I do not know what I would have of it.	**1.8**	**2.1**
(13) If I included it, I would feel good.	3.4	3.3
(14) I believe that this would be good for me.	3.5	3.5
(15) I feel that I should include it.	**3.5**	**3.2**
(16) I would do this, but I'm not sure that I would continue for a long time.	2.1	2.2

TABLE 6: Below are some statements about ICT.

Statements	pre-test	post-test
(1) ICT enables learning that is more effective.	3.9	3.9
(2) ICT supports diverse forms of learning.	4.2	4.1
(3) Students use ICT to achieve better learning outcomes.	**3.2**	**3.4**
(4) ICT has a significant impact on better knowledge transfer.	3.6	3.6
(5) ICT is helpful for teachers to teach in a more effective way.	3.9	3.8
(6) ICT is helpful to teachers to deliver knowledge in a variety of ways.	4.2	4.1
(7) ICT is helpful to teachers, enabling them to express their thinking in a better way.	**3.5**	**3.7**

The TABLE 6 shows that students increasingly feel that ICT enables them to achieve better learning outcomes (subsection 3) (χ^2=7.72, p=0.102) that suggest some statistical significant trends and facilitate the ease of expression (subsection 7) (χ^2=2.34, p=0.674). The later grade is expected because during their study they need to prepare multiple seminar work and present them to colleagues. The process of avocation of their work is much easier with the ICT than without it.

The TABLE 7 shows no huge differences between pre- and post-test results. Scores of the expected outcomes after the education are actually very favourable. Maximum grade is five but we know no student would grade himself with the max number in the ICT at the Faculty of Arts (the fact of life). Students know others students, they compare their knowledge with the knowledge of students from CS (Computer Science), hence the results. One interesting positive change can be seen at the subtopic 8 (*provide learners with learning activities with ICT*) (χ^2=2.46, p=0.653) which gives us hint that our effort in the winter semester actually give some results; not statistically significant though.

TABLE 7: Evaluate how you will be able to use ICT effectively in class when working with students after completing your education.

I expect I be able ...	pre-test	post-test
(1) to positively motivate learners to use ICT.	3.8	3.9
(2) prepare students for a critical use of ICT.	4.0	4.0
(3) provide learners with ICT-based knowledge and skills.	3.8	3.9
(4) provide learners with learning activities with ICT.	**3.8**	**4.0**
(5) to offer students the opportunity to express ideas creatively using ICT.	3.9	3.9
(6) to support pupils in finding information through ICT.	4.1	4.0
(7) to support students in the processing and management of data through ICT.	3.9	3.9
(8) to support pupils in presenting information through ICT.	4.1	4.0
(9) to support pupils for communicating with ICT in a safe, responsible and effective way.	4.1	4.1
(10) support pupils to work with ICT in the group.	3.9	3.9
(11) educate learners for the conscious use of ICT (e.g. respect and adaptation of the user's working environment, intellectual property, etc.).	3.9	3.9
(12) select ICT applications for a particular educational environment.	3.7	3.8
(13) re-design the ICT application for a particular educational environment.	3.2	3.3
(14) use ICT to distinguish between learning and teaching.	3.7	3.8
(15) to monitor the learning progress of students in digital mode.	3.7	3.9
(16) assess students with ICT.	3.6	3.6
(17) use ICT for proper communication with pupils.	3.8	3.9
(18) to create a learning environment with available infrastructure.	3.7	3.7
(19) to effectively select ICT applications in creating a learning environment (eg, the appropriate size group selection).	3.7	3.7

IV. INTERPRETATION

To get a better insight we decide to make closer view on educational study programs involved into the project. We have selected study programs of English, Geography, Germany, Pedagogy and Slovene language. In this topic we are going to review additional question in the post-test questionnaire where we wanted to get students' evaluation of the work we have done during the winter semester. For the evaluation we have prepared four additional, 5 level Likert scale question:

- In the previous test I have overstate my ICT knowledge.
- How would you rate the progress of your ICT knowledge gained in this semester?
- I estimate that my use of ICT in learning has improved over the past semester
- In the past semester, I have received enough examples of the use of ICT in education so that I can use them in my future work.

The TABLE 8 shows that students do not deviate from their knowledge estimates. In most study programs, the ICT is just a tool. Production of multimedia elements are not required and no additional required knowledge needs to be acquired.

TABLE 8: In the previous test I have overstate my ICT knowledge.

Study program	Knowledge overstatement
English language	2,9
Geography	3,0
German language	3,0
Pedagogy	3,0
Slovene language	2,9
Grand Total	3,0

Interestingly some students (English language, and Slovene language) even consider that they understate their knowledge assessment.

TABLE 9: How would you rate the progress of your ICT knowledge gained in this semester?

Study program	knowledge gained
English language	2,9
Geography	3,8
German language	3,4
Pedagogy	3,5
Slovene language	3,2
Grand Total	3,2

TABLE 9 get better results. The progress is most effective in Geography, followed by the Pedagogy and the German language. The English language shows even little drop but this is expected. The students of English language will jet to experience new approach in summer semester. This grade proves that our measurement works.

TABLE 10: I estimate that my use of ICT in learning has improved over the past semester

Study program	ICT skills improvement
English language	3,2
Geography	3,8
German language	3,6
Pedagogy	3,5
Slovene language	3,1
Grand Total	3,3

The TABLE 10 shown improvement in all segments. Geography leads the way with the Slovene language at the bottom. The results from the Slovene language studies is expected because we cannot expect the reflection of the change if only one course is prepared with ICT in mind.

Table 11: In the past semester, I have received enough examples of the use of ICT in education so that I can use them in my future work.

Study program	examples of use of ICT
English	3,2
Geography	3,3
German language	3,6
Pedagogy	3,0
Slovene language	3,0
Grand Total	3,2

The Table 11 shows us the undisputed leader – German language studies. We have jet to see how this is possible. Is it because of the excellence of the lecturer or there are some other factors we do not see them jet.

V. FINAL CONSIDERATIONS

In the past semester, we have prepared and used new approaches of ICT in education for different study programs. The matrices we have establish show some positive and negative trends that are expected and could be easily explained. Nevertheless, some results surprised us. We have known that young generations have good ICT knowledge and they are obvious ICT consumers. The teachers role is different as he/she should be also ICT producer. Especially in the e-learning materials production and application of ICT in education. Future teachers accept that ICT is reality but they have certain doubts about its effectiveness. From the students' answers, we could deduct that cost-benefit analysis is not in favour of ICT. Initial cost in labour and time are too much for most of them. Though they know the benefits later, they rather stay in the traditional educational procedures.

The interesting fact was gained from one group of students who were closely monitored during the whole semester. None of the student overestimate their knowledge. However, on the other questions we see that one of the student have different opinion than the others. Results are brutal and could demonstrate that one unsatisfied student could easily diminish all positive statistics in small groups. If we have students who do not like new approaches and they have the right to vote then we have no answer.

Table 12: General pedagogy students team responses.

pedagogy	knowledge overstatement	knowledge gained	ICT skills improvement	examples of use of ICT
student1	3	4	4	3
student2	3	4	4	3
student3	3	2	2	2
student4	3	4	4	4

student5	3	4	4	3

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Using Physics Simulation Environment for Better Students' Performance

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Abstract **- In the past we were witnessed the drop of interest for studying physics. Many reasons for that were identified and improved but some are still present. To understand physics students need huge mathematical knowledge that is beyond their abilities in primary and secondary schools. Physics experiments are real physics but the measurements generally differ from the physics equations in primary and secondary education. Many things have to be over-simplified from the real world experiment for students to solve the problem analytically by using math equations. In the past years, we used simulations for examining physics phenomena that were able to hide complex mathematics and show the same behaviour like physics experiments. However, with the drop of support of Java applets all those applets become obsolete. We are now facing dilemma, do we need to recreate simulations or use simulation environment and use the process of creation of simulations as learning tool. With the case study method, we have tested one example of free physics simulation environment Algodoo to see which group of students is the best for such approach. This didactical approach is not suitable for all students but it has important benefits for the others.**

Keywords - education, physics, simulation environment, didactics

I. INTRODUCTION

Physics is one of three fundamental core sciences, together with biology and chemistry [1]. Physics is one of the physical sciences, beside geology, astronomy and chemistry [2]. Physics is among other typical subjects, e.g. mathematics or languages, one of the crucial consisting parts of almost all school curricula in the world [3]. The presence of physics differs by countries, however in majority of European countries the subject physics is as obligatory subject included in primary and also in secondary schools of higher level (e.g. gymnasiums and 4-year technical schools) [3]. Thus, the society understand the physics as important part of students' education. Based on several researches [4] [5] [6], at least in Slovenia, the physics is one of the most un-popular subjects in the school. On the other hand, the students understand the importance of the physical knowledge and in addition, the students' knowledge itself is in comparison to other countries satisfactory [7]. Consequently, in the last decade (and even earlier) we were witnessed the decrease of interest by secondary school students, for studying physics at faculty level [8]. Which is actually very disappointing fact if we take into account that this profile of knowledge and competences is of great importance in nowadays and that the students with 1st or 2nd study level diploma have excellent job and salary opportunities [9]. Numerous faculties with physics studies [10] [11] [12] tried to overcome these troubles. We are convinced that the origin of the drop of interest for studying physics is not in non-sufficient popularity (or advertising) but in non-adequate teaching approach in primary and secondary schools. The gap between real world physics and introduced examples in the school is too deep. In the classroom, the teacher typically introduce simplified examples [13] [14] to ensure that the physical model, which describes the physical phenomena, can be solved analytically with students' mathematical knowledge at the specific level of education. The result is not the "learning excitement" of students, just the opposite. The student cannot recognize the importance of purified examples to gain the basic understanding and to prepare foundations for later deepening of knowledge. The students – and this is of great importance – see in such examples only non-realistic theoretical physics, not connected with real life situations [15]. Even if the students are able to use the physics knowledge to manipulate various problems, they do not develop interest to study physics [4]; consequently, the number of physicists in the society is decreasing [9], despite the needs in the job-market. To solve real physics problems today, the students do not need huge mathematical knowledge, because there exist excellent simulation software. By our opinion, using such adequate software at teaching/learning physics in the way of solving more authentically problems [16] can help the teacher/student to overcome one of the greatest obstacles in the process of development of functional physical knowledge.

The paper is structured in the following way. After introduction, we describe different ways to use simulation in physics education. It all started with java applets but later more elaborate simulation environments become available that enable using simulations without programming them. The discussion about using the simulation in education explains the didactics background and methodology in our pilot research. Physics simulation environments are described as next, following by the chapter with presentation of our case study (using simulation in primary school physics education) and results.

II. FROM USING EXISTING SIMULATIONS TO BUILDING OUR OWN

A. Java applets

In the world of previous century web pages, the Java applets were welcomed addition to the user experience in the web browsing. They could be translated to the byte code, transmitted to the user, and executed on the user computers in the virtual machine (JVM) seamlessly integrated to the web browser. The general idea was refreshing; code was much faster than any interpreted code (Java script, VB script). However, the problem of virtual machine versions and security have made Java applets obsolete. Today we have almost no support for Java applets in portable devices. It is still possible to use Java applets on the computers but this is the last dying breath of the technology.

The Java applets for physics (sometimes called physlets [17] [18]) enable us to upgrade learning materials with the simulations. Small physlets provide the playground for the students to explore the physics background of natural phenomena. They provide the means to change parameters and observe simulated phenomena on computer. Even today, the web pages with physlets can be found for mechanics, fluids, waves, thermodynamics, electromagnetism, circuits, and optics [18]. The idea is not dead, it only seeks new technology to move on. In the short time, we are going to find new code of the previous designed experiments in interpreted languages. The processing power of the modern computers is enough to provide same user experience in the interpreted languages as it was previously possible only in the semi-compiled languages.

B. Simulation environments

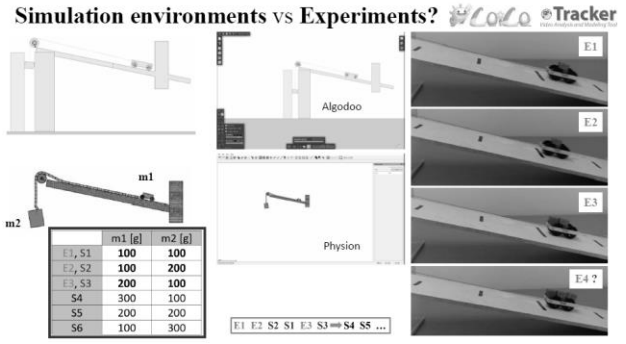
In this work, we mainly focus on three simulation software tools (simulation environments): Algodoo, Step and Physion. They are all free accessible. Their common property is the conversion of three-dimensional (3D) phenomena into two-dimensional (2D). Thus, all analyzed examples are in 2D, which is appropriate for the majority of the introduced problems in schools, but not always. Such simulation software tools enable users (teacher, student) to insert simple objects such as squares, circles, springs and other objects into the simulation environment (virtual space). After running the simulation, the inserted objects begin to move regarding correlating interactions, determined by physical model of the simulation. For the learning process of students is more beneficial the second proposal. The students have to learn a lot of physics by constructing the physical model before to build it in the simulation environment. However, the lack in mathematical knowledge is there no obstacle for the students, since the problem is solved by the mathematical/physical engine, included in the software.

C. Strategy of combining experiments and simulations at teaching physics

We have to keep in mind that the physics is one of the fundamental sciences and that the skills to perform experiments at physics is crucial. Experimental part of physics is of great importance for gradual acquirement of knowledge and natural science competences in general. Consequently, the experiment should not be substituted but supplemented with ICT tools, e.g. simulations [19].

There are multiple scenario to use experiments and simulations in physics. In our previous research [20] we have tested multiple scenarios in primary school. The learning outcome depends on right choice of sequence of experiment and simulations – different scenario were observed and assessed - should we use experiment first and scenario later or vice versa was tested extensively [20].

The optimal scenario was the one that starts in the following way. For introduction of specific physical phenomena in the classroom, the teacher need to prepare experiment with at least three different sets of parameters, those are 1st experiment (E1), 2nd experiment (E2) and 3rd experiment (E3). The corresponding simulations are S1, S2 and S3. The teaching process starts with E1, than E2. It is followed by S2 and S1. The experiment E1 prepare the audience (primary school students) to the broad overview of the phenomena (the first information). The experiment E2 is used to test the understanding of the phenomena. The experiment E2 is analyzed in detail with the simulation S2 to fulfill information proximity. The simulation S1 is then used to verify the learning outcomes by combining of the memorized experiences of experiment E1 and the simulation results in S1. At that point we introduce the simulation S3 for new set of experimental parameters in order to predict the time-dynamics of the future experiment. If no contradiction is seen according to the previously gained knowledge and experiences, we perform the experiment E3. Such sequence of experiment and simulations means that the teacher has successfully established the confidence of the simulations' outcomes and he can continue using simulations (S4, S5 ...) as teaching tools in the future without corresponding experiments (E4, E5 ...). The experiment and simulation can lead to better teaching and learning achievements if used in such sequence. We presented the results of the investigation regarding the optimal scenario of introducing both, experiments and simulation, at the International conference on teaching physics in secondary schools [20]. We tested several experiments: Newton's low at vehicle and accelerating mass, metal balls of different radia falling in different liquids, accelerating rotation of objects with different momentum of inertia, and oscillations of objects with different mass on different springs. We tested different scenarios: i) E1, E2, E3, S1, S2, S3, S4 etc., ii) E1, S1, E2, S2, E3, S3, S4 etc., iii) E1, E2, S2, S1, S3, E3, S4 etc. iv) E1, E2, E3, S3, S2, S1, S4 etc. and several more. In our case study [20], we find out that the scenario leading to best results in understanding was the iii) E1, E2, S2, S1, S3, E3, S4 etc. (Figure 1), which we already explained more in detail.



	m1 [g]	m2 [g]
E1, S1	100	100
E2, S2	100	200
E3, S3	200	100
S4	300	100
S5	200	200
S6	100	300

Figure 1. Velocity-measurement device in Algodoo.

In the following chapters, we first shortly introduce all three analyzed software tools (Algodoo, Step and Physion) and then we present the simulation construction processes of the same physical problem in all simulation environments. We also analyzed this software in context of physics teaching to show their versatility in use at primary and secondary school. We analyzed the primary and secondary school physics curriculums in Slovenia (we think, the content is similar elsewhere) and gave suggestions on suitability of individual topics for application of simulations. The three presented simulation programs are compared based on the criteria arising from classroom application. The results of simulation software comparison, their practicability and ideas on simulation use, presented in this work, enable teachers easily to decide which simulation environment they will use in their lessons.

III. SIMULATION ENVIRONMENTS: ALGODOO, STEP AND PHYSION

There are many possibilities to prepare simulations. Most flexible solution is if someone prepare its own. However, this is most time consuming and require reasonable amount of programming knowledge and skills [21]. Most teachers does not have time to design and code its own programs (simulations). The three public available free software for simulation design (simulation environments) were tested and verified (Algodoo, Step, and Physion) [19]. Despite their differences, they all enable design of physics experiments and they are sufficiently accurate to use them for simulation or prepare for the practical (lab) work.

For the purpose of this article we have prepared the simulation of "velocity-measurement device". The differences are seen on figures: Algodoo (Figure 2), Step (Figure 3), and Physion (Figure 4). Differences are noticeable but mostly in the sense of user interface design. The outcomes of the analyzed simulations are comparable and if we consider recommendation for simulating 3D world in 2D simulation environment [19], we get better results than an untrained student does from the physics experiments.

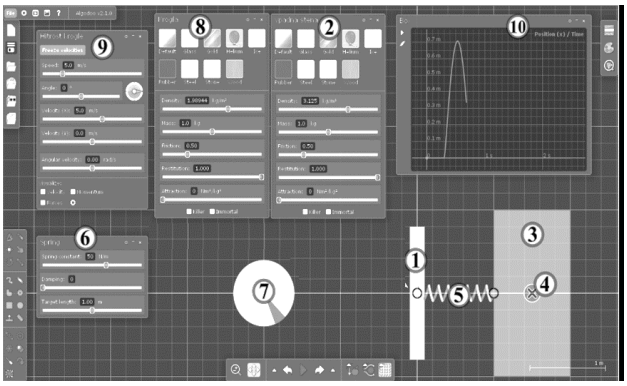


Figure 2. Velocity-measurement device in Algodoo.

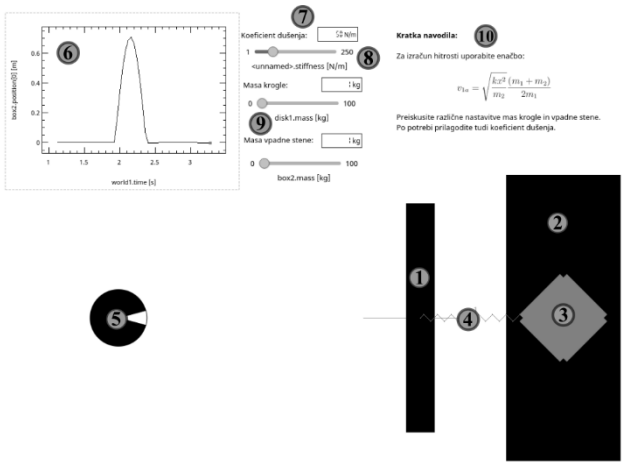


Figure 3. Velocity-measurement device in Step.

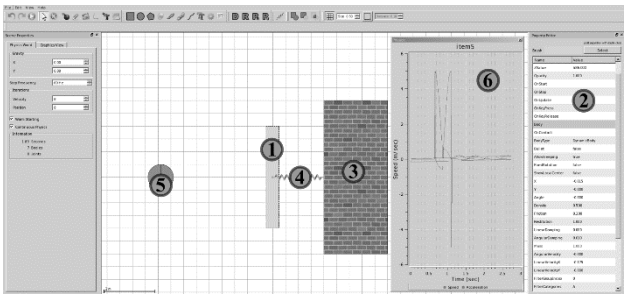


Figure 4. Velocity-measurement device in Physion.

IV. CASE STUDY – ALGODOO IN PRIMARY SCHOOL

In November 2017 we have tested qualitatively one lesson of introducing Algodoo simulation environment into the 8th class of primary school in Slovenia. We have decided to use Algodoo because it can be used on different operation system, including Windows that are used almost exclusively in our primary schools, it is user friendly (especially for primary school students) and covers most of the topics for primary school physics. More advantages of Algodoo in comparison with Step and Physion ware presented in [20]. In the classroom were 24 students in the age of approx. 14 years (12 female and 12 male). However, in our study we did not focus on the gender of students. By using the case study learning method [22] [23] [24] [25], we have tested for which group of students described learning strategy (chapter 1.C

in the article) gives the best learning outcomes. The students in the classroom ware classified into three sub-groups, based on previous results at physics: low-achievers (LA), average-achievers (AA) and high-achievers (HA). Each of the sub-groups involved 8 students. Each student has worked alone in the computer classroom (Figure 5). Students use the simulation environment to analyze the physical phenomena of movement of objects on the slope (which object will come faster down the slope, if we use a ring or a disc of the same diameter and mass) (Figure 5).

Figure 5. The disc and the ring of the same mass and outside radia accelerate on the slope differently as a consequence of different rotational inertia.

In the classroom, the teacher shows the experiment inspired by the video [26]. In our study, the ball was not analyzed by using simulation, because the cross-section of the cylinder (disc) and ball is the same: a circle. However, the rotational inertia of those objects differs. The mass of the objects is not distributed uniquely with the distance of the rotational axis. The simulation engine use the disk in this case, one need to go deeper in the simulation environment software to change those parameters (moment of inertia for the ball), which is more appropriate for the secondary schools. Anyway, the mathematical knowledge of primary school students to provide the comparison of movement even for ring and disc by rolling down the slope was not sufficient; this ensure the adequateness of the chosen example. The students need to build the simulation to find the answers.

Figure 6. Students in primary school at usin Algodoo simulation environment.

V. RESULTS AND DISCUSSION

We would like to inform the readers that we did not make the survey or test to gather results of the experiment. Results were gathered by teacher (highly trained professional) with many years of experience in teaching physics. Despite the fact that this may have influenced the learning process, we have to be aware that teachers have competences and position to assess students' knowledge. They are expert in the teaching and they know their students. Their judgment about the efficiency of physics tools used in learning should not be easily dismissed. The teacher used several methods to gain the information needed to assess the knowledge and understanding of students: method of observation, method of spontaneous questioning (with assessment of answers), real-time analysis of student's questions (it's important what they ask), frequency of teacher's interventions needed, the mistakes and the correct ideas at building the simulation, the recognized knowledge in short individual discussions with students etc.

Students, separated in sub-groups (LA, AA, HA) firstly observed the experiment, demonstrated by the teacher in front of all. Than they look at the video of the same experiment [26]. By using the video, the students can stop the movie, analyze initial, medium and final state. The students can discuss the learning topic with each other and with the teacher, they prepare questions and seek the answers (gaining physical knowledge, building the physical model of the phenomena). Afterward the teacher introduced the simulation environment Algodoo, surprisingly numerous students sad that they were familiar with this software. They also said that they are using it for fun. However, in our case they build the simulation in Algodoo. The purpose of the simulation was to find the key difference between different objects moving down the slope and to ,measure the time to reach the bottom.

The students in LA sub-group had huge problems in understanding the phenomena itself, not speaking about the lack of skills in using Algodoo in appropriate way. This sub-group could understand only basic elements on the screen after predetermined time to run simulation in the computer classroom. They forget to attach the objects

to the background grid and simulation could not even start. Simulation building process was too demanding for this group therefore they need already prepared simulations to achieve any learning outcomes. Therefore, we transferred one working simulation to them, so they could start the simulation and analyze the results. At this stage the LA students ware successful at using the simulation, but still they could not use it to understand the physics background. For them the simulation was nothing but the "computer game" (Table 1)..

The AA students had also significant problems by building the simulation, but the content of the problem was slightly different in comparison with the LA students. The AA students were successful in the technical part of the building the simulation (how to choose the object, how to attach it to the background grid, how to define properties of the object etc.). However, they still could not connect the physical model with the simulation, e.g. ring consist of two cylinders: one of solid material and one empty inside (or filled with air) (Figure 5). The students in AA sub-group came some steps further in comparison with LA students, but they did not reached the level of gaining the physical knowledge using the bond between experiment, video and simulation. At the end of the lesson, we transferred also in this sub-group one working simulation to students, so they could start the simulation and analyze the results. They were not able to distinguish the important parameters and analyzing the consequences by setting the values differently. They used the simulation, but not in the way to achieve better physical knowledge (Table 1).

The students in HA sub-group were very enthusiastic and motivated (and collaborative in the first part of the lesson). They understood rapidly the key events in the experiment; they analyzed the video in detail and immediately started with building the simulation. In this sub-group, there were almost all already familiar with Algodoo, which was important advantage (skilled in finding tools, objects, menus to change parameters of objects, to define interactions, e.g. intensity and direction of gravity etc.). The process of building the simulation was a competition for them (who will be the first, which simulation will work without mistakes, which one will be the prettiest etc.). We recognized elements of gaming at this stage. Almost all simulations were well prepared. Therefore, we can transfer one good example from this sub-group to LA and AA sub-group. However, only the students in the HA sub-group used the building process and the phase of using the simulation to gain deeper physical knowledge. They understood that if the mass of the body is more concentrated on larger distance of the rotating axis (like in case of the hollow ring), the object need more time to reach the end of the slope in comparison with homogeneous disk (Figure 5), where some parts of the mass are also closer to the axis (Table 1).

Table 1: Assessment of the results of three sub-groups of students based on set of criteria.

	Sub-group of students		
CRITERIA	**LA**	**AA**	**HA**
Understanding the phenomena	sufficient	medium	high
Skills in building simulation	lack of skills in building own simulation	Low connection between the physical model; successful at technical part	almost all already familiar with Algodoo, almost all simulations were well prepared
Successfully working own simulation	No (understand only basic elements)	No (simulation was working but not presenting the experiment entirely)	Yes, in general (at some students: only small interventions needed)
Running simulation	Only as »computer game« (using one working simulation to them, not their own one)	Running own simulation with bad connection with physics	Running own simulation after implementing some improvements at some students
Using simulation to gain knowledge in physics	No (not even with the working simulation of the HA group)	Not successful enough: not able to distinguish the important parameters and analyzing the consequences by setting the values differently (by using the working simulation of the HA group)	Highly motivated students. Elements of gaming or competition appeared. They used the building process and the phase of using the simulation to gain deeper physical knowledge.

VI. CONCLUSION

The final remark is that in the LA sub-group there were no positive aspects of this approach for the members of this subgroup. The AA members have at least gained experiences at using Algodoo, but we need to invest more time to explain the physical phenomena to the students in this sub-group. Maybe in slower teaching with more moderation and explanation also this sub-group member would have more benefits. By our opinion, the presented approach is adequate for members of the HA sub-group. The results of all stages of the presented lesson were positive and encouraging. Thus, this didactical approach is not suitable for all students but it has important benefits for members of some sub-groups.

For further work we suggest, that it would be good to repeat the same lesson in more classrooms (higher number of students), which can enable also quantitative comparisons. We also suggest that more different lessons should be prepared, not only to follow the differences between those sub-groups (LA, AA, HA) but also to evaluate our original proposed Strategy of combining experiments and simulations at teaching physics (the sequence: E1, E2, S2, S1, S3, E3, S4, S5…). In addition, the influence of presence of skills by using Algodoo should be analyzed more in detail. In case of using different operating systems also comparison between different simulation environments (Algodoo, Step and Physion) can be executed. Furthermore, it would be desirable also to analyze the primary and secondary school curriculum for the subject physics in order to

provide ideas for lessons, where the experiment and simulation can be beneficiary combined.

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Outlines for science digital competence of elementary school students

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***Abstract* - Many of the digital competences of students can be transferred from their homes and out-of-school environments, but it is unrealistic to expect that students will become proficient in the use of equipment such as whiteboards or data-loggers outside school. An emergent research topic is thus "Are science teachers succeeding in transferring to their students the digital competences specific to the study of science?" In the initial research phase, our intention was to prepare a Digital Competence Framework for Science Learning for Elementary school Students, and a proposal for how this could be applied in the science classroom. We began from a study of the Slovenian syllabus for Computer Science and Multimedia in elementary school. We discovered that, in science education, we cannot rely on students' digital competence even at the basic level (use of e-mail, internet browsers, word processors and home multimedia), a situation that calls for intervention by science teachers. Additionally, the school subject Computer Science and Multimedia is elective, which is another reason that we cannot expect students to be digitally competent in all classrooms, nor we can expect this kind of digital competency merely on account of the abundance of digital technology all around us. A framework was prepared and adapted for the basic, general and subject specific levels. Specific classroom situations are identified for clarifying the concepts, and classroom practices based on tested sources are proposed for presentation at the conference.**

Keywords - computers, digital competence, elementary school, ICT, science teachers

I. INTRODUCTION

Information and communication technology (ICT) has become, within a very short time, one of the basic building blocks of modern society [1], influencing humans in basically all aspects of life, as both visible and invisible technology. There is no longer any doubt that modern citizens should be digitally literate [2, 3, 4]; however, it remains an open question what share of education in the application of digital competence should be delegated to families, what share to the educational system, what share to employers, and what should be designated for self-education. This is one reason that school leaders, teachers and students face an increasingly complex and challenging school environment [5, 6]. Recently, we have witnessed children's ability to use digital technology even before they are literate. The same is true for Slovenia, and in Slovenian elementary schools it is hard to find a student who is unfamiliar with the use of the computers and mobile technologies, or who lacks access to the Internet, at least in the school library and public places. Given the presence of stationary and mobile digital technologies all around them and its saturation of everyday life, todays' school leavers can be recognized as digital natives [7, 8], to distinguish them from "digital immigrants," being persons born before the widespread usage of digital technology. Digital natives are said to possess skills allowing them to work with technologies in a natural way. Although these ideas are promoted by think tanks such as the reference [9], the term digital native does not indicate that students are automatically digitally knowledgeable or information literate [10]. At the other level, there is a major difference between knowledge about technology and students' ability to apply technology [11].

Reference [3] published a framework of eight key competences for lifelong learning as "a combination of knowledge, skills and attitudes appropriate to the context". The digital competence of citizens [2] has recently been recognized as part of the key competences allowing citizens to succeed in digitally rich environments. The problem of operationalizing digital competence was recently addressed by the Digital Competence Framework for Citizens [2], with the aim of providing a general frame of reference and self-evaluation tools. However, society cannot rely on self-educated citizens; for the education of digitally competent students, therefore, we need digitally competent teachers. As was recognized in previous work by the authors [12] digitally competent science teachers need to possess subject and domain specific competences. This is because science teaching is unique in its methods and equipment, such as virtual and computer supported hands-on laboratories, which call for specific competence on the part of teachers and students. The digital competence of science teachers was described at three levels: basic, general professional and special professional [12]. However, success in digitally rich school environments calls for recognition of the contextual digital competences of students, as well. The reason is that many recent computer-supported educational practices (e.g. use of data loggers) in school science do not have their counterparts in other educational subjects or home use. This paper proposes a list of and levels for digital competence (basic, general and specific) among elementary school students, competences that should be achieved by and shared with their science teachers in fully operational computer-supported school science education.

Beyond the scope of present paper lie those competences needed for manipulation and application of computer-supported technologies in technics and

technology, such as the operation of CNC machines, projection by use of sophisticated programmes such as Pro/engineer, 3D printing and robotics.

A. *Position of ICT education in Slovenian elementary schools*

The use of ICT in Slovenian schools outside of specialized subjects like Computer Science or Informatics is encouraged but not obligatory for teachers. In Denmark, as an example, preservice teachers have to pass a license qualification exam that verifies their digital competence, to ensure quality information and communications technology (ICT) usage [13]. In Slovenia, on the other hand, the education of preservice elementary and lower secondary school science teachers about ICT is very diverse and dependent on individual faculties and programmes.

The use of ICT in and for education in Slovenian elementary schools depends on decisions taken at the level of a school and its teachers. Subjects like Computer Science or Informatics are not obligatory; however, some schools do offer elective subjects. Because the Slovenian school system is centralized, syllabi for elective subjects are prepared by teams of experts and approved by governmental bodies. Given the rule that a sufficient number of students need to be enrolled in each elected subject, this means in practice that students do not have equal opportunities to enroll in elective subjects and to achieve key digital competences. If they enroll in the subjects Information Literacy or Informatics, they can achieve generic skills such as editing of texts and multimedia materials and knowledge about computer networks. A limited number of students choose Robotics; however, the skills achieved are difficult to transfer into Science education. According to the content of both elective subjects, students can neither adopt nor adapt science digital competences unless they choose both subjects, what rarely happens. From this point of view, student adaptations of science digital competences depends on there being digitally competent science teachers. However, according to reference [14] adaptation of digital competence also depends on students' self-efficacy, strategic information use, previous academic achievement, cultural capital and language integration at home.

B. *Defining digital competence*

Competences are combinations of knowledge, skills and attitudes. Therefore, a digitally competent person is someone who has the theoretical knowledge, practical skills and attitudes appropriate for ICT usage. Initially, digital competence was described as a mixture of digital skills, with the social and emotional aspects of using and understanding digital devices [15]. The European Commission [16] has defined digital competence as involving the confident and critical use of Information Society Technology for work, leisure and communication. Digital competence is grounded in basic ICT skills, i.e. the use of computers to retrieve, assess, store, produce, present and exchange information, and to communicate and participate in collaborative networks via the Internet [15].

Recently, many terms have been connected with digital competence, as synonyms, as part of it or as a supplement. The following list is by no means comprehensive: digital competence, digital literacy, media literacy, ICT literacy, 21st-century skills, digital skills, computer skills, Internet skills, [14 e-skills, information literacy and media literacy [17]. All these digital literacy terms serve to identify and analyse what students should be able to achieve with digital tools and technology [18]. Many people use the terms digital competence and digital literacy as synonyms, but this is not the case [14]. Sometimes the terms are defined narrowly, and sometimes the two concepts overlap. The wide variety of terms reflects the rapid development of technology but also different areas of interest, such as library studies or computer science [19, 20]. Reference [9] suggests that governments should make an effort to identify and conceptualise the required set of skills and competences, and then incorporate them into the educational standards. However, this would be a Sisyphean task. Frameworks for digital competence are changing rapidly and continuously. Some policy-related papers recommend that approaches should be dynamic and regularly revised because of the evolving new technologies and their use in society. Changes in society and culture, based on new technology, have an impact on terminology. It is expected that both the content and the scope will still change [21].

In this article, the term digital competence is applied as dealing with the technical conditions, understandings, and critical reflections students are able to use. Digital competences are not inborn. Students need to invest effort, interest and time in order to develop their own level of digital competence [7]. The development of digital competence is considered a continuum, from instrumental skills, to productive and strategic personal competence and cognitive skills [22]. Therefore, digital competence includes students' ability to use technology for consuming and accessing information. Moreover, digital competence also includes how students make use of technology to process, acquire and evaluate the information they have retrieved. Finally, digital competence means that students can produce and communicate information with digital tools or media [14]. For digitally competent students, the educational system needs digitally competent teachers. The need to incorporate of digitally qualified teachers into this process is reflected in the initiative to prepare a Digital Competence Framework for Educators [23].

II. SCIENCE DIGITAL COMPETENCE

Digital competence "involves the confident and critical use of information society technology (IST) and thus basic skills in information and communication technology (ICT)" [12]. The term digital competence should be understood as having the skill, ability and knowledge to successfully use computers, their related applications and software in the practice of teaching and education [13]. Adopting digital competence is a process in which all schoolteachers should be involved. They must be prepared to cooperate with other educators in the effort to educate digitally competent students.

In teachers' lives, ICT plays a dual role. The first is to fulfil teachers' personal needs as digital citizens (such as

the skills with and knowledge of computers as a clerical, informational and multimedia tool). The second role is at the professional level and does not end with the use of ICT to improve their content teaching, maintain school e-administration and function as a desktop library.

Science teachers have a special role in educating for science digital competence. It is recognized that science teaching, especially in its practical aspect, laboratory exercises and fieldwork, goes beyond the common teaching practices used in most other subjects [24]. In practical and laboratory work, ICT is regularly used in the form of data-loggers, digital microscopy, controllers, etc., comprising instructional practices rarely or never used in other subjects. For complete development of digital competence in science teaching, the teacher must be keen on the basic acquisition, classification, analysis, assessment and presentation of primary data, while also being competent in the sound use of the technology connected with computer interfaces [12]. In such cases, we can recognize digital competence as being closely connected to the description of technological competence within the theoretical framework of Technological Pedagogical Content Knowledge [25]. In their words (p. 1028), "Teachers need to know not just the subject matter they teach but also the manner in which the subject matter can be changed by the application of technology …, and knowing how teaching might change as the result of using particular technologies."

Science education offers multiple opportunities for using ICT. Basic ICT knowledge means document creation, information collection, communication and the use of multimedia, but besides these ICT skills, the most important element involves virtual and real, computer-supported biological laboratory (CSL) exercises [26, 27].

Science teachers are responsible for using digital technology in the school laboratory, during fieldwork or in the classroom. Students can use computers as sophisticated typewriters, as desktop libraries or communication tools and for multimedia in literally every subject, while the use of ICT units as processors, controllers and data-loggers can be introduced in only a limited set of school subjects or activities [28]. This being the case, if, for example, one teacher at a school does not promote the use of computers in the classroom as a tool for finding information, the loss for students is minor, because with equivalent work in other subjects they can fill the gap. If, on the other hand, science teachers do not use data-loggers in the school laboratory, there is nobody at school to cover the missing knowledge [29].

A. Content and Levels of Digital Science Competence for Students

According to many authors, ICT use in the classroom can be subdivided into categories. Reference [30] identified six categories of ICT use by teachers; reference [31] identified two types of strategies or usage patterns for ICTs in schools; reference [17] described twelve digital competence areas; reference [32] suggests five aspects as part of school-based learning; reference [2] described eight proficiency levels in ICT use; reference [12] identified three levels of digital science competence. In this article teachers' and students' science digital competence are recognized according to the following classification. The range of digital competences (basic, general and special digital competences) in each level are represented in Figure 1. Basic digital competences include the majority of the digital competences; special digital competences include minority, and very special digital competences the remainder.

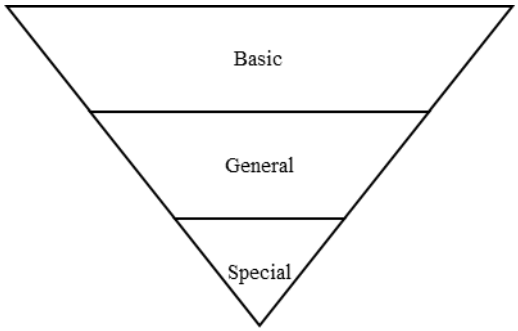

Figure 1: Diagram of numerous digital competences by levels.

1) Basic digital competences can be described as citizen competences, where students autonomously and with appropriate guidance can identify information needs; find data, information and content through a simple search in digital environments; find how to access these data, information and content and navigate between them; and identify simple personal search strategies [2]. The list of basic digital skills includes skills like using e-mail, internet browsers, word processors and home multimedia [12]. Students can learn basic digital competences from any digitally competent teacher, or nowadays, even before starting school. For most Slovenian students, their first contact with ICT is not in the school environment, and this is why teachers can expect students to have some basic digital knowledge and skills that can serve as a basis for upgrading their ICT pre-knowledge. Those expectations are not appropriate. Not all students will have the same level of ICT pre-knowledge; thus, it is important to identify and understand the background and home environment.

2) General digital competence is described as ICT usage common to all teachers (using Interactive boards, school e-administration, Moodle, etc.), where students can adopt general digital competence in school [12]. The list of general digital competences is shorter than that for basic digital competences, and the general competences are more specific than the basic digital competences (Figure 1). Students mostly use and adapt just parts of general teachers' digital competence because they lack access to some technology or application (e.g. school e-administration, Moodle administrator) but some general digital competence students adopt as well as teacher (eg. use of an interactive board, calibration of an interactive board, using prepared interactive animations; preparing a digital quiz).

3) Special – professional digital competences imply subject specific usage of ICT. Science digital competence (Sciences, meaning Biology, Chemistry and Physic) are classified as follows: use of data loggers, digital microscopy, subject-specific software, virtual laboratory, etc. [12]. Using digital technology in the school

laboratory, during fieldwork or in the classroom requires additional knowledge and skills that students can only acquire in Science school subjects, but in the Digital Competence Framework for Educators [23], this kind of digital competence is absent, although students may learn science digital competence from those teachers who are digitally competent in the Sciences.

III. CONLUSION

According to the Digital Competence Framework for Educators [23], digital competence can be broadly defined as the confident, critical and creative use of ICT to achieve goals related to work, employability, learning, leisure, as well as inclusion and/or participation in society. Science digital competence is not identical to digital competence, so the Digital Competence Framework for Educators [23] is insufficiently specific for Science teachers. Science digital competence is an enormously specific area, and science teachers need more and different ICT knowledge, skills and pedagogical instruction than teachers of other school subjects. From this point of view, teaching Science school subjects as a digitally competent teacher offers a greater challenge than teaching other school subjects. To achieve an appropriate engagement with digital competences, pre-service science teachers should be required to pass a licensing exam to verify their science digital competency, as one way of ensuring quality ICT usage, as is current practice in Denmark.

Science teachers alone are responsible for using digital technology in school science practice. If they do not use science digital competence in their science classrooms, nobody in our schools is providing students with science digital knowledge and skills.

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Perceived User Experience and Performance of Intelligent Personal Assistants Employed in Higher Education Settings

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***Abstract* - The application of intelligent personal assistants (IPAs) in the educational context is a relatively new paradigm. One of the key features of an intelligent personal assistant is the ability to respond to user voice input through natural language processing. Implementation of intelligent personal assistants (IPAs) in higher education teaching process is associated with the students' adoption and satisfaction with IPAs. With the objective to explore students' experience and performance evaluation of IPAs on their smartphones, an empirical study was carried out. Data was gathered by means of post-use questionnaire after completed predefined scenario of interaction with two IPAs: Google Assistant and Lyra. The analysis of collected data uncovered pros and cons of IPAs perceived by students from two Croatian higher education institutions. Empirical findings are presented, whereas implications for educational ecosystem are briefly discussed.**

Keywords - Perceived User Experience, Performance, Intelligent Personal Assistants, Higher Education

I. INTRODUCTION

According to Kim and Suh [1], intelligent personal assistant (IPA) is "a software agent that assists people to perform basic tasks or services for an individual, usually providing information via natural language". On the other hand, Manikonda et al. [2] defined intelligent personal assistants (IPAs) as "systems that are capable of learning the interests and behavior of the user and respond accordingly".

IPAs are often deployed on mobile devices, personal computers, smart home devices (e.g., intelligent speakers), and wearable devices (e.g., smart watches and convenient natural user interfaces) [3].

This innovative technologies (IPAs) combine set of tasks, such as speech recognition, language understanding, dialogue management, language creation and speech synthesis) to respond to user queries and needs [4].

On today's market, a large number of IPAs (such as Google Assistant, Siri, Lyra, Alexa, Amazon Echo, Microsoft Cortana, etc.) are available, providing reactive (e.g. weather forecast, restaurant reservations, etc.) and proactive support (e.g. recalling users on upcoming events, relevant contextual information, etc.) [3].

Because IPAs provide users the right information at the right time, Sun et al. [5] emphasize that it is a crucial for personal assistants to understand users' intent which are closely related to the context of using IPAs.

When educational ecosystem is considered, IPAs represent a new paradigm. For example, Dizon [6] found that university students of English as a foreign language in Japan perceive IPAs (e.g. Alexa) as useful tools that enhance language learning.

Results from relevant literature review show that there are not many studies that explain how students interact with IPAs, and the influence of those applications to students' ability to perform tasks in higher educational process.

Students' adoption and satisfaction with IPAs are very important factors for successful implementation of IPAs into higher educational process.

The objective of this paper is to examine the degree of perceived students' experience and perceived performance of using IPAs in educational settings.

The remainder of the paper is structured as follows. Brief theoretical foundation is provided in next section. Findings of the empirical study are presented and discussed in third section. Concluding remarks and future work plans are offered in last section.

II. RELATED WORK

One of the most important factors influencing the broad acceptance of IPAs are quality management factors composed of usability and user experience [7].

In general, user experience (UX) "covers all aspects of end-user interaction with the company, its services, and its products" [8]. According to Nielsen Norman Group [8], it is "important to distinguish the entire user experience from the user interface (UI)".

According to Orehovački et al. [9], "usability refers to the evaluation of pragmatic attributes whereas user experience consists of the application of subjective measuring instruments (e.g. questionnaires) to evaluate hedonic attributes". Performance refers to attributes that

measure the quality of task execution by means of IPAs [9, 10].

Jiang et al. [11] developed a model for automatic online evaluation of intelligent assistants. Results of their study show that satisfaction is the major indicator of user experience because it is consistently correlated with changes in user interests towards the system (e.g. web search tasks are more open-ended and complex, and chat is the most open-ended task, etc.)

Manikonda et al. [2] found that there are multiple privacy issues when users interact with IPAs and many users take actions such as "returning the product", "muting the microphone", "limiting the usage – example only using to set alarms", etc.

The results of empirical study conducted by Siddike et al. [12] indicate that using IPAs (e.g. Siri) improves performance in individual's work. The authors emphasize that successful interaction of people with cognitive assistant (CA) improves human knowledge and intelligence. The results of their research show that trust, privacy, accuracy, ease of use, and management are key drivers for the success of existing CAs. Siddike et al. [12] concluded that one of the challenges is how to define and measure the users' improved performance in the context of IPAs and proposed a framework for measuring improved human performance through interaction with CAs.

The analysis of the relevant literature suggests that there is a small number of studies related to the students' experience and their perceived performance of IPAs in higher educational process. The set forth motivated us to initiate research in that respect.

III. METHODOLOGY

A. *Participants*

A total of 309 respondents (63.4% male, 36.6% female), aged 19.94 years (SD = 2.770) on average, took part in the study. At the time study took place, 57.9% of the sample were enrolled to one of the undergraduate study programs at Polytechnic of Rijeka (POLYRI) while remaining 42.1% were undergraduate students of Informatics at the Department of Information and Communication Technologies, Juraj Dobrila University of Pula. Majority of participants (83.5%) completed scenario of interaction with IPAs on smartphones that run Android operating system.

As can be observed from the responses to questionnaire items shown in Figure 1, in most cases (91.3%), students are employing their smartphones for accessing social networking sites like Facebook which was followed by other activities such as Viber (84.5%), making and receiving calls (84.5%), listening to music (80.9%), Web browsing (78.6%), watching videos on services such as YouTube (69.6%), sending SMS messages (67.6%), taking photos (64.4%), accessing the educational content published on learning management system (55%). Remaining demographics characteristics of respondents can be found in [7].

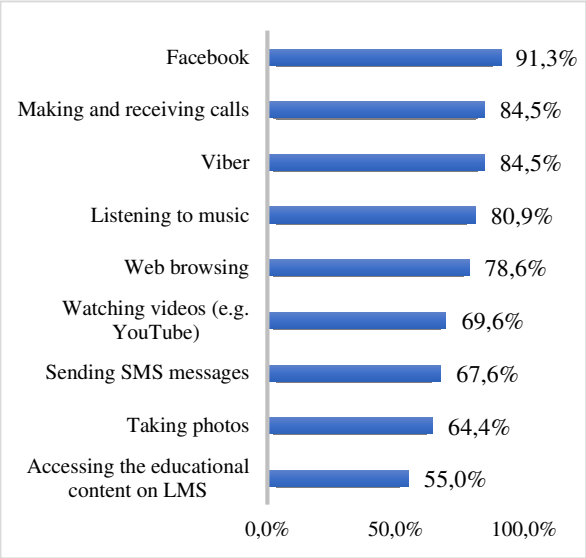

Figure 1. Percentage of students using their smartphones to access different applications

B. *Apparatus*

Based on the set of quality attributes proposed in [9] and items introduced in [10], measuring instrument in the form of post-use questionnaire was designed. It was composed of 12 items related to participants' demography and 229 items measuring quality facets. Responses to the questionnaire items were modulated on a five-point Likert scale (1-strongly agree, 5–strongly disagree).

Perceived user experience refers to attributes meant for measuring the extent to which [10]: the IPA has visually appealing user interface (aesthetics); the IPA is beneficial in the context of tasks execution (usefulness); the interaction with the IPA holds the users' attention and stimulates their imagination (playfulness); users have positive perception about the use of IPA (attitude towards use); the IPA has met users' expectations (satisfaction); the IPA arouses users' emotional responses (pleasure); users have the intention to continue to use the IPA and recommend it to others (loyalty); and social web application is popular (reputation).

Perceived performance refers to attributes that measure the extent to which the IPA [10]: enables users to execute tasks accurately and completely (effectiveness); enables users to quickly perform tasks (efficiency); responds promptly to users' actions (response time); is capable to operate under an increased or expanding workload (scalability); and is usable within and beyond initially intended contexts of use (context coverage).

The sum of responses to items assigned to corresponding attribute was used as a composite measure which reflects particular user experience and performance aspect.

Reliability in terms of the internal consistency of the aforementioned scales was measured with Cronbach's alpha coefficient. It can be concluded from the data in Table I that almost all of the constructs had a satisfactory internal consistency (above 0.80) for both IPAs applications, except for the scales scalability 0.63 for

Google Assistant and 0.67 for Lyra) and reputation (0.69) for which the Cronbach's alpha is still considered to be acceptable. Study findings in terms of mean and standard

TABLE I. RELIABILITY OF SCALES

Constructs	*Number of items*	Cronbach's alpha	
		Google *Assistant*	*Lyra*
USEFULNESS	6	.91	.92
PLAYFULNESS	6	.82	.83
ATTITUDE TOWARD USE	6	.94	.94
SATISFACTION	8	.95	.93
PLEASURE	6	.93	.92
AESTHETICS	5	.91	.90
REPUTATION	3	.69	
LOYALTY	7	.94	.95
EFFECTIVENESS	7	.88	.88
EFFICIENCY	5	.88	.88
RESPONSE TIME	5	.88	.87
SCALABILITY	3	.63	.67
CONTEXT COVERAGE	4	.86	.83

deviation values for each scale in the form of composite measure are summarized in Table II and Table III.

C. Procedure

Upon arriving to the lab, each participant received a form containing a list of 55 representative steps of interaction. Participants were asked to carry out all scenario steps twice – first with Google Assistant and thereafter by means of Lyra (both shown in Figure 2, Figure 3). The duration of the study was three hours.

IV. RESULTS AND DISCUSSION

The main findings of this study are shown (see Appendix) in Table II (Google Assistant) and Table III (Lyra). Results of data analysis, indicate that 67.55% and 43.60% of study subjects are planning to continue to use Google Assistant and Lyra, respectively, or recommend it to others. It was also found that 40.61% and 32.90% of students reported that Google Assistant and Lyra respectively, hold the users' attention and stimulate their imagination.

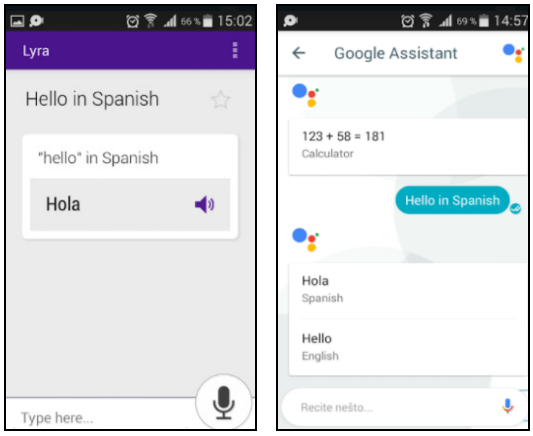

Figure 2. An example of scenario-based assignment completed with Lyra (left) and Google Assistant (right) – question: "*Hello in Spanish*"

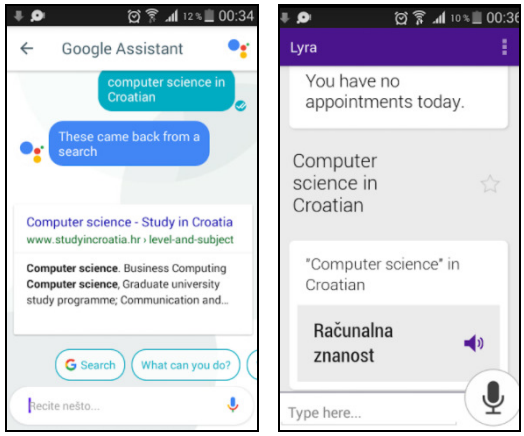

Figure 3. An example of scenario-based assignment completed with Lyra (left) and Google Assistant (right) – question: "*Computer science in Croatian*"

In addition, 34.52 % of study participants stated that popularity of IPAs (Google Assistant and Lyra) application affect their decision to use it.

Furthermore, 33.76% and 21.36% of students agree to have a positive attitude toward that applications usage. Moreover, it was discovered that only 31.76% and 11% of respondents agree that Google Assistant and Lyra, respectively, meet their expectations.

Similarly, only 27.29% and 15.48% of study subjects is convinced that Google Assistant and Lyra, respectively, meet users' hedonic goals and arouse their emotional responses.

The analysis of collected data is also implying that only 23.79% and 14.56% of students believe that Google Assistant and Lyra, respectively, improve user's performance in executing tasks. The data gathered from study participants revealed that only 14.89% and 10.03% of them agree that Google Assistant and Lyra, respectively, has visually attractive user interface.

It was also found that only 23.52% and 21.14% of study participants agree that Google Assistant and Lyra, respectively, are capable to operate under an increased or expanding workload (e.g. simultaneous work of a large

number of users or simultaneous execution of a large number of complex tasks, etc.).

Furthermore, the findings of the study imply that only 28.48% and 12.99% of students believe that by using Google Assistant and Lyra, respectively, tasks can be performed accurately and completely.

It was also discovered that only 18.71% and 11.26% of study subjects agree that the execution of a task using Google Drive and Microsoft OneDrive, respectively, saves resources (e.g. time to complete the task, etc.).

The results of research shown that only 8.67% and 7.06% of students believe that the Google Assistant and Lyra, respectively responds promptly to users' actions.

Finally, it was found that only 9.87% and 5.83% of respondents agree that the Google Assistant and Lyra, respectively, are usable within and beyond initially intended contexts of use.

V. CONCLUSION

Intelligent personal assistants (IPAs) are one of the most innovative technologies used in higher educational process. The aim of this paper was to examine facets of perceived user experience and perceived performance in the context of IPAs. For that purpose, an empirical study was carried out. Cronbach's Alpha coefficient was employed for assessing the construct reliability.

The analysis of the collected data suggests that although most students expressed their willingness to continue using IPAs (e.g. 67.55% and 43.60% in the context of Google Assistant and Lyra, respectively), other factors point to the fact that the students did not fully recognize the usefulness of IPAs in the educational context.

One third of respondents agrees that Google Assistant and Lyra meet users' expectations and stimulate emotional responses. On the other hand, only a small number of respondents believe that IPAs improve users' performance in task execution, that with IPAs tasks can be performed accurately and completely, and that IPAs are useful within and beyond the initialized context of use.

It is important to note that the large majority of respondents were first time users of intelligent personal assistants on their smartphones. The results of this empirical study indicate that IPAs have potential in the higher educational process because the large majority of students intend to use these applications in near future.

Taking all the aforementioned into account, findings reported in this paper could be used by practitioners as guidelines to control quality of IPAs and develop features to increase their educational potential. In addition, researchers can employ presented results as a background for future advances in the field.

Taking into account that work presented in this paper is part of an ongoing research, our future work will be focused on modeling the interrelations of determined dimensions of perceived user experience and performance with respect to IPAs.

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APPENDIX

TABLE II. ATTRIBUTES OF USER EXPERIENCE AND PERFORMANCE IN THE CONTEXT OF INTELLIGENT PERSONAL ASSISTANT GOOGLE ASSISTANT PERCEIVED BY STUDENTS (N=309)

IPA – GOOGLE ASSISTANT **Attributes**	Response **%** in each level					**Mean**	**SD**
	Strongly Agree (1)	**Agree (2)**	**Neither agree nor disagree (3)**	**Disagree (4)**	**Strongly Disagree (5)**		
USER EXPERIENCE							
USEFULNESS	**5.56**	**18.23**	23.57	38.62	14.02	15.76	5.45
PLAYFULNESS	**16.72**	**23.89**	25.35	24.43	9.61	18.82	5.12
ATTITUDE TOWARD USE	**12.08**	**21.68**	23.14	24.49	18.61	17.05	6.57
SATISFACTION	**9.71**	**22.05**	23.17	32.73	12.34	22.72	8.12
PLEASURE	**10.46**	**16.83**	23.52	32.63	16.56	16.32	6.09
AESTHETICS	**4.08**	**10.81**	18.32	38.95	27.84	9.84	4.27
REPUTATION	**9.39**	**25.13**	22.22	34.74	8.52	8.76	2.64
LOYALTY	**44.20**	**23.35**	16.83	11.84	3.78	27.46	7.03
PERFORMANCE							
EFFECTIVENESS	**5.50**	**22.98**	25.01	35.37	11.14	19.34	5.69
EFFICIENCY	**4.60**	**14.11**	19.60	37.61	24.08	11.88	4.56
RESPONSE TIME	**2.46**	**6.21**	9.45	38.45	43.43	9.29	4.07
SCALABILITY	**7.98**	**15.54**	28.15	29.77	18.56	7.94	2.63
CONTEXT COVERAGE	**2.35**	**7.52**	17.31	44.66	28.16	8.45	3.24

TABLE III. ATTRIBUTES OF USER EXPERIENCE AND PERFORMANCE IN THE CONTEXT OF INTELLIGENT PERSONAL ASSISTANT (LYRA) PERCEIVED BY STUDENTS (N=309)

IPA - LYRA **Attributes**	Response % in each level					**Mean**	**SD**
	Strongly Agree (1)	**Agree (2)**	**Neither agree nor disagree (3)**	**Disagree (4)**	**Strongly Disagree (5)**		
USER EXPERIENCE							
USEFULNESS	**4.85**	**9.71**	16.34	41.26	27.84	15.76	5.45
PLAYFULNESS	**14.40**	**18.50**	22.44	28.86	15.80	18.82	5.12
ATTITUDE TOWARD USE	**9.39**	**11.97**	17.64	30.74	30.26	17.05	6.57
SATISFACTION	**3.92**	**7.08**	15.78	41.46	31.76	22.72	8.12
PLEASURE	**6.47**	**9.01**	17.16	35.54	31.82	16.32	6.09
AESTHETICS	**2.27**	**7.76**	12.88	38.71	38.38	9.84	4.27
REPUTATION	**9.39**	**25.13**	22.22	34.74	8.52	8.76	2.64
LOYALTY	**27.37**	**16.23**	18.77	24.27	13.36	27.46	7.03
PERFORMANCE							
EFFECTIVENESS	**2.87**	**10.12**	14.79	44.48	27.74	19.34	5.69
EFFICIENCY	**3.04**	**8.22**	14.11	37.99	36.64	11.88	4.56
RESPONSE TIME	**2.14**	**4.92**	6.15	35.53	51.26	9.29	4.07
SCALABILITY	**7.66**	**13.48**	25.89	30.53	22.44	7.94	2.63
CONTEXT COVERAGE	**1.06**	**4.77**	16.25	42.73	35.19	8.45	3.24

The importance of multiple intelligences and growth mindset – research among students of University College Algebra

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Dramatic changes in the global society and economic structures due to information technology revolution and mass production and dissemination of the new knowledge demands a rapid response from individuals for them to have successful lives. People have very different kinds of mental and intellectual strengths, and they must be taken into account when we think about learning process which plays the critical role in this new knowledge economy with the focus on 'human capital.' This paper presents the research conducted over the student population of University College Algebra with the aim of identifying the most critical factors that students consider having a significant impact on their capacity to learn, ability to relate *new information* to prior *knowledge*, pose and solve problems and accordingly achieve a successful career. The survey was conducted through the prism of different kinds of intelligence and mindsets that are considered paramount for human success in the economy of the future.

Keywords - multiple intelligence, growth mindset, knowledge economy, human capital.

I. INTRODUCTION

We are experiencing dramatic changes in the global society and economic structures due to information technology revolution. The collection, validation, and dissemination of information and knowledge are crucial; they provide and guarantee power as well as wealth. Mass production and dissemination of new ideas demand from us a rapid response and open minds to see how we could integrate challenging information and expanding knowledge. Education plays the critical role in the knowledge economy and changes from traditional economic models to 'human capital' models. Human capital refers to the ability to solve problems, to be productive, to think creatively, to recall information and reinterpret them in a new light. Therefore, high expectations are set before education: we want 'new skills, new jobs, new capacity to cope with rapid change, new perspectives for leading fulfilled lives - from the cradle to the grave'[1]. Students think and learn in many different ways, and education must follow. However, there is now a large volume of evidence from all realms of science that unless individuals take a very active role in their studying, unless they ask questions, to recreate and transform facts in their mind if and as is needed, the ideas disappear. People have very different kinds of minds, and intellectual strengths and they are critical in how we learn.

Many educators now recognize that and support Multiple Intelligence theory and research on growth mindset because both can ultimately empower students to take ownership of their learning![2].

II. MULTIPLE INTELLIGENCES AND MINDSETS PARADIGM

A. *Multiple intelligences according to Gardner*

Intelligence has been the subject of scientific community research for years and remains the subject of debate until today. For example, one of the definitions describes intelligence as a complex practical property of mind, integrating numerous mental abilities, such as the capacities to reason, solve problems, think abstractly, comprehend ideas and language, and learn. The study of intelligence within psychology regards this trait as distinct from creativity or personality[3]. However, the definition of intelligence has been, and continues to be, subject of reflection, consideration and accordingly the subject of discussions and debates.

The definition that comes from Mainstream Science on Intelligence, which was signed in 1994 by 52 scientists, defines intelligence as - a very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience. It is not merely book learning, a narrow academic skill, or test-taking smarts. Instead, it reflects a broader and more in-depth capability for comprehending our surroundings—'catching on,' 'making sense' of things, or 'figuring out' what to do[4].

The traditional belief in the field of educational and cognitive sciences that intelligence is something that a man is born with was challenged by Dr. Howard Gardner, psychologist, and professor of neuroscience at Harvard University. According to his definition[5], intelligence is:

- The ability to create a useful product or offer a service that is valued in a culture.

- A set of skills that make it possible for a person to solve problems in life.
- The potential for finding or creating solutions for problems, which involves gathering new knowledge[6].

Gardner developed the theory of multiple intelligences that initially introduced seven different types of intelligence. He identifies them as follows[7]:

Linguistic intelligence includes 'sensitivity to spoken and written language, the ability to learn languages, and the capacity to use language to accomplish certain goals.' It also 'includes the ability to use language to express oneself rhetorically or poetically effectively, and language as a means to remember information.' Writers, poets, lawyers, and speakers are among those that have high linguistic intelligence.

Logical-mathematical intelligence involves 'the capacity to analyze problems logically, carry out mathematical operations and investigate issues scientifically,' so 'it entails the ability to detect patterns, reason deductively and think logically,'and this intelligence is most often associated with scientific and mathematical thinking.

Musical intelligence entails 'skill in the performance, composition, and appreciation of musical patterns, and encompasses the capacity to recognize and compose musical pitches, tones, and rhythms.' Also, it runs in an almost structural parallel to linguistic intelligence.

Bodily-kinesthetic intelligence refers to 'the potential of using one's whole body or parts of the body to solve problems, the ability to use mental abilities to coordinate bodily movements.' Also, it is important to see the mental and physical activity as related.

Spatial intelligence entails 'the potential to recognize and use the patterns of wide space and more confined areas'.

Interpersonal intelligence is 'the capacity to understand the intentions, motivations, and desires of other people' and it allows people to work efficiently with others. So it is crucial for educators, salespeople, religious and political leaders and counselors to have a well-developed interpersonal intelligence.

Intrapersonal intelligence includes 'the capacity to understand oneself, to appreciate one's feelings, fears and motivations' as well as having a useful working model of ourselves and ability to use such information to regulate our lives.

It is important to pay attention that, as far as classical education is concerned, linguistic and logical-mathematical types of intelligence are most valued in schools, so especially in that spirit, according to Gardner and his followers[7].

Gardner leaves the idea of expanding his theories open for discussions and development. However as Gardner warned when approaching this subject, it is important to have in mind that multiple intelligence is often mistaken for learning styles, which are ways how an individual chooses to learn or how an individual approaches a range of tasks while multiple intelligences show different intellectual abilities[7].

B. Mindsets paradigm

Much of the individual's success depends on an individual's attitude towards life. When one wants to determine whether one has a positive or negative attitude towards life one usually asks the classic question whether the glass is half full or half empty. This is perhaps a trivial question because we have heard it so many times that we made it sound trivial. Research[8] shows that depending on the attitude we assume in the learning process, one can develop characteristics that are necessary to be successful in personal life and the economy of the future.

Research done by a psychology professor at Stanford University Carol Dweck shows that there is a significant difference between children with fixed mindset and children with a growth mindset. Children who have fixed mindset are more focused on the form and presentation of themselves and their results. Because of this narrow focus, they do not care about the content or investing effort, focusing mainly on the innate abilities that they consider to be unchangeable. Because of this superficial approach, children with fixed mindset often do not fulfill their potential. On the other hand, children who have a growth mindset are focused on investing effort into thorough content processing and are focused on the learning process. The form and self-presentation are irrelevant to them and, most importantly, they are not afraid to make mistakes. Children with growth mindset also think that their innate traits are not unchangeable and can be developed if enough effort is invested. From these research results show that the approach that teachers use to work with children has a significant impact on the development of one or another type of mindset which as a result has a significant difference in the development of children and results of their learning experience[8].

If we accept that it is possible to change the way we think and that it has a significant impact on the success of individuals, it is necessary to teach children in a way that will enable them to take advantage of their potential to the greatest extent possible.

In addition to categorizing people as a fixed or growth mindset, which then reflects on all other aspects of their life, some scientists like Howard Gardner go a step further and bring an expanded view of the minds we should nurture in individuals so that they can be successful in the economy of the future, but also in your everyday personal life. Dr. Gardner presented his ideas of the minds for the future[9] which is in some way a result of his long career as a developmental psychologist, but also a continuation of research about different kinds of intelligence[10]. According to Gardner, the minds that each person needs to develop to be successful in the economy of the future, which will be primarily based on human capital, are a disciplined mind, a synthesizing mind, a creative mind, respecting the mind and the ethical mind.

According to some research[11] to become an expert in any skill one needs to invest around ten thousand hours of practicing that skill. Whether it is ten thousand hours or not, it is certain that without investing considerable time and

effort in any skill in a structured way, it is not possible to become an expert at any reasonable time, so discipline is undoubtedly something that is necessary to install in human beings since the early age. A *disciplined mind* implies responsibility in work, but also the readiness to accept the consequences of one's actions and decisions, and directly relies on the growth mindset that has been mentioned above.

Today, and especially in the future, when information is available from the vast number of sources, it is crucial to have the ability to select and objectively consume this information, to make conclusions based on objective truth, and to present those conclusions to those who depend on us. This will be possible if we develop *synthesizing mind* in young people. Synthesizing mind is closely related to the disciplined mind and a growth mindset. The synthesizing mind is a mind that will enable not only individuals but also society as a whole to live by objective truth and no longer by superficial opinions, feelings or superstitions when making important decisions for society.

It is clear to all, or it should be, that the civilization whose benefits we enjoy are created by hardworking individuals rather than masses of people. These individuals are the ones who are creative, who think differently than most, they see into the future, imagine a better world and then build it. Imagine how the world today would look like without internal combustion engine, book printing, the internet or, God forbid, electricity? Creativity is one of the few critical elements without which civilization cannot develop. Gardner under the term *creative mind* thinks about the mind that challenges the status quo and deals with possibilities, offers new solutions to existing problems, in short, a mind that creates a new reality for the rest of us. The research[12] shows that creativity is one of the most desirable traits that humans can possess, and according to some experts[13] there is evidence that shows that creativity can be discovered despite limiting and an uncreative environment in our schools.

People who grow up in different environments under the influence of different cultures will inevitably have different value systems that will guide them in their daily decision making and affect relationships with other people. Because the world is increasingly integrated, it is necessary to be respectful in everyday interactions with people from different cultures to work together for the common good. This, of course, must never be at the expense of reasonable behavior by the objective truth, for in this case we are all doomed to fail. A *respectful mind* is something we need to develop in people for practical reasons, precisely because we have different value systems, to be able to function efficiently in the more complex economic conditions of today, and especially the future.

Since every individual is part of a larger entity in which he lives and helps to build, it is paramount for all members to be aware of this fact, so that one can make the most out of his role in the society. The *ethical mind* Gardner's advocate describes individuals place in a broader context of society and emphasizes the fact that we need to teach people how to accomplish their goals in the context of the environment in which they live. Individuals goals need to be in accord with societies so that the individual and the society have the greatest benefit of such relationship. This is not an easy task, but it is a necessary one.

All of these minds, respectful mind, disciplined mind, synthesizing mind, ethical mind and creative mind should be developed in a balanced way so that children can grow to become valuable people who are building a better world for everyone. Although this kind of mindset will enable every individual to be more successful in their personal and business life, a 20000-foot view is required to appreciate benefits of developing such a mindset in people fully. Society, in general, is something that affects all stakeholders, and from that point of view, the development of individual members of that society should be of utmost importance.

III. RESEARCH METHODOLOGY OF DOMINANT MINDSET AMONG STUDENTS OF UNIVERSITY COLLEGE ALGEBRA

A. Research Subject, Purpose and Hypothesis

The subject of this paper is the dominant mindset of students and its role in learning motivation.

This study examines whether students of the University College Algebra believe that intelligence and talent are fixed abilities. There are two extremes; one belief is that life choices cannot change or improve one's intelligence and another belief is that one's life choices can change the level of intelligence and have a positive impact on one's life. The research was done by evaluating twenty statements concerning ability, mindset and personality/character mindset. Emily Diehl (2008) has designed a Mind-set quiz[14] based on the Dweck's book *Mindset: The New Psychology of Success* and she has made the scale of 'growth and fixed mindsets' which we used for research purposes[15].

More specifically, The research was aimed at how students evaluate their impact on their abilities, personality and character traits and characteristics.

B. Methodological framework and instruments

In this paper, we used the quantitative method. The data were collected by a questionnaire that contained twenty multiple choice questions.

The Mindset Quiz was adapted from Classroom 2.0 network[14]. The questions were predefined and offered to students who were asked to identify the extent to which they agree or disagree with the statement. Potential answers on each of the twenty statements were: Strongly Agree, Agree, Disagree and Strongly Disagree.

The survey was conducted on the obligatory lectures of the students at the University College Algebra in January 2018. After explaining the purpose of the examination, all students that received the questionnaires were asked to answer the questions honestly.

The data processing of the survey results was made through the Microsoft Excel tool.

C. Participants

A random pattern sample was used in the research and consists of the students of the undergraduate study

programs: Applied Computing, Multimedia Computing, and Digital marketing at the University College Algebra. The population sample included 104 students, with 11 polls being declared invalid. The total sample was 93 respondents of undergraduate students (100%). 11 female (12%) and 82 male (88%), and of which 61 students (66%) studies on study program Applied Computing, 11 students (12%) on study program Multimedia Computing and 21 students (23%) on study program Digital Marketing (Table I.). The total number of students in the first academic year is 60 (65%), in the second academic year is 33 (35%), and there were no participants who were in the third academic year (0%). No respondent is older than 27 years.

TABLE I. STRUCTURE OF PARTICIPATION BY STUDY, GENDER AND ACADEMIC YEAR

Undegraduate Study Program	Applied Computing	Multimedia Computing	Digital marketing
Total number of Students per Study Program (N)	61	11	21
Number of Studnets by gender			
Male	58	10	14
Female	3	1	7
Number of Students per academic year			
First year	28	11	21
Second year	33	0	0

D. Results

The underlying hypothesis of this research is that dominant mindset affects student's desire to improve and will for advancement in a way that students who have a growth mindset are more motivated to learn, work and overcome difficulties.

One of the fundamental questions of this research was the question of ability mindset sphere; if students consider that intelligence is something fundamental that they can or can't change very much? The research has shown that the highest number of students disagree (45%) or strongly disagree (14%) that their intelligence is something fundamental about them that they cannot change very much, but 34% of students think agree and 6% strongly agree with it. However, 47% of the participants disagree, and 10% strongly disagree with the statement "One can always substantially change how intelligent one is.", moreover, only 4% strongly agree along with 39% of students who agree with this statement.

Regarding personality/character mindset statements, results show that 61% students disagree with the statement "One can always change fundamental things about the kind of person one is.". On the other hand, 18% strongly disagree, while only 20% of students agree (17%) or strongly agree (3%) with that statement. 51% of participants agree, and 3% strongly agree with the statement "Some people are good and kind, and some are not - it is not often that people change.", while 46% of the participants disagree and, 3% strongly disagree with this statement.

Only 4% of students agree (and 0% strongly agree) that they appreciate when parents, coaches, teachers give them feedback about their performance and a high number of students disagree (59%) or strongly disagree (37%). The 94% of students disagree (66%) or strongly disagree (28%) about often getting angry when they get feedback about their performance, but only 4% agree and 2% strongly agree with the statement.

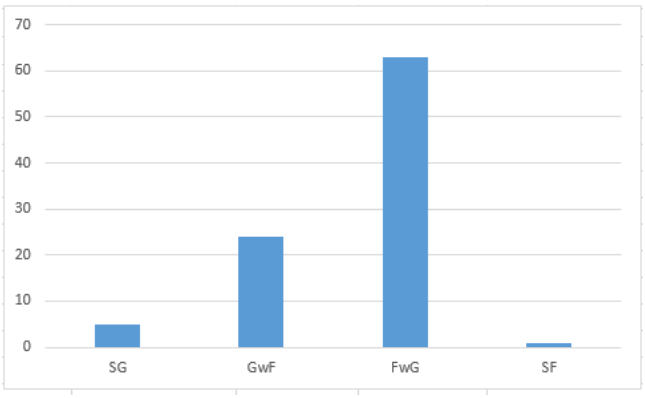
83% of students disagree (61%) or strongly disagree (22%) with the statement "Important reason why one does one's school work is that one like to learn new things.", Moreover, only 17% agree (from what 5% strongly agree) with that. As far as the statement "Truly smart people do not need to try hard" is concerned results showed that most of the students disagree (57%) or strongly disagree (29%), and only 4% strongly agree or agree (10%) with this statement.

Emily Diehl suggested the processing of the results in a way that each of the statements makes between 0 and 3 points (more in a MindsetQuiz table scores adapted from Classroom 2.0 network[14]), and the total sum of points is divided into four categories:

1. *Strong Growth Mindset*
2. *Growth Mindset with some Fixed ideas*
3. *Fixed Mindset with some Growth ideas*
4. *Strong Fixed Mindset.*

Through the proposed distribution of scores results shows (Figure I.) that only 5 students (5%) have Strongly Growth Mindset (SG), 24 students (27%) have Growth Mindset with some Fixed ideas (GwF), 63 students (69%) have Fixed Mindset with some Growth ideas (FwG) and only 1 student (1%) has Strong Fixed Mindset (SF).

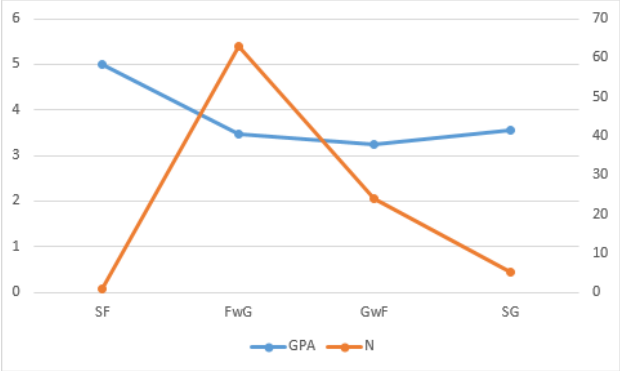
FIGURE I. NUMBER OF STUDENTS PER EACH OF 4 CATEGORIES OF MINDSETS



An additional research question was whether there is a correlation between the dominant mindset and the better grade score. As a relevant student's grade point average (GPA) for the first year students was obtained the average grade achieved on state examination at the end of secondary school and for the 2nd year students was

obtained the grade point average achieved in the previous academic year (Figure II).

FIGURE II. NUMBER OF STUDENTS (N) AND THEIR GRADE POINT AVERAGE (GPA) PER EACH OF 4 CATEGORIES OF THE MINDSETS



Although it can be assumed that students who have developed a growth mindset or growth mindset with some fixed ideas also have greater achievements which can be seen in average grade rating, it has not been possible to derive direct correlation between grade score and dominant mindset.

E. Limiting elements of the research and recommendations for further researching

Before any conclusions can be made it is important to emphasize the difficulties encountered during the research and ultimately its limiting elements.

The sample used in the survey was very small - students of the undergraduate study programs present at the time the survey took place. Out of 104 students who completed the survey, there were 11 invalid questionnaires, which gives a total sample of 93 students. The method of distributing the survey was limited to sampling. This should be changed in future research so that more relevant data can be acquired.

Also, for future research, it is important to define what success means so that it can be easier to measure the impact of growth mindset on increased motivation necessary for achieving success. The distinction should also be made between male and female students.

Maybe one of the most important things is considering longitudinal research on the same subjects so that it can be determined whether there is an influence of the learning experience at the university concerning the change in the mindset.

IV. CONCLUSION

The results of research among students of University College Algebra show that more than half of them (precisely 57%) do not think about the intelligence as something that you cannot work on and what can't be changed. However, it is also apparent that total 70% of participants have a dominant fixed mindset with some or none growth ideas, which 83% of students do not consider a school work as an important way to learn new things and 96% of students do not appreciate given feedback about their performance.

Although the population sample was not significant, it is possible and even highly likely, that the results reflect more fundamental fact about our educational system which is that our education system is not aimed at encouraging students to live up to their potential. Moreover, it would be interesting, if not necessary, to conduct research that could define causal link and correlation between student's academic success and their dominant mindset. This is something that would be worth a while to investigate in the future to stimulate learning 'how to think' and student's development as individuals in every aspect. Finally, that is the central postulate of the concept of human capital; quality of labor is proportionate to the quality of employees, and quality of employees is proportionate to investment in them.

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Light-programming from secondary school to university studies

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***Abstract* - The ability of acquiring programming skills in schools shows significant difference among students. The creating of the algorithms causes the most outstanding difficulty. In our previous researches we examined what kind of methods and devices can measure the algorithm creating skill from the early childhood to university students. We developed a computer-based technology, the light-programming, which helped to distinguish our results from age and the level of programming learning. In our further examination we demonstrated that the level of acquiring programming knowledge in schools correlated with the results of the algorithm creating ability but there is no linear connection. However students who are worse at programming have worse results at the light-programming test. We assume that the components of algorithm creating ability defined by genetics are crucial. It is possible that our results can be compared to psychology tests. That's why our researcher team broadened with psychologists.**

Keywords - Light programming; ability; algorithm

I. INTRODUCTION

The intense development of computer science has led to a need of well-trained professionals to an extent never apparent before. To adapt to the challenges of the labour market, the response of the education system was mass-trainings. One of its consequences is that less and less talented professionals graduate. What used to be basic requirements of graduation in the field of computer science 10 to 15 years ago can no longer be expected from current graduates. Hoping to get a good job, students with less affinity for and talent at this field choose computer science majors.

The fact that working in computer science is elevating to higher and higher levels of abstraction with the development of software tools even reinforces the situation. They are working with ready-to-use units, and application generators, and there is no time for a deeper understanding of algorithms.

Algorithmic thinking is an essential component of programming abilities. In our everyday lives, in learning and at work, we perform algorithms, create algorithms for others, plan series of activities and processes of information-flow. The process is transparent to those that understand the bases of these activities [3].

Algorithmic thinking is a key to understanding several aspects of information technology. However, certain types do not necessarily require using or understanding fine mathematics, but are rather independent from it [2].

Genetics, social and learning processes play a crucial role, similarly to all other skills, but to a various extent. Creation of algorithms is the resultant of a complex, high-level neurological process. During analysis, one needs to interpret the main series of steps, as well as each sub-task, which lead to the solution together. Algorithm creating ability can be observed in toddlers mainly due to inherited components, which are being modified with age by more and more gained skills. Yet, the difference is definitive on all levels of education [11]. Certain students – even the ones in higher-education – get the flow of it almost instantly, and create amazing things soon, while others have a hard time understanding basic-level algorithms, which are solved with ease by certain primary-school pupils. The difference between certain students stands out so much that it needs to be researched by all means, and that serves as the basis of our work.

II. THE TESTING SYSTEM

During our earlier work, we have already developed a testing system called light-programming [9], which can measure algorithm creating ability, before the appearance of writing skills. The subjects can be measured with the same system through under-graduate level, fairly independently of age.
The essence of light-programming is that the subject needs to divide a moving pattern of lights presented into steps, and „turn it into code." That is, construct a series of steps that resembles the presented pattern as much as possible. The presented pattern gives a visual experience, so the need for memory is insignificant. Successfully following the pattern is the consequence of the correct division into steps. With the solution, we can measure the number of mistakes, the time between clicks, and several other parameters.

For the test, we have made the hardware and software of a microcontroller-based measuring device operating with real LED lights and push-buttons [21, 19]. We have developed a simple, but effective system of devices,

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which is as little dependent on the learnt components of skills and the short term memory - STM - as possible. When we were planning our research, we have made the didactically essential follow-up a top priority. So, our aim is to get the same subject to take our test along with other dedicated tests in connection to it at various ages. The universality of the testing system makes complete statistical comparison possible at various ages [7].

During light-programming, the subjects can see 8-16 "sources" of light. They can appear as red circles on a screen or touch-screen, or as luminous LED sources of light of a digital electronic testing-device. The subjects can turn on the lights with a mouse-click or using real buttons. The pattern that the subjects have created can be recorded using another button, so they can create a program out of it. The patterns written into memory can be projected consecutively using the "run" button, so a moving play of lights is projected.

At the beginning of the measurement, the system projects a pre-programmed moving play of lights. The subjects memorize it, but since it is a symmetric, regular pattern, high memory performance is not needed. After this, the subject divides the previously seen play of lights into steps (creates an algorithm), and inputs the patterns needed to copy the original step by step. For programming, one does not need the ability to read, but needs the ability to create algorithms. In many cases, the children perform better than adults.

The submitted solutions can be measured objectively from several aspects. The degree of compliance with the presented pattern, the time used and the number of faulty button-clicks can all be measured and quantified objectively.

III. IN THE BACKGROUND OF PROGRAMMING TALENT

The development of technology has led computer science and programming to be among the in-demand occupations in a few decades. The demand for well-trained programmers is huge, and this trend is going to increase in the next few decades. However, scientific literature fairly neglects the psychological background of this profession. We only have ideas about what makes an excellent programmer, but not too many proofs support these. Yet, the explanation to the lack of research is not only that psychologists neglect the issue, but it is also vital to emphasize that this field is hard to measure. The quantity and quality of formal education as well as the quantity of other kind of knowledge gained in informal ways have a huge role. In contrast with learnt factors, we can measure inherited attributes more precisely. It is important to mention that we are not looking for an average programming talent, since programming does not require talent or even passion, as Jacob Kaplan-Moss has put it [17]. Yet, the main goal of our research is to detect the talented ones. But who do we consider talented?

IV. *THE TALENT*

Talent is a concept that is hard to define. Although we know that there are outstanding people with ability or performance above average, it is still hard to define their difference from others, if there is any. In childhood, good skills, quick learning and zest, which are the foundations of learning and developing potentials, stand out in their environment, but in adulthood, the criterion of talent will be special and fresh approach of a given field and the creative activity, that is, productivity.

Talent is defined as an ability born with us, then developed by purposeful activity and practice, which can create performances that far extends beyond average on a certain defined field of human activity [10]. The author emphasizes the continuity, field-specificity and above average nature of the development of talent, which henceforth cannot be defined merely by the actual existence or lack of a certain skill or attribute. The talent is able to reach an outstanding level of activity, and thus outstanding performance using opportunities, special tasks and challenges [8]. In this definition, top priority is given to activities based on environmental opportunities, then the development of abilities owing to involvement into and practise of these activities, in addition to emphasizing continuity. [4] highlights the attributes of social relevance and the subjective, emotional aspects, when he composes in his definition: Talent means (1) potential, opportunity, promise, hope, chance (2) in a human field of activity (3) for an outstanding performance, which (4) is socially useful, and/or which (5) leads to satisfaction, the feeling of joy, so the sense of accomplishment for the person who reached it. Subotnik and her colleagues [18] point out, in connection with the definition of talent, that it reflects to social values, it leads to visible results in most times (especially in adulthood), it is field-specific, the result of the interaction of biological, pedagogical, psychological and social factors, as well as relative, and it is recognized via reference to average or above average. In connection to the determining nature of social values, it is important to mention that the large-scale lack of computer scientists enhances the need for computer skills and their measurement.

V. INTELLIGENCE AND TALENT

With the expansion of psychometry, the examination of mental abilities and intelligence, and emphasizing their priority created a strong line in the field of talent search at the beginning of the 20th century, and with Binet's intelligence test, identification of talents have thus become available. Terman held this point of view so crucial that when he started his unique, longitudinal, examination tracing the life paths of the talents in the 20s of the last century, he chose one and a half thousand participants via intelligence tests, based on a quite strict ($IQ \geq 140$) criterion. Interestingly, his results show that the IQ did not correlate with success, but the successful life-path of the youngsters picked for the program was rather the result of family background [14]. So the greatest creators are not necessarily among the most intelligent ones, but several environmental factors, motivation, and other personal traits strongly affect the development. Still, intelligence is an essential condition, even predictor of success on certain fields of life according to several studies.

Several results have been reached in connection with the relationship between school performance and intelligence. In the 5-year-long tracing examination of

more than 70 000 children Deary et al. [5] found that general intelligence measured at the age of 11 is in significant and strong correlation with the exam results at the age of 16 (r=.81). This firm connection is nuanced by the lack of data on family background in the analysis, even pointed out by the authors. Via the meta-analysis of 109 previous examinations, Robbins et al. [16] have come to the conclusion that academic self-efficacy and a motivation of accomplishment determine the Grade Point Average in higher education the most intensely, while academic abilities turn out to be determining factors regarding the time spent in higher education. During the examination of 164 students between ages 13-14, Duckworth and Seligman [6] found that there is an average, but significant (.32) correlation between IQ and general academic performance, and besides these, they highlight the correlation (.67) between various indicators of self-discipline and performance.

VI. Other Abilities

Another important ability might be memory, or working memory to be more exact. It assures the storage, retrieval and manipulation of information during more complex cognitive tasks, such as learning. Alan Baddeley and Graham Hitch's theory was published in 1974 [1]. According to the model, the working memory contains three components: phonological loop, central executive, visuo-spatial sketchpad, and later a forth one, the episodic buffer was added. The task of the phonological loop is the short-term storage of verbal information, while visuo-spatial sketchpad temporarily stores and manipulates images. The episodic buffer connects and stores these pieces of information. The central executive maintains attention and supervises the system of working memory. The studies examining working memory have found that working memory shows a significant increase in performance under age of 17, then it stagnates till age of 45, then performance starts to decrease. Yet, working memory is not an unalterable indicator that one holds, but it can be developed. It is important because it shows a strong correlation (r=0,72) with fluid intelligence, and its development increases the value of intelligence as well [15].

Perhaps the most significant ability in connection with our research – besides the previous ones – is the problem-solving ability, which became the focus of studies since 2000s. Mostly pedagogical researches concentrate on it, because problem-solving ability appears to be a basic skill of future learning in ideas that compose learning goals of the 21st century [12]. Besides the varied approach, most definitions partly agree on how they define problem: problem exists if there is a gap between the starting and final states, that is, the path leading to the final state is unknown [13]. With the development of technology, research of the topic has been expanding, since there is a need to use a pre-determined order of steps, and to execute a series of interactions with the devices in question to operate smart phones and various household devices, and most automated machines [15].

There are other kinds of skills that cannot be measured numerically, but that are very important to successfully work in computer science. Besides cognitive abilities, one needs determination to learn and work, and Andrea Magyari highlights an important skill, self-improvement beyond these. She thinks it is essential because it does not only need to be an attribute as a beginner, but also as an experienced computer scientist who has been working for several decades. Technology is in a constant development, and if one does not keep up with it, they will simply lag behind compared to others, and they will not stand put, perhaps even lose competitiveness in their profession [17].

Besides intelligence and a few above mentioned abilities, several other things can affect programming abilities, and the researches to come will deal with which factors will help finding talented youngsters more efficiently.

VII. Microcontroller-based Tester

We have implemented the measuring system on three platforms: one based on micro-controllers with tangible buttons and luminous LED diodes, one Android-based system that can be operated with a touch-screen, and a mouse-operated program that works in PC environment. The three platforms have different input system each: button-push, touch and mouse-click. We are already observing that different input method leads to different results even with the same subjects. The reason to this is probably the fact that a different input method needs a different manual activity. Their comparative examination will provide us with an exciting new chapter in our research.

The Arduino micro-controller that we used has several I/O ports, so we could easily implement the control of buttons and LEDs. The push-buttons operate based on a “positive logic,” that is, when they are pushed logical 1 becomes the input from the micro-controller. Debouncing has been resolved in the software. Besides presenting the information on its LCD screen, the tester sends data via its serial port. So, there is an opportunity to receive and process information with another device, PC for instance, or micro-controller, or another smart device developed to it. At the same time, power source can be provided via the USB port [21].

Not only the activity needed for manual input affects the subjects, but also physical hardware, the sight of electronics. This method is the closest to natural problem-solving, like constructional toys or playful task-solving with bricks.

VIII. Android Application

The Android application projects the play of lights based on a text file that we provide, then it analyses the responses given by the subject, and writes a csv file based on the subject's data and results.

Using a smart-phone can even lead to better results, since according to Seifert's results, a mobile device can be more motivating, entertaining than traditional devices [20].

The input is given on a touch-screen, so manual manipulation is needed as well. Visual perception, the

coordination of the hand and fingers need cerebral cortex activity in different ways.

The program stores the same parameters as the one with micro-controllers and the PC version. We transport the result files to PC, where we can process and analyse them.

IX. PC VERSION

The version made for PC is the latest one, in which we use the mouse to input solutions. Although software development is the most convenient here, and we do not have to deal with the I/O problem either, there is the least visual experience here as well. The PC interface, the mouse provide an ordinary, less exciting environment for the subjects, and it can be observed in the test results as well.

X. PRELIMINARY MEASUREMENTS

So far, we are searching for the type of connection between the parameters we registered and the algorithm creating ability. As a result, how can they be connected to programming skills, and is it reflected in the academic performance of the students who learn programming? Our analyses show promising results so far.

So far, the system is under metering, so only preliminary measurements of 33 students are available. We used the PC-based device for the below measurements. Comparison of the three testing systems is the goal of our future research.

We have tested students of a 13th grade vocational school class, mostly between the ages of 19 and 20. They have already gained their high-school diploma with advanced computer science, and now they are studying further to gain an intermediate programmer diploma. In our examinations, we consider one class each. So the number of patterns is not high, n=17 in this case. Yet, they have learned the same from the same teachers, at the same place, for the same length of time, so it is suitable to compare data to each other. We have measured a test composed of five consecutive light-programming exercises. We have registered the entire time needed for the solution, the average time between clicks, and the number of clicks needed for the whole solution, summed up at each exercise. The lower the value on the Y axis, the better the three parameters are. After this, we have put the students in order based on their programming grades, and represented them on X axis from the good students to the ones with bad performance.

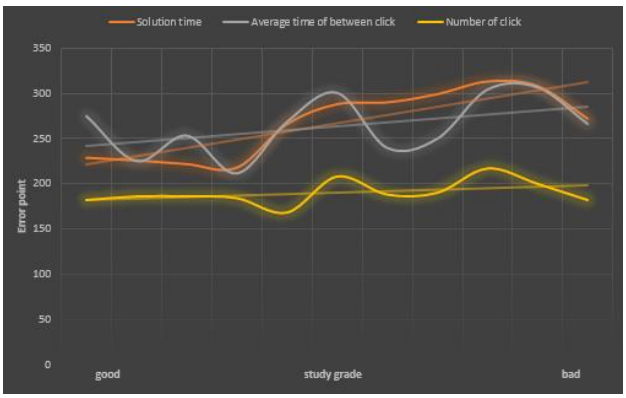

Figure 1. Correlation between three light-programming parameters and academic performance (class 13.)

To all three curves, we have adjusted a trend-line, which shows that a tight correlation exists between the measured parameters and programming performance. That is, better programming students solved light-programming exercises in a shorter time, with less mistakes.

We have repeated the test in the 11th grade as well, with students mostly between ages of 17 and 18 (N=16). They also have advanced computer science classes, but they have only been learning programming for slightly more than a year.

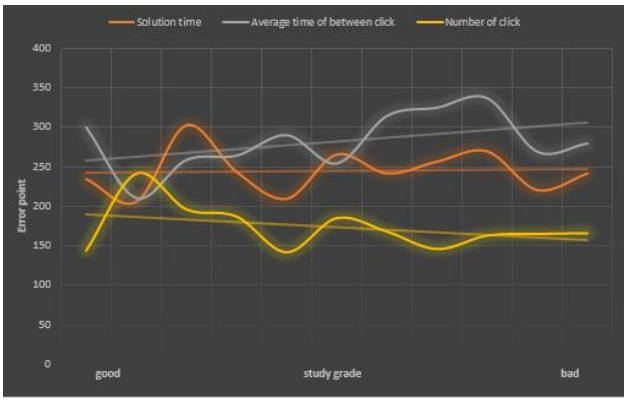

Figure 2. Correlation between three light-programming parameters and academic performance (class 11.)

It is interesting that while time between clicks is shorter in cases of good students, similarly to the 13th graders' results, the other two parameters are different. Time of solution is mostly the same with everybody. The clicks used for the solution, however, show an opposite tendency, and better students clicked more. It seems that they have rather solved the exercises in a hurry, with more mistakes. They are younger, with less programming experience, contrary to the ones in higher grades, who show calmer problem-solving.

XI. CONCLUSION

Our goal was to implement the light-programming testing system, as well as to test the system and its usability, and collecting preliminary measurement results. So far, collecting and evaluating a great number of samples was not our goal, and neither was the comparison of our testing systems.

We have stated that effective programming is in correlation with early algorithm creating ability. Several authors and psychological studies establish the significance of gained and inherited abilities in the process of becoming a successful programmer.

According to the current state of our research we have managed to create a testing system that measures the algorithm creating ability, with the help of our previously elaborated light-programming. The tester has been implemented on three different platforms: micro-controller based physical I/O units, Android-based touch-screen, and PC-based mouse input. The three platforms show different results, which will be compared and analysed as a future goal. The three platforms show different results, which we have planned to compare and analyse in the future.

We have performed measuring with two classes of different age, both of whom learn programming. Our results suggest that there is an obvious connection between the parameters registered by our tester and the academic performance in the programming field. Our preliminary results are promising a lot of valuable future results.

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Simulation of a Pick-and-Place Cube Robot by Means of the Simulation Software Kuka Sim Pro

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Abstract — **In this paper the creation of the program code for industrial robot and the simulation of a robot cell by means of the simulation software KUKA Sim Pro in version 2.2.2, is presented. Simulated and programmed is, in reality existing KUKA-robot cell with industrial robot of the type KR6 R900 sixx (Agilus) with signal connected conveyor belt. The software KUKA Sim Pro is a application for design of 3D-layouts of a plant components and production lines including KUKA-robots. On this occasion, any layouts and concept designs can be simulated and be analyzed. The used components were taken from the integrated library or were partly newly created. The industrial robot KUKA KR6 R900 sixx counts to the quickest robots of the world. In this work, the simulation of the robot cell and periphery is elaborated, as well as with it, connected practical circumstances and issues with the programming of the abovementioned robot. The topic is also presented from the didactical and educational point of view.**

Keywords – Industrial Robot, Simulation, KUKA Sim Pro, Pick-and-Place, Cube, Education

I. INTRODUCTION

Comparing the simulation systems for robots of today with those of the 90s, it can be argued, that compared to the 90s, there are nowadays a lot of useful simulation systems which can be effortlessly used in the industrial practice and education. The rising offer of such simulation systems hangs immediately together up with the development of the IT technology and the computer engineering. As stated in [1], the middle and the end of the 90's have been marked by the use of the Java based systems. The main improvement of the robot simulation systems, has been caused by the development of the suitable simulation robot libraries, also of the libraries for older industrial robot models [2] which have been already mathematically well modelled in the 60's. There are many reasons nowadays why to use simulation systems in industrial practice. As stated by [3] by using of simulations wrong decisions can be avoided already in planning stadium and therefore they are sound decisive factor in the planning process. Furthermore they can save the costs because in the regularly case, the simulation costs are much lower as investment costs or the target cost of the real process. Behind it, simulation leads to a more quick solution than analytic procedures, detailed representation of the existing system can lead to new cognitions and often the simulation technology is generally the only analytical possibility to scrutinize the project, because a real realization of the model would not be possible in practice. All those are factors, which support the idea of the necessity of simulation systems' usage in the industry but also in the educational practices at school and/or universities. However, the successful use of such systems requires profound knowledge, not only about the simulation software itself, but also about the margin disciplines and branches of learning, which concern the real simulation problem. Especially the "3D fabric simulation is complex and its implementation requires knowledge in different fields" [4, p. 634]. In the following section, it will be, with the help of a practical problem formulation explained, how industrial robot simulation software can be used in the practical case.

II. SYSTEM COMPONENTS AND SIMULATION ENVIRONMENT

The choice of the suitable simulation software is one of the important decisions in the simulation practice. Different criteria influence this choice. Besides, is to be noted that there are, as a rule, slight decisive differences if the software is seated for industrial purposes or if it used for education purposes. The essential decisive factors for the simulation choice in the educational application are explained in [1]. Accordingly, especially hardware demands and the licensing conditions have to be taking into consideration [1, p. 1013]. Out of the different robot industrial simulation systems available on the market, as e.g. RoboGuide by FANUC or Robot Studio by ABB, the KUKA SIM Pro software has been used in the realization of the project described in this paper. The main reason for it, are the hardware demands, because simulation is applied to the existing industrial robot KUKA KR6 R900 sixx, which is also available in the library of the named simulation platform.

A. KUKA.Sim Pro

KUKA.Sim Pro is a special program for the creation of 3D-layouts of arrangements with KUKA industrial robots. Any layouts and draughts can be simulated and be examined with it. Therefore, the software system is appropriate for engineering or system integrators. The program library is extended compared with the older software versions and it disposes numerous smart components and geometries with own parametric behavior, as e.g. conveyor belts or light barriers. The software offers, also wide-ranging API and

COM functionalities which allow the integration of the own plug-ins. An integration of the Python scripts is also possible. Optionally are available possibilities for imports of different CAD formats as Siemens NX, CATIA V5, STEP or Pro Engineer [5]. By using of the virtual machine, the KUKA SIM Pro software can be directly coupled with the real time programming software of KUKA, so called Office Lite application, so that simulated program application can be transferred to the real industrial robot system and can be tested under the real environmental conditions [6].

B. KR AGILUS R900 sixx

The KR AGILUS R900 sixx robot reaches maximum repeat accuracy and continuous precision thanks to his robust construction. It is known as one of the quickest robots of the world, what became successfully presented in numerous advertising campaigns of the KUKA Company [7]. At extreme speed the robot reduces the cycle times and on that way increases the manufacturing quality without getting out of the tact. The robot disposes with the highest precision characteristics on the smallest space thanks to his integrated energy supply and proven KR C4 compact control unit. Therefore this systems has been used in the following practical application, described in the next section. The main characteristics of the robot are summarized in the following table:

TABLE I. MAIN CHARACTERISTICS OF KR AGILUS R900 SIXX

CHARACTERISTIC	VALUE
Nominal load / Maximal load	3 kg /6 Kg
Interfaces	USB, EtherNet, DVI-I
BUS connections	PROFINET, EtherNet/IP, PROFIBUS, DeviceNet, EtherCAT
Position repeat accuracy	+/- 0,03mm
Axis	6
Velocity with nominal load	300 °/s

III. REAL ENVIRONMENT AND SIMULATION

The real simulation environment is introduced in following block representation.

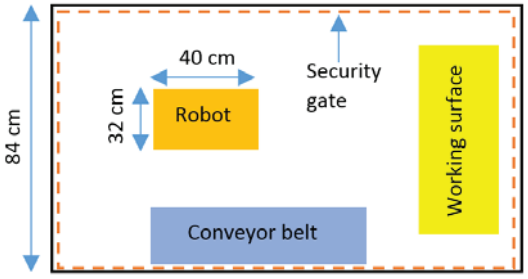

Figure 1. Block represenataion of the real eviroment

The purpose of the project is the creation of a program design in addition to the digital simulation of a really existing robot system in Sim KUKA Pro 2.2.2, using the available KUKA KR6 R900 sixx robot and conveyor belt connected with the robot control unit [8]. Once the robot and conveyor belt program are started, if not already in the basic position, the robot moves first in its basic position. This is presented in the following figure.

Figure 2. Robot system basic position

A conveyor belt, with integrated light barrier, transports an aluminium cube with the dimensions (HxWxD): 100 mm x 100 mm x 100 mm in the defined position. As soon as the conveyor belt is launched, the robot moves in the pre-position for removal of the cube and waits, till the workpiece interrupts the light barrier.

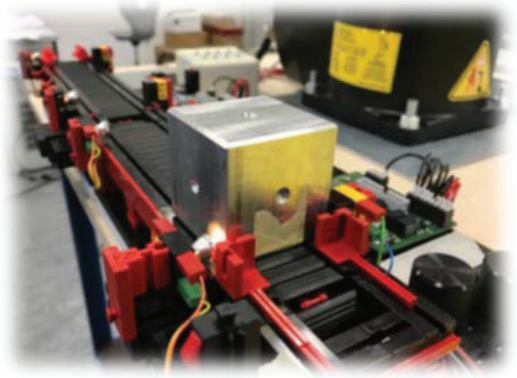

Figure 3. Conveyor belt with aluminum cube

Then, it removes the cube from the defined position and places it, in the working surface in the form of a palletizing task.

Figure 4. Palletizing the cubes

This continuously task is repeated till all 11 cubes are palletized.

A. Control program extract

The extract of the real control program written in KUKA Robot Language used for this task and combined with the PLC control unit is presented in the following:

```
;1. First section

WAIT FOR (IN 7 , WORKPIECE CONVEYOR‘)

IF $IN [7]==TRUE THEN

WAIT Time=1 sec

PTP BAND1 Vel=100% PDAT10 Tool[1]:flange Base[0]
OUT 1 ‘Gripper open’ State=FALSE OUT 4 ‘Gripper
closed’ State=TRUE PTP UBAND1 CONT Vel=100%
PDAT9 Tool[2] Base[0] PTP UP11 CONT Vel=100%
PDAT6 Tool[1]:flange Base[0] PTP P11 Vel=100% PDAT8
Tool[1]:flange Base[0] OUT 4 ‘Gripper closed’
State=FALSE OUT 1 ‘Gripper open’ State=TRUE PTP
UP11 CONT Vel=100% PDAT6 Tool[1]:flange Base[0]
PTP UBAND1 Vel=100% PDAT9 Tool[2] Base[0]

ELSE END IF
```

The program waits on the workpiece at the removal position of the conveyer belt. This is realized with the WAIT FOR (IN 7 ,WORKPIECE CONVEYOR‘) command. After the input signal reaches the logical TRUE condition, the robot waits one second and moves to the gripping position „PTP BAND1“. On the workpiece storage position P11 the grip arm is opened again, the workpiece is stored and the waiting position over the decrease point of the conveyor belt is started up. Now, here the robot waits again for a new workpiece. In the both next other processes the procedure is the same, merely the storage position of the workpiece changes.

B. Simulation components

This task has been simulated. In the first step of the simulation, the components of the cube robot have been defined. These are presented in the following simulation figure [9].

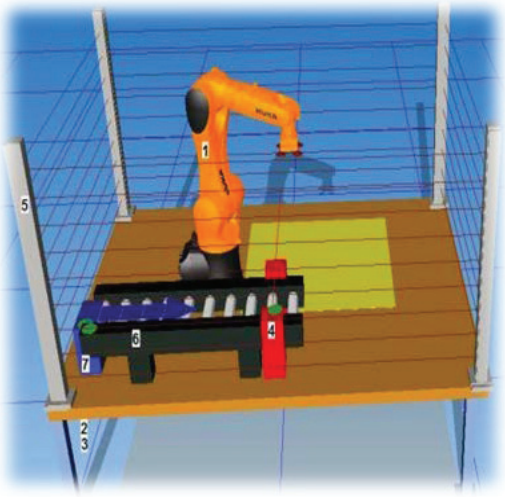

Figure 5. Simulation components draft

The simulation components are numerated and presented in the following table.

TABLE II. SIMULATION COMPONENTS

POSITION	DESCRIPTION
1	Robot KR6 R900sixx
2	Control Unit
3	Peripherie
4	Sensor (H-Sensors)
5	Security Gate
6	Conveyor belt
7	Creator

All listed components are real, excluding the “Creator”, which is software based simulation function for creating the cubes. All components are selected and composed from the program library of KUKA Sim Pro 2.2 Library [cf. 10]

IV. ROBOT PROGRAMMING WITH THE SIMULATION SOFTWARE

In this project the programming has been done with RSL and KUKA.Office-Lite. Taking into account the nominal amount of the publication pages, the following description is limited to the description of the RSL programming. The detailed steps of programming are described in [10]. In order to write the program, at first the robot must be activated. For this purpose, two options are possible, activation by choice of a "sheet" on the robot foot or activation by direct choice of a robot in the tab "Teachen".

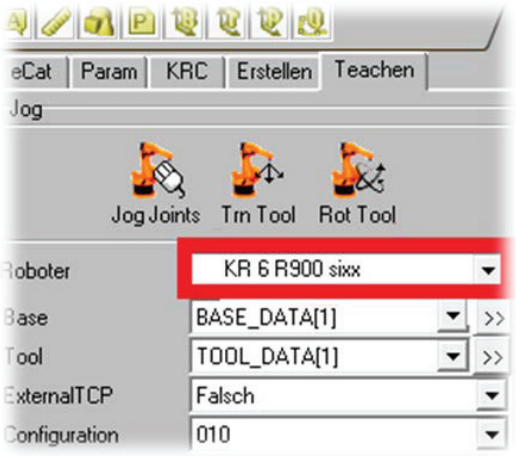

Figure 6. Activation of the robot

A. *Main and subroutines*

If the task is complex, it is recommended that subroutines containing similar characteristics are defined. The main sequence is already introduced by the simulation system. It is used for activation of the subroutines. For the realization of this task in total 13 subroutines have been written. The sequences mentioned are presented in the following figure:

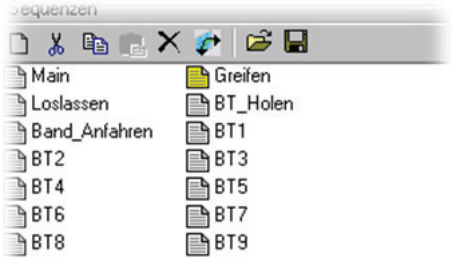

Figure 7. Main and subroutines

The subroutines for gripping and release of the working piece, exist out of one instruction. The output necessary for gripping procedure and for release of the working piece, changes in this instruction the logical condition. This includes the definition of the gripping area, and becomes realized by changing the parameters of the robot. The subroutine BT1, contains the basic geometrical coordinates of the simulation space and is used for definition of the other subroutines in order to realize all gripping and release steps.
After following further adjustments necessary for creation of the simulation program, the final simulation has been realized. In-between, it is extend with visualization of the geometrical trajectories in order to show the differences between the movement types of the robot a for example point-to-point, cyclic or linear movement.

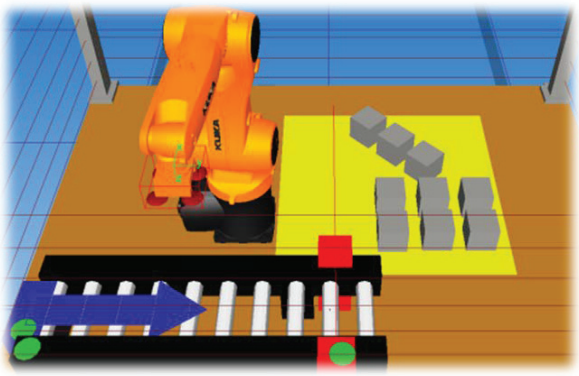

Figure 8. Signal simulation without tracing signals

V. CONCLUSION

This paper presents a practical example of realization of the industrial robot simulation based on the real KUKA robot system. It includes initial explanation how peripheral actuators can be implemented in the process by means of the simulation software. The main effort in the simulation task, is related to the programming of the geometric trajectories and calculations of them. It includes the transformation of the coordinates, by using of different coordination system transformation methods and including them into the program writing task. This part of the work is, by reason of the scale, not presented in this work.

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Projekt GLAT - poticanje algoritamskog razmišljanja korištenjem didaktičkih igara

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***Sažetak* - Projekt „Games for Learning Algorithmic Thinking“ (GLAT) sufinanciran je Erasmus+ programom Strateška partnerstva za područje općeg obrazovanja i traje do listopada 2019. godine. Koordinator projekta je Sveučilište u Rijeci – Odjel za informatiku, a projektni tim čine eksperti iz područja e-učenja i programiranja iz Hrvatske, Slovenije, Estonije, Makedonije i Bugarske. Glavni je cilj projekta poticanje uključivanja elemenata programiranja i algoritamskog razmišljanja u poučavanje različitih predmeta u nižim razredima osnovne škole na zabavan i atraktivan način. Naglasak je na korištenju obrazovnih strategija učenja uz pomoć igara koje će kod učenika potaknuti kreativnost, logičko razmišljanje i vještine rješavanja problema.**

U radu se opisuje kontekst i razlozi za pokretanje GLAT projekta, planirani intelektualni rezultati, aktivnosti projekta te njegov očekivani učinak. Najvažnije aktivnosti uključuju stručno usavršavanje učitelja razredne nastave koji će se na radionicama upoznati s inovativnim metodama izvođenja nastave pomoću IKT, a naglasak će biti na korištenju didaktičkih igara. Planirani intelektualni rezultati uključuju silabus radionica i materijale za učenje te scenarije poučavanja koje će učitelji provoditi u nastavi sa svojim učenicima. Silabus s materijalima za učenje i najboljim primjerima scenarija bit će objavljen na hrvatskom i engleskom jeziku, pa će ga uz hrvatske nastavnike moći koristiti i nastavnici diljem Europe.

Ključne riječi – projekt GLAT; algoritamsko razmišljanje; programiranje; didaktičke igre; scenarij poučavanja

I. UVOD

Informacijsko-komunikacijske tehnologije (IKT) predstavljaju jedno od područja koje se danas najbrže razvija i koje predstavlja glavni pokretač razvoja gospodarstva i društva [1]. Unatoč tome ishodi učenja vezani ne samo uz IKT teme nego i razvoj općih digitalnih kompetencija su i dalje nedovoljno zastupljeni kao dio školskog kurikuluma. To je slučaj u osnovnim školama u Hrvatskoj ali i u drugim zemljama Europske unije [2]. Prema [3], među pet osnovnih područja digitalnih kompetencija pripada i kreiranje digitalnih sadržaja koje uključuje i kompetenciju *programiranje* opisanu kao sposobnost planiranja i razvoja niza naredbi razumljivih računalu za rješavanje zadanog problema ili izvođenje određene zadaće. Ovo je područje posebno zanemareno u obrazovanju. U europskim školama se ne pruža dovoljno mogućnosti učenicima za istraživanje programiranja niti se učenici uče algoritamskom načinu razmišljanja i vještinama kodiranja [2]. Ishodi učenja koji se odnose na programiranje trebali bi biti zastupljeni ne samo u informatičkim predmetima već posredno uključeni i u svakodnevno učenje različitih predmeta od najranijeg uzrasta učenika.

Jedan od projekata s temom iz spomenutog područja je GLAT - *Games for Learning Algorithmic Thinking* sufinanciran Erasmus+ programom u okviru Ključne aktivnosti 2, Strateška partnerstva za područje općeg obrazovanja. Glavni je cilj projekta poticanje uključivanja elemenata programiranja i algoritamskog razmišljanja u poučavanje različitih predmeta u nižim razredima osnovne škole na zabavan i atraktivan način.

Projektom će se nastojati potaknuti integraciju elemenata učenja programiranja u svakodnevno učenje kod učenika mlađeg uzrasta (od prvog do četvrtog razreda osnovne škole) kroz stručno usavršavanje učitelja razredne nastave za stjecanje digitalnih vještina, ali i suvremenih znanja i vještina usmjerenih k inovativnom poučavanju u području IKT. Tako će se učitelji upoznati s inovativnim metodologijama poučavanja koje koriste IKT poput problemskog učenja, učenja propitivanjem, učenja uz pomoć igara (eng. *Game Based Learning* - GBL). Posebna pažnja će se posvetiti učenju uz pomoć didaktičkih igara (eng. *serious games*) odnosno konkretnoj primjeni GBL i igrifikacije (eng. *gamification*) za učenje digitalnih vještina općenito te posebice vještina programiranja. Nastavnici će novousvojena znanja i vještine primjenjivati u svojoj nastavnoj praksi u školama te se kao krajnji cilj očekuje poboljšanje stavova učenika prema programiranju i razvoj algoritamskog načina razmišljanja kod učenika mlađe dobi što će dugoročno doprinijeti povećanju i njihova interesa za odabir budućih zanimanja iz STEM i IKT područja.

Projektni tim okuplja europske stručnjake na području metodike nastave informatike i e-učenja koji će raditi na osmišljavanju edukacije izravno usmjerene na grupu hrvatskih učitelja no koju će biti moguće primijeniti na učitelje širom Europe. Koordinator projekta je Sveučilište u Rijeci – Odjel za informatiku, a partneri su: Učiteljski fakultet Sveučilišta u Rijeci, Sveučilište u Tallinnu (Estonija), Pedagoški fakultet Sveučilišta u Ljubljani

(Slovenija), Sveučilište Sv. Ćiril i Metod u Skopju (Makedonija) i Jugozapadno sveučilište "Neofit Rilski" u Blagoevgradu (Bugarska).

Projekt je započeo u listopadu 2017. godine i trajat će dvije godine, a najvažnije aktivnosti uključuju stručno usavršavanje nastavnika putem tri radionice na kojima će biti upoznati s različitim inovativnim metodama izvođenja nastave uz uporabu informacijsko-komunikacijske tehnologije (IKT). Naglasak će biti na korištenju obrazovnih strategija učenja uz pomoć igara te poticanju kreativnosti, logičkog razmišljanja i vještine rješavanja problema.

Glavni rezultat projekta predstavljat će zaokružena cjelina silabusa radionica i materijala za polaznike na hrvatskom i engleskom jeziku, upotpunjena primjerima dobre prakse nastavnika i objedinjena pomoću online platforme za e-učenje koja će ujedno omogućiti nastavnicima razmjenu iskustava i ideja o primjeni inovativnih metodologija poučavanja u njihovoj nastavi. Silabus će se i ubuduće moći koristiti za organizaciju programa stručnog usavršavanja nastavnika, tečaja ili sličnog oblika edukacije u Hrvatskoj, zemljama partnerima i šire.

II. KONTEKST I VAŽNOST ISTRAŽIVANJA

Unatoč prepoznatoj važnosti STEM (akronim sastavljen od eng. riječi *science, technology, engineering i mathematics* - znanost, tehnologija, inženjerstvo i matematika) i IKT područja, ne samo u Hrvatskoj nego i u velikom broju ostalih europskih zemalja, ishodi učenja vezani uz IKT kao i uz razvoj općih digitalnih kompetencija nisu dovoljno zastupljeni u obrazovnim kurikulima posebice osnovnih škola [2]. Na osnovu provedenih istraživanja [4], [5] je poznato kako se u Hrvatskoj škole u prosjeku svrstavaju u kategoriju „digitalnih početnica“ u kojima nastavnici nedovoljno koriste IKT za unaprjeđenje poučavanja.

Za sada je u Hrvatskoj Informatika još uvijek samo izborni predmet u osnovnoj školi od 5. do 8. razreda. Prema saznanjima predlagača projekta, ona često ne uključuje u dovoljnoj mjeri učenje programiranja jer ga učenici smatraju preteškim i nezanimljivim. Također je razvijanje algoritamskog načina razmišljanja kod učenika od prvog do četvrtog razreda osnovne škole zanemareno i nedovoljno prisutno. Promjene su najavljene u sklopu kurikularne reforme koja je započela 2015. Tako se u Prijedlogu kurikuluma za OŠ kao jedna od domena tehničkoga i informatičkog područja kurikuluma navodi rješavanje problema i programiranje [6].

Isto tako, u Hrvatskoj je nedovoljna pažnja posvećena i razvoju kompetencija za primjenu digitalne tehnologije kod formalnog obrazovanja kod budućih učitelja i nastavnika. Odgovarajućih predmeta na studijima koji školuju buduće učitelje razredne nastave nema dovoljno, a posebice ne onih koje bi uvele modele poput GBL i uvođenja elemenata kreiranja sadržaja i kodiranja u nastavu. Ukoliko takvi predmeti i postoje, oni pokrivaju samo dio kompetencija i većinom su izborni. Primjerice, na Učiteljskom fakultetu Sveučilišta u Rijeci jedan od izbornih predmeta na Učiteljskom studiju je „Izvannastavne informatičke i tehničke aktivnosti“. Slična je situacija i s većinom studijskih programa za učitelje diljem Europe. Za početak bi trebalo omogućiti da se zainteresirani učitelji dalje usavršavaju u ovom području putem programa cjeloživotnog učenja no u budućnosti bi se odgovarajući predmeti trebali ugraditi u studijske programe.

U projektu GLAT inovativno je to što će se njegovi rezultati moći iskoristiti za informalno, neformalno i formalno učenje. Projekt tako nije usmjeren samo na samostalno učenje već i neformalno učenje odnosno stručno usavršavanje nastavnika razredne nastave s ciljem njihova osposobljavanja za uvođenje koncepata kodiranja i algoritamskog načina razmišljanja za učenika mlađih razreda osnovne škole. Smatramo kako ovi nastavnici nemaju dodatna predznanja da bi ove elemente samostalno uvodili.

Razvijeni silabus programa s materijalima za učenje i primjerima dobre prakse moći će se koristiti i za samostalno učenje jer će biti dostupan online za sve nastavnike zainteresirane za takav oblik učenja. Isto tako, moći će ga preuzeti i prilagoditi sve institucije (u Hrvatskoj, zemljama partnerima i šire u Europi) koje žele razviti programe cjeloživotnog neformalnog učenja po mješovitom modelu e-učenja. Smatramo da je dio ovakvih programa koji se izvodi u klasičnom obliku nastave (eng. *face-to-face*, f2f) posebice značajan kako bi se povećala motivacija polaznika i omogućila razmjena dobre prakse s predavačima i ostalim kolegama. Također će se moduli programa moći koristiti kako bi se dizajnirali predmeti i uključili kao izborni ili obavezni u formalno obrazovanje nastavnika, odnosno studijske programe institucija koje obrazuju buduće učitelje.

III. INTELEKTUALNI REZULTATI I AKTIVNOSTI PROJEKTA GLAT

Projektni tim okupljen je na način koji će osigurati uspješnu suradnju i zajednički rad eksperata na ostvarivanju rezultata projekta. Planirana su tri intelektualna rezultata: O1 – silabus i materijali radionica, O2 – scenariji poučavanja i O3 – završna verzija silabusa i materijala za učenje.

A. O1 - Silabus i materijali za radionice

U okviru O1 partneri će razvijati silabus i materijale za učenje za tri dvodnevne radionice za fokus grupu učitelja u ukupnom trajanju od 48 sati za dio koji će se izvoditi f2f. Definirat će se ishodi učenja koji će se odnositi na inovativno poučavanje u području IKT, a posebna pažnja će se posvetiti učenju uz pomoć digitalnih didaktičkih igara.

Osim popisa nastavnih tema, silabus će sadržavati ciljeve tečaja i razrađene ishode učenja te nastavne strategije odnosno odabrane pedagoške metode i aktivnosti koje će se realizirati s polaznicima radionica (uključujući individualne i suradničke strategije). Planirat će se i zadaci za polaznike s posebnim naglaskom na izradu scenarija poučavanja odnosno pripreme za nastavu u digitalnom obliku koje će polaznici započeti pripremati na radionicama, a nastaviti kao individualni rad. Partneri će pripremiti nastavne teme u obliku prezentacija za f2f dio radionica te popratni materijal koji se sastoji od

tekstova, primjera i odabranih IKT alata (npr. alati za izradu igara, gotove igre iz programiranja, alati weba 2.0 i sl.). Svi materijali će biti objavljeni kao e-tečaj u web sustavu za upravljanje učenjem (LMS) Moodle.

B. O2 - Scenariji poučavanja

Scenariji poučavanja su dokumenti u kojima će nastavnik prikazati kako provesti nastavne aktivnosti na inovativan način, suvremenim pedagoškim metodama uz primjenu odgovarajućih digitalnih sadržaja i alata. Najvažniji elementi navedeni u scenarijima su opis aktivnosti i ishoda učenja koji se aktivnostima ostvaruju te metode i digitalni alati korišteni za njihovu realizaciju. Scenariji poučavanja mogu se primijeniti u nastavi svakog predmeta kao cijeli nastavni sat ili njegov dio [7]. Osmišljavanje scenarija poučavanja olakšavaju alati koji omogućuju grafički prikaz elemenata scenarija. Jedan od takvih grafičkih alata je Le Planner [8] koji je razvijen na Sveučilištu u Tallinu za projekt Creative Classroom [9].

Prilikom izrade scenarija u projektu GLAT osnovni cilj će biti potaknuti algoritamski način razmišljanja kod učenika kao priprema za kasnije učenje programiranja. Pri tome će se učenik staviti u središte nastavnoga procesa i potaknut će se ga na istraživanje, razmišljanje, samostalno zaključivanje i djelovanje. Scenariji će biti osmišljeni tako da se sadržaji vezani uz kodiranje približe učenicima na pristupačan način, povezivanjem sa situacijama iz svakodnevnog života i integriranjem u sadržaje različitih nastavnih predmeta. Kao prevladavajuća strategija poučavanja koristiti će se GBL, ali i elementi problemskog učenja i učenja propitivanjem. Vodit će se računa o tome da je opremljenost škola IKT opremom različita. Iako će naglasak biti na korištenju digitalnih alata, pažnja će se posvetiti i onim scenarijima koji neće koristiti IKT te će se razviti primjeri igri i drugih aktivnosti koje se odvijaju u razredu bez uporabe računala (tzv. *unplugged activities* [10]).

Nastavnici okupljeni u fokus grupu sudjelovat će na f2f radionicama te će na kraju svake od njih započeti s osmišljavanjem svojih scenarija učenja koji će uključivati načine na koji bi elemente kodiranja uključili u učenje različitih predmeta. Moći će samostalno odabrati nastavni predmet, nastavnu cjelinu unutar predmeta te metodologiju i aktivnosti za učenike. Tijekom radionice eksperti će ih voditi i pomoći im u definiranju i skiciranju početnih ideja putem alata Le Planner, a nakon radionica nastavit će samostalni rad uz online mentoriranje eksperata te razmjenu ideja i savjeta s ostalim kolegama putem komunikacijskih kanala dostupnih u LMS-u e-tečaja. Konačne dorađene verzije scenarija poučavanja nastavnici će implementirati u razredu sa svojim učenicima.

C. O3 – završna verzija silabusa i materijala za učenje.

Posljednji rezultat projekta je vezan uz evaluaciju rezultata održanih radionica i scenarija poučavanja kako bi se načinila zaokružena cjelina koja se sastoji od unaprijeđenog silabusa radionica s materijalima za učenje upotpunjenim primjerima dobre prakse nastavnika (od svih načinjenih scenarija poučavanja odabrati će se oni najbolji i prevesti na engleski jezik).

Prilikom izrade unaprijeđenog silabusa koristit će se iskustva eksperata stečena tijekom radionica s fokus grupom i prilikom pregledavanja scenarija poučavanja kao i mišljenja nastavnika i učenika prikupljena putem anketiranja i intervjuiranja. Naime, iako će se evaluacija radionica odvijati neposredno na kraju svake f2f radionice, izvršit će se i sveobuhvatno istraživanje po završetku svih radionica. Psiholozi u timu Učiteljskog fakulteta će pripremiti upitnike i intervjue kojima će se provjeriti ne samo zadovoljstvo nastavnika provedenom edukacijom već i prikupiti sugestije za poboljšanje. Upitnik će se pripremiti i za učenike s kojima su učitelji proveli svoje scenarije poučavanja.

Silabus s popratnim materijalima će biti pripremljen na hrvatskom i engleskom jeziku i dostupan putem online platforme za e-učenje ne samo nastavnicima koji su sudjelovali u fokus grupi i njihovim kolegama u školama, već i široj javnosti u zemljama partnera, ali i ostalim Europskim zemljama.

D. Radionice

Najvažnije aktivnosti projekta uključuju stručno usavršavanje nastavnika koji će se upoznati s različitim inovativnim metodama izvođenja nastave uz uporabu informacijsko-komunikacijske tehnologije, a naglasak će biti na korištenju didaktičkih igara te poticanju kreativnosti, logičkog razmišljanja i vještine rješavanja problema.

Tijekom projekta će nastavnici okupljeni u fokus grupu sudjelovati na edukaciji oblikovanoj prema mješovitom modelu e-učenja. Ključni dio će predstavljati tri dvodnevne radionice (tri modula) koje će se održati u Hrvatskoj na Odjelu za informatiku Sveučilišta u Rijeci dok će se online dio edukacije odvijati putem sustava za e-učenje Moodle. Fokus grupu će činiti dvadesetak nastavnika razredne nastave iz Hrvatske koji će biti odabrani u suradnji Agencije za odgoj i obrazovanje (AZOO) i Učiteljskog fakulteta. Sudjelovanje na radionicama predstavljat će oblik stručnog usavršavanja nastavnika koje se standardno provodi u organizaciji AZOO. Za termine radionica odabrani su travanj 2018. godine, zadnji tjedan u kolovozu 2018. i siječanj 2019. kao periodi školskih praznika za učenike koji su uobičajeni za stručna usavršavanja nastavnika.

Eksperti iz partnerskih organizacija će učitelje voditi kroz program silabusa uvodeći ih prvo u područje putem teorijskih tema, a zatim nastavljajući prikazom primjera i odgovarajućih alata. Kao što je već spomenuto, u drugom dijelu svake radionice, učitelji će na osnovu stečenih znanja i vještina, te uz pomoć eksperata, započeti s osmišljavanjem scenarija učenja koji će obuhvaćati obrađene metodologije učenja i digitalne resurse. Teme tri modula su: *Učenje uz pomoć igara u razrednoj nastavi*, *Problemsko učenje, logičke igre i zagonetke*, *Igre i alati za učenje programiranja*.

E. Ostale aktivnosti

Tijekom projekta kontinuirano će se provoditi niz aktivnosti za diseminaciju i popularizaciju rezultata u zemljama svih partnera.

Na različitim događanjima poput konferencija, radionica, seminara s temom uporabe IKT u obrazovanju u zemljama partnerima i ostalim europskim zemljama eksperti koji sudjeluju u projektu će prezentirati rezultate kolegama - stručnjacima iz ovog područja, te posebice učiteljima u osnovnim školama. U Hrvatskoj će vrlo važan kanal diseminacije biti nastavnici u fokus grupi koji će u svojim školama diseminirati razvijene scenarije poučavanja te stručnjaci iz regionalnog ureda AZOO u Rijeci.

Kao završno događanje pri kraju projekta će se organizirati video konferencija na kojoj će se rezultati prezentirati nastavnicima, stručnjacima iz ovog područja, ali i široj zainteresiranoj javnosti.

S ciljem informiranja o projektu i njegovim rezultatima dizajnirano je web sjedište (Slika 1) [11]. Dodatno, materijali za učenje sa scenarijima poučavanja biti će dostupni na platformi za e-učenje (LMS). Odabran je sustav za e-učenje MoD Centra za e-učenje Sveučilišnog računskog centra (SRCE) koji se temelji na platformi Moodle te je kreiran e-kolegij „Games for Learning Algorithmic Thinking“ [12]. I web sjedište i e-kolegij ostat će dostupni online i otvoreni za daljnje korištenje i nakon završetka projekta.

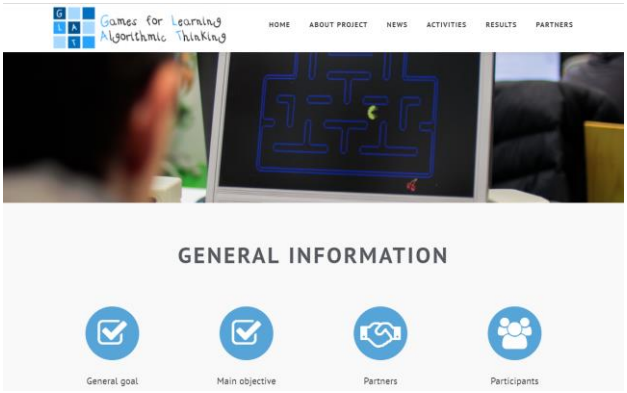
IV. OČEKIVANI UČINAK PROJEKTA

Očekuje se da će projekt GLAT imati utjecaj ne samo na neposredne sudionike, veći i znatno šire. Neposredni sudionici - nastavnici razredne nastave okupljani u fokus grupu steći će značajno iskustvo sudjelovanjem na radionicama i razvojem scenarija učenja. U tome će im pomoći europski eksperti iz područja e-učenja i programiranja koji će s njima podijeliti svoja stručna znanja i primjere iz prakse.

Projekt je usmjeren i prema svim ostalim nastavnicima jer će rezultati projekta biti prezentirani u svim zemljama partnera, a razvijeni materijali za učenje s primjerima dobre prakse će biti dostupni nastavnicima za poboljšanje svojih kompetencija odnosno stjecanje suvremenih znanja i vještina usmjerenih k inovativnom poučavanju u području IKT i kodiranja.

Osim za samostalno, informalno učenje rezultati projekta će se koristiti i za neformalno obrazovanje. Nakon završetka projekta se na Sveučilištu u Rijeci, u organizaciji Učiteljskog fakulteta i u suradnji s Odjelom za informatiku, planira pokrenuti akreditirani program cjeloživotnog učenja namijenjen učiteljima razredne nastave koji će omogućiti jačanje profila zanimanja nastavnik odnosno poboljšati kompetencije nastavnika. U konačnici, rezultati projekta će poslužiti i za formalno obrazovanje odnosno upotpunjavanje planova i programa studija Učiteljskog fakulteta te nastavničkog smjera studija Informatike obaveznim i/ili izbornim predmetima čime će se ostvariti i utjecaj na studente – buduće učitelje.

Rezultati projekta moći će se odmah koristiti za informalno učenje u zemljama partnerima i šire jer će biti prevedeni na engleski jezik, a u budućnosti će se na sličan način kao i u Hrvatskoj moći organizirati i akreditirati i odgovarajući oblici neformalnog i/ili formalnog obrazovanja.



Slika 1. Web sjedište glat.uniri.hr

Utjecaj projekta na učenike će se neposredno odraziti u školama iz kojih su nastavnici koji čine fokus grupu i koji će implementirati nove scenarije poučavanja u svojim razredima. Pritom će se učenici putem GBL i drugih suvremenih pedagoških pristupa dobiti priliku istraživati kodiranje i razvijati algoritamsko razmišljanje već od najranije uzrasta.

Budućim širenjem utjecaja rezultata projekta na veće skupine nastavnika i učenika očekuje se i općenito poboljšanje stava učenika prema programiranju što će rezultirati većim brojem učenika koji će izabrati svoje buduće karijere u IKT i STEM područjima. Na taj će način u konačnici neposrednu korist imati svi uključeni partneri, kao i ostale visokoškolske institucije koje izvode studijske programe iz informatike i računarstva jer će ih upisivati veći broj kvalitetnijih studenata.

V. ZAKLJUČAK

Projektom GLAT se učenicima i nastavnicima pruža potpora za usvajanje digitalnih kompetencija, posebice onih koji se odnose na područje kreiranja digitalnog sadržaja. Među nastavnicima osnovnih škola se provodi osposobljavanje kojim se promoviraju inovativne metode i pedagoški pristupi za uvođenje elemenata kodiranja i algoritamskog razmišljanja u nastavu, daje se podrška za efikasno korištenje IKT u obrazovanju te se razvijaju materijali za učenje s primjerima dobre prakse i provode aktivnosti za diseminaciju i popularizaciju rezultata. Nastavnici će stečene vještine i kompetencije promovirati svojim učenicima tako što će ih koristiti u svom nastavnom radu u školi što će rezultirati razvojem i njihovih digitalnih kompetencija. Kod učenika nižih razreda osnovne škole će se poticati kreativnost, algoritamsko razmišljanje i vještine rješavanja problema na zabavan i atraktivan način pomoću didaktičkih igara.

U tijeku su aktivnosti pripreme silabusa i izrade materijala za prvu radionicu, a započele su i aktivnosti diseminacije. Projektni tim vjeruje da će rezultatima ovoga projekta pridonijeti području obrazovanja potpomognutog IKT tehnologijama u Hrvatskoj, u zemljama partnerima, ali i šire. Kao krajnji cilj projekta očekuje se poboljšanje stavova učenika prema programiranju te razvoj algoritamskog načina razmišljanja kod učenika mlađe dobi što će dugoročno doprinijeti smanjivanju „straha“ od programiranja te povećati njihov

interes za odabir budućih zanimanja iz IKT i STEM područja.

ZAHVALE

Sufinancirano sredstvima programa Europske unije Erasmus+ Ključna aktivnosti 2, Strateška partnerstva za područje općeg obrazovanja, projekt „Games for Learning Algorithmic Thinking“ (2017-1-HR01-KA201-035362).

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Razvoj učinkovitih predmetno specifičnih ishoda učenja kod poučavanja osnova programiranja

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Sažetak - Ishodi učenja pišu se kao kratke formulacije namijenjene opisu znanja, vještina, kompetencija, stavova i ponašanja, odnosno navika za koje se očekuje da će uspješan učenik demonstrirati završetkom određenog iskustva učenja. Orijentirani trebaju biti na dugoročno značajno i trajno učenje. Tijekom svog školovanja za zanimanje Tehničar za računalstvo, učenici trebaju steći kompetencije za obavljanje budućih poslova i radnih zadataka struke, te kroz sastavne predmeta kurikuluma trebaju pokazati u kojoj su mjeri savladali za te predmete konkretne i specifične ishode (CLO – Course Learning Outcomes). Stoga je važno da predmetni nastavnici umiju oblikovati i napisati učinkovite i svrsishodne ishode učenja. Jasni i pomno razvijeni ishodi učenja imaju izravan pozitivan utjecaj na učenike i njihovo učinkovitije učenje, omogućuju zajednička očekivanja za učenike i nastavnike, a sami nastavnici jasnije odlučuju o smjerovima i opsegu sadržaja po predmetima tijekom školovanja. Pri pisanju učinkovitih ishoda učenja vrijedna su pomoć tri okvira učenja (Bloomova taksonomija, ICE model – Ideas, Connections and Extensions te SOLO – Structure of Observed Learning Outcomes taksonomija). U radu su navedene mogućnosti razvoja učinkovitih ishoda učenja u području vrlo bitnom za razvoj specifičnih stručnih kompetencija (predmet Algoritmi i programiranje). Naglasak je na prepoznavanju i jasnom postavljanju upravljivih ishoda učenja, dovoljno sažetih, dosegljivih, ali i značajnih na duže vrijeme.

I. UVOD

Ishodi učenja su kratke formulacije koje opisuju znanja, vještine, kompetencije, stavove i ponašanja (navike) za koje se očekuje da će ih uspješan učenik demonstrirati završetkom nekog iskustva učenja (u cjelokupnom programu (kurikulumu) ili nastavnom predmetu u okviru programa). Oblikovani trebaju biti tako da opisuju neko dugoročno značajno i trajno učenje.

Od 2013. godine strukovne škole imaju mogućnost provedbe strukovnih kurikuluma programiranih u skladu s metodologijom u kojoj svaki program (strukovni kurikulum) obično ima niz apstraktnih ishoda (Program Learning Outcomes - PLO) opisanih detaljnijim ishodima učenja za svaki od niza nastavnih predmeta koji ga čine. Nadalje, svaki nastavni predmet ima vlastite, konkretnije specifične ishode učenja (Course Learning Outcomes - CLO).

Dobro osmišljeni, učinkoviti i svrhoviti ishodi učenja imaju izravan pozitivan utjecaj na učenike i njihovo učenje. U takvim okolnostima učenici i nastavnici imaju zajednička očekivanja od nastavnog programa i/ili predmeta, učenje i poučavanje su djelotvorniji, a nastavnici jasnije odlučuju o usmjeravanju i obuhvatu po nastavnim predmetima.

II. PREDNOSTI KORIŠTENJA ISHODA UČENJA

Neke iz niza prednosti pisanja i oblikovanja predmetno spefičnih ishoda učenja (CLO) su [1]:

- nastavnicima pomažu da učenicima konkretnije predoče što se od njih u nastavnom predmetu očekuje,
- učenicima pomažu da uče učinkovitije jer su svjesniji svog mjesta u kurikulumu,
- pojašnjavaju očekivanja učenicima koja oni mogu imati polaženjem određenog programa, odnosno nastavnog predmeta,
- pomažu nastavnicima da ih koriste kao predložak za učinkovitije oblikovanje svojih nastavnih materijala,
- pomažu nastavnicima u odabiru odgovarajućih strategija poučavanja (nastava, seminar, samoučenje, laboratorijske vježbe) ovisno o namjeravanom ishodu učenja,
- pomažu u stvaranju i oblikovanju ispita,
- osiguravaju primjenu odgovarajućih strategija ocjenjivanja.

Na programskoj i na institucionalnoj razini ishodi učenja povećavaju transparentnost, kreditnu prohodnost i usporedivost standarda osiguravanja kvalitete. Ishodi učenja pojednostavljuju prijenos kreditnih bodova omogućavajući mobilnost učenika kroz identificiranje i stvaranje različitih putova napretka kroz i između različitih obrazovnih putova (i sustava), posebno u kontekstu cjeloživotnog učenja [2].

III. PISANJE UČINKOVITIH ISHODA UČENJA

Ishodi učenja trebali bi biti napisani kao jednostavne tvrdnje namijenjene opisivanju učenja koje je esencijalno i trajno, učenja koje je dugoročno važno i koje učenicima ostaje i nakon što su zaboravili mnoge detalje nastave u okviru određenog programa. Pri tom je, dakle, naglašena usmjerenost na učenje i očekivane sposobnosti učenika nakon što s uspjehom apsolviraju nastavu.

Zato se, u osnovi, ishod učenja sastoji od izravne tvrdnje koja često započinje sa.. “uspješni učenici moći će.. “ čemu se dodaje neki aktivni glagol koji označava planiranu razinu učenja imajući u vidu kontekst u kojem će učenik biti u stanju demonstrirati rezultat koji dokazuje učenjem ostvarenu promjenu.

Iako se većinom ishode učenja povezuje sa završetkom programa ili nastave, dobro je provjeravati postignuća vezana uz ishode učenja i tijekom iskustva učenja, a ne samo na kraju aktivnosti. Time postaje jasnije u kojoj bi točki eventualno trebale biti izvršene kurikularne promjene kako bi na kraju učenje bilo uspješnije.

Prilikom pisanja ishoda učenja pažnju treba obratiti na to da ih ne bude ni premalo, ni previše – da ih bude dovoljno kako bi mogli jasno odražavati sve bitno što će učenik moći (trebati) demonstrirati na kraju programa ili nastave (obično je taj broj između 4 ili 5 i 8 ili 10).

Osim na broj ishoda, kod planiranja pažnju treba obratiti i na njihovu formulaciju. Dobro napisan ishod učenja [12]:

- uključuje različite razine učenja i kognitivne složenosti,
- učenik ga može dosegnuti unutar raspoloživog vremena i na trenutno dostignutoj razini učenja na kojoj se učenik nalazi,
- može biti procijenjen upotrebom nekog prihvatljivog i provedivog oblika ocjenjivanja,
- može biti procijenjen upotrebom različitih strategija učenja,
- može biti priopćen na sustavan način. Ishodi učenja snažniji su kad su poznati, eksplicitno izraženi i razumljivi,
- izbjegava glagole koji su neodređeni, nejasni ili otvoreni za mnogostruke interpretacije (kao što je npr. razumjeti, naučiti…)
- je izbalansiran. Ako je ishod predetaljan, postoji potreba razvijanja niza drugih ishoda putem kojih bi se osiguralo predviđenu širinu učenja. Ako je ishod preopćenit, postaje teško demonstrirati stupanj udovoljavanja, odnosno procjenjivanja adekvatnosti rezultata učenja takvom ishodu.

"Dobro napisani ishodi učenja ostvaruju preslikavanja sadržaja kurikuluma – npr da bi se vidjelo kako reflektiraju postavljene pokazatelje ili mjerila, koje su ključne vještine usvojene, gdje se ista vještina ili sadržaj pojavljuju više od jednom u programu, sposobnosti koje učenici usvajaju svojim napredovanjem kroz razine programa" [13].

IV. Okviri učenja

Prilikom formuliranja ishoda učenja naglašena je važnost odabira odgovarajućih aktivnih glagola, npr. glagole poput identificirati, definirati, oponašati, slijediti ili nabrojati povezuje se sa učenjem temeljenim na pamćenju, dok se glagole poput evaluirati, prosuditi, kritizirati ili kreirati vezuju uz kognitivno složenije, dublje učenje

Obično je kod odabira aktivnog glagola korisno oslanjati se na neki od postojeća tri okvira učenja: Bloomovu (revidiranu) taksonomiju, ICE model (Ideas, Connections and Extensions) ili na SOLO taksonomiju (Structure of Observed Learning Outcomes).

Bloomova taksonomija učenje u svakoj od tri odvojene domene: kognitivnoj, psihomotornoj i afektivnoj opisuje rastuće razine složenosti. Taksonomija je hijerarhijska na način da učenici ne mogu postizati razine višeg reda ako nisu svladali niže razine. Tako npr. da bi učenici znanje primjenili, prvo ga trebaju razumjeti. Ponuđeni skup glagola omogućuje predviđenu artikulaciju ishoda učenja.

ICE okvir opisuje iterativni rast i stupnjeviti napredak učenika prema dubljem razumijevanju pri čemu je učenje integrirano preko domena. U temelju su ideje, diskretni dijelići informacije ili koraci u procesu koji čini učenje. Povezivanjem ideja učenici stvaraju relacije od prijašnjeg znanja i iskustva ka novim naučenim konceptima. Proširenja obuhvaćaju stvaranje novog učenja i primjenu znanja na potpuno nove situacije u kojima učenici prepoznaju posljedice njihovog učenja. Pri tome učenje ima nelinearnu i nehijerarhijsku prirodu.

SOLO taksonomija strukturira učenje u pet razina od kvantitativnog rasta u učenju (dohvaćanjem novih količina informacija) do kvalitativnog rasta (stvaranjem značenja i prijenosom ideja prema novim situacijama i iskustvima). Prestrukturalna razina odnosi se na fazu prije početka ciklusa učenja. Prilikom ulaska u ciklus učenja učenici prelaze od dodavanja jednostavnih ideja i koncepata prema skiciranju složenih veza i razlikovanja među idejama, te eventualno dostižu proširenu apstraktnu fazu.

V. Ishodi učenja i obrazovni model temeljen na ishodima učenja

Planiranjem ishoda učenja, nastavnici u suvremenom sustavu obrazovanja svjedoče značajnim pomacima s usmjerenosti na izlaganje građe i informacija kao nakanu nastavnika prilikom izvođenja nastave - prema onom što učenici stvarno trebaju naučiti i demonstrirati završetkom svog iskustva učenja (poznatije kao "na učenika usmjereno učenje", učenje kod kojeg je učenik u centru – "learner-centered approach"). Ovakav novi pristup tako naglašava kako je važnije ono što učenici uče i da li uče uspješno, od onog kada i kako uče. [14]

Nije poznato da u literature postoji jasno slaganje vezano uz specifičnu razliku među pojmovima kao što su ishodi učenja, svrha i ciljevi, no prihvaćeno je kako su ishodi učenja izravne tvrdnje koje opisuju znanja, vještine i ponašanje uma za koje se učekuje da će uspješni učenici pouzdano demonstrirati nakon svog iskustva učenja.

Schulman [2005] opisuje kako ova ideja obuhvaća tri tipa učenja: kognitivno - pri kojem učenik uči razmišljati kao stručnjak, praktično - pri kojem se uči izvedbi poput stručnjaka te moralno - pri čemu uči razmišljati i djelovati na odgovoran i etični način integriran kroz sve tri domene.

Ishodi učenja mogu biti ustrojeni na različitim razinama, uključujući pojedini nastavni sat, temu ili lekciju, nastavni predmet, čitav tečaj, program, instituciju ili područje.

Ishodi učenja za nastavni predmet obično su oblikovani kao eksplicitne, jasne i precizne tvrdnje koje upisuju specifična znanja, vještine i ponašanje uma koje će učenik prikazati kao rezultat svog iskustva u tom predmetu. Na programskoj razini, svi nastavni predmeti trebaju biti organizirani tako da oblikuju cjelovit i koherentan kurikulum temljen na namjeravanim ishodima

učenja na pojedinim nastavnim predmetima, dakle zbirno ishodi učenja nastavnog predmeta predstavljeni su i ugrađeni u ishodima učenja cjelokupnog programa. Ishodi učenja programa pomažu učenicima oblikovanje tipa učenja koje će moći cjelovito demonstrirati temeljem svojih iskustava učenja u određenom programu.

VI. Ishodi učenja za nastavni predmet (CLO Course Learning Outcomes)

Ishodi učenja vezani uz nastavni predmet (CLO) su tvrdnje u specifičnim i mjerljivim pojmovima (izrazima) o onom što će učenik znati ili biti u stanju učiniti kao rezultat uspješnog apsolviranja nastavnog predmeta.

Jasno izražavanje ishoda učenja vezanih uz nastavni predmet omogućuje priopćavanje očekivanog standarda izvedbe i služi kao osnova za evaluaciju učinkovitosti procesa učenja i poučavanja u tom predmetu.

Neki primjeri dobre prakse koji mogu poslužiti kao smjernice prilikom pisanja predmetno specifičnih ishoda učenja [4]:

- prestavljaju kognitivnu, afektivnu i bihevijoralnu dimenziju učenja koju je moguće potvrditi,
- usmjereni su na ponašanje, odnosno izvedbu učenika (ne na izvedbu nastave),
- koriste radne i aktivne glagole,
- specifični su, mjerljivi i mogu se promatrati,
- realistični su i dosegljivi,
- usklađeni su sa ishodima cjelokupnog programa,
- učenicima su razumljivi,
- odražavaju specifični, jedinstveni sadržaj određenog nastavnog predmeta,
- ima ih između četiri i osam (nema čvrstog broja koji bi neki nastavni predmet zahtjevao). Više od osam postaje nezgrapno za usredotočenost, razvoj i procjenjivanje, a manje od četiri obično pokazuje kako su trenutno postavljeni preširoko, što ograničava njihovu upotrebljivost ili ukazuje na to da nastavi nedostaje širine ili dubine,
- jasno izražavanje ishoda učenja vezanih uz nastavni predmet prezentira očekivani standard izvedbe i služi kao osnova evaluacije učinkovitosti procesa učenja i poučavanja u tom nastavnom predmetu.

Dodatno, slijedeće smjernice mogu pomoći sastavljanju i pisanju predmetno specifičnih ishoda učenja:

1. Tvrdnja počinje riječima kao što su «Učenici će moći…» koju slijedi preciziranje onog što se učekuje da će uspješni učenici demonstrirati nakon što apsolviraju nastavni predmet: znanja, sposobnosti, te vještine koje se može mjeriti kako bi se procijenilo jesu li ili ne (i do koje mjere) učenici naučili tim nastavnim predmetom obuhvaćen dio cjelokupnog kurikuluma.
2. Utvrđuju željenu izvedbu, odnosno ponašanje učenika upotrebljavajući konkretne aktivne ili radne glagole (pisati, primijeniti, interpretirati, opisati..) učinak kojih je moguće mjeriti.
3. Izbjegavaju glagole kao što su: učenici će naučiti, vjerovati, čuti, shvatiti, znati, vidjeti, ustanoviti, zapamtiti, misliti, razviti, razumjeti, iskusiti, osjetiti, prihvatiti…
4. Izbjegavaju fraze kao što su: učenici će biti upoznati sa, svjesni, sposobni, zbližiti se, biti zainteresirani za.. (bolje je razmišljati na način što će konkretno učenici učiniti kako bi dokazali svoju svijest, zbližavanje ili prihvaćanje itd.)
5. Izbjegavaju bespotrebna proširenja izjava: Učenici će biti sposobni ~~demonstrirati sposobnost~~ primjene tehnike i… Učenici će ~~razviti sposobnost~~ proizvesti… Učenici će biti sposobni ~~demonstrirati sposobnost~~ kodiranja interaktivnih… Učenici će ~~naučiti sposobnost~~ kritičnog prosuđivanja metodologije…

Nakon što su ishodi učenja sastavljeni, korisno je provjeriti i utvrditi imaju li slijedeće značajke:

- Jesu li koncizni, izravno i jasno postavljeni?
- Jesu li ostvarivi?
- Jesu li smisleni? Hoće li imati stvarno dugoročni značaj?
- Može li ih se promatrati? Opisuju li kako će izgledati učenje?
- Može li se njima upravljati?
- Jesu li uravnoteženi?
- Koje su stavke podskup drugih stavaka? Koje stavke mogu biti grupirane zajedno jer upućuju na istu izvedbu? Nedostaju li neki kritični elementi?
- Koliko dobro odražavaju kontekst nastavnog predmeta, nastavne aktivnosti, strategije ocjenjivanja te očekivanja odgovarajuće razine obrazovanja?

VII. Glagoli za pisanje predmetno specifičnih ishoda učenja

U nastavku je prikazana tablica sa reprezentativnom listom glagola koji se mogu koristiti kod pisanja ishoda učenja. Glagoli su radni u smislu da se odnose na aktivnosti učenika koje mogu biti praćene i evaluirane na odgovarajući način [5].

TABLICA I. Prijedlozi glagola za pisanje predmetno specifičnih ishoda učenja po grupama

Prijedlozi glagola po skupinama	
Glagoli koji opisuju obuhvat i pripremu sredstava, materijala i tekstova različith vrsta	Pristupiti, usvojiti, sakupiti, akumulirati, izdvojiti, prikupiti, locirati, pribaviti, povratiti…
Glagoli koji označavaju što učenici čine kako bi posvjedočili informaciju, materijale, tekstove..	Citirati, dokumentirati, zabilježiti, referencirati
Glagoli koji označavaju načine na koje učenik karakterizira objekte znanja ili stvoreni materijal, izvedbu, ponašanje	Kategorizirati, klasificirati, definirati, opisati, odrediti, uokviriti, identificirati, specificirati, odrediti prioritete
Glagoli koji opisuju što učenici rade kod procesiranja podataka i srodnih informacija	Kalkulirati, odrediti, manipulirati, mjeriti, riješiti, ispitati, prosuditi
Glagoli koji nadalje opisuju načine na koje učenici oblikuju podatke, informacije, materijale	Posložiti, sklopiti, organizirati, poredati, usporediti, razvrstati
Glagoli koji opisuju što učenici rade kod objašnjavanja stajališta, stvaralaštva, skupa motrišta ili teksta	Artikulirati, razjasniti, eksplicirati, ilustrirati, interpretirati, prevesti, elaborirati, skicirati, objasniti

Glagoli koji ulaze u kognitivne aktivnosti (analizirati)	Usporediti, diferencirati, razlikovati, oblikovati, suprotstaviti, preslikati, prilagoditi, unificirati
Glagoli koji opisuju što učenici rade kad istražuju	Ispitati, eksperimentirati, istražiti, izricati hipoteze, proučavati
Glagoli koji opisuju što učenici rade kad kombiniraju ideje, materijale, promatranja	Asimilirati, konsolidirati, spojiti, povezati, integrirati, sintetizirati, sumirati, pridružiti, sastaviti
Glagoli koji opisuju što učenici rade u različitim oblicima stvaranja	Izgraditi, složiti, konstruirati, umijeti, kreirati, dizajnirati, razviti, generirati, modelirati, oblikovati, simulirati
Glagoli koji opisuju različite načine na koji učenici primjenjuju materijale učenja	Primijeniti, izvesti, provesti, demonstrirati, implementirati, proizvesti, koristiti, izvršiti, namjestiti
Glagoli koji opisuju različite izvršne funkcije izvedbe učenika	Upravljati, rukovoditi, kontrolirati, koordinirati, sudjelovati, usklađivati, voditi, optimizirati, planirati, provoditi
Glagoli koji opisuju oblike promišljenih (dogovorenih) aktivnosti u kojima učenici sudjeluju	Raspravljati, diskutirati, argumentirati, izazvati, debatirati, braniti, opravdavati, odlučivati, osporavati, zagovarati, ubjeđivati
Glagoli koji označavaju kaku učenici vrednuju objekte, iskustva, tekstove, proizvode i dr.	Pregledati, procijeniti, vrednovati, evaluirati, prosuditi, rangirati
Glagoli koji referenciraju tipove komunikacije u kojima se traži sudjelovanje učenika	Izvjestiti, editirati, kodirati, dekodirati, preslikati, prikazati, nacrtati
Glagoli koji se odnose na načine komunikacije za označavanje što učenici rade u grupama	Kolaborirati, surađivati, pregovarati, sudjelovati, pridonositi
Glagoli koji opisuju što učenici rade kod ponovnog promišljanja ili rekonstrukcije	Prilagoditi se, uskladiti, adaptirati, poboljšati, modificirati, promijeniti, odraziti, dotjerati, prespitati

VIII. RAZMATRANJE ISHODA UČENJA U PROGRAMU STJECANJA KVALIFIKACIJE TEHNIČAR ZA RAČUNALSTVO

Ideja rada bila je provesti općenito razmatranje, komentirati i usporediti postojeće ishoda učenja na dvije razine:

A. na razini programa – kvalifikacije (PLO)
B. na razini nastavnog predmeta (CLO) za predmet Algoritmi i programiranje.

Ishodi učenja analizirani su kvalitativno i kvantitativno uz navođenje zaključaka i sugestija.

A. Ishodi učenja na razini programa – standarda kvalifikacije

U Odluci o donošenju standarda kvalifikacije [6] u točki 2.1. u zajedničkom su poglavlju pod nazivom Kompetencije i ishodi učenja u listi navedene i kompetencije i ishodi što je onemogućilo precizno odvajanje kompetencija od ishoda učenja.

Naime, pojam kompetencije podrazumijeva znanja, vještine i stavove pomoću kojih je pojedinac osposobljen za izvršavanje određenog posla. U tom smislu, kompetencije predstavljaju kombinaciju znanja i njegove primjene (vještine), stavova i odgovornosti iz kojih se planiraju, odnosno izvode ishodi učenja određenog obrazovnog programa. Prema [7] ishodi učenja su tvrdnje koje objašnjavaju kompetenciju koju bi učenik trebao steći nakon uspješno završenog procesa poučavanja. Pri tome stečene kompetencije mogu i nadilaziti utvrđene ishode učenja. Postizanjem pripadajućih definiranih ishoda učenja učenik razvija i stječe određene kompetencije potrebne za zapošljavanje.

Lista u spomenutom poglavlju Kompetencije i ishodi učenja sadrži ukupno 28 navoda od kojih, u svrhu daljnjeg razmatranja i usporedbe s CLO, kao navod najbliskije povezan s predmetom Algoritmi i programiranje može se izdvojiti:

- upotrijebiti i primjenjivati temeljne programske strukture i algoritme (nizove, polja, petlje, grananja) u izradbi programskih rješenja manjeg stupnja složenosti korištenjem metoda i alata sekvencijalnog programiranja.

Oba spomenuta glagola: upotrijebiti i primjeniti spadaju u razinu primjene, odnosno višu razinu razumijevanja (treća od šest) u kognitivnoj domeni Bloomove taksonomije.

Ovaj ishod uključuje i pojam "u izradbi" koji u stvari podrazumijeva dodatni aktivni glagol "izraditi" koji također pripada višim razinama složenosti. Stoga formulacija "upotrijebiti i primjenjivati temeljne programske strukture i algoritme u izradbi programskih rješenja manjeg stupnja složenosti korištenjem metoda i alata sekvencijalnog programiranja" upućuje na potrebu planiranja nekoliko važnih ishoda učenja na razini planiranja za predmet. Ishodi su navedeni u Tablici II u nastavku:

TABLICA II. KOMPETENCIJE U DOMENI NASTAVNOG PREDMETA ALGORITMI I PROGRAMIRANJE

Glagoli	Disciplinarni kontekst
Upotrijebiti primjenjivati….	Temeljne programske strukture
Upotrijebiti primjenjivati….	Temeljni algoritmi
Izraditi	Programsko rješenje
Koristiti	Metode i alati sekvencijalnog programiranja

Neke nedoumice vezane uz ovako postavljen ishod, odnosno kompetenciju mogu biti:

- možda bi nastavnicima više odgovaralo da su odvojeno navedene kompetencije i ishodi učenja,
- terminološki nije sasvim sigurno misli li se pod pojmom "temeljne programske strukture" na pravocrtni tijek programa, grananja i petlje,
- uobičajeno je da se pod temeljne algoritme podrazumijevaju algoritmi za pretraživanje i sortiranje, no da li samo ti i ne bi li trebalo i neke druge algoritme (vezane uz npr. grafove),
- u praksi shvaćanje formulacije "manjeg stupnja složenosti" može prilično ovisiti o nastavniku,
- terminološki je donekle nejasno na što se odnosi formulacija "metode i alati sekvencijalnog programiranja".

B. *Ishodi učenja na razini nastavnog predmeta Algoritmi i programiranje*

U Odluci o donošenju standarda kvalifikacije [6], te u Odluci o uvođenju strukovnog kurikuluma za stjecanje kvalifikacije [8] navedeni su ishodi učenja za predmet Algoritmi i programiranje (po šest ishoda za svaki razred – uči se u prvom i drugom razredu - koji su zatim objedinjeni u zajedničku listu od 12 što je sveukupno nešto više od uobičajeno preporučenog maksimalnog broja od deset):

- objasniti važnost algoritama u procesu rješavanja problema (razina 2),
- razmotriti tipične strukture podataka i pripadnih algoritama te prepoznati važna svojstva algoritama (razina 2, razina 1),
- odabrati i osmisliti algoritme za rješavanje jednostavnijih problema (razina 3, razina 5),
- koristiti naredbe za upis i ispis podataka (razina 3),
- primijeniti naredbe za grananje i ponavljanje dijelova programa (razina 3),
- koristiti jednodimenzionalna i dvodimenzionalna polja te nizove znakova (razina 3),
- koristiti algoritme za pretraživanje i razvrstavanje (razina 3),
- kreirati i primijeniti funkcije u programu (razina 5, razina 3),
- koristiti pokazivače u radu s poljima i funkcijama (razina 3),
- dizajnirati i koristiti strukture podataka (razina 5, razina 3),
- kreirati i koristiti datoteke (razina 5, razina 3),
- primijeniti naredbe za rad sa grafikom u izradbi različitih crteža i animacija (razina 3).

Može se zaključiti kako se razina 1 pojavljuje jednom, razina 2 dva puta, razina 3 je najčešća i pojavljuje se čak deset puta, no u četiri slučaja javlja se i razina 5 u području sinteze, odnosno kreacije, što očito ovaj predmet svrstava u skupinu kognitivno zahtjevnijih.

U svrhu usporedbe korišteni su ishodi učenja oblikovani za dva slična predmeta [9]: CISC 101 (Elements of Computing Science) i CISC 121 (Introduction to Computing Science), koji se izvode u nešto većoj satnici no sadržajno nema većih razlika u odnosu na predmet Algoritmi i programiranje. Tablica III. navodi predmete te odgovarajuće ishode učenja.

Kao cilj, odnosno svrha skupa ishoda učenja u [6] zapisano je: "razviti algoritamski način razmišljanja u rješavanju problema i ovladati osnovama korištenja programskog jezika kao alata za rješavanje problema." Evidentno je kako se ishodi učenja u oba ova predmeta oslanjaju na sličan kontekst te također udovoljavaju spomenutom cilju.

Dojam je da su ovako (prema tablici) napisani ishodi učenja koncizniji, kao i da jasnije grupiraju stavke poštujući i zadržavajući međusobne odnose podstavaka.

TABLICA III. PRIMJERI ISHODA UĆENJA ZA NASTAVNE PREDMETE U KOJIMA SE TAKOĐER POUČAVA VJEŠTINA PROGRAMIRANJA

Predmet	Ishodi učenja
CISC 101: Elements of Computing Science - Uvod u algoritme, definicija, oblikovanje, kodiranje i izvođenje na računalima	- oblikovati računalom izvedivo rješenja problema opisanog prirodnim jezikom, - izraziti rješenja na algoritamski način, - učinkovito i jasno konvertirati algoritam u proceduralni program - pravilno koristiti modularnost, ponavljanja (brojano i neograničeno), uvjete i jednostavne podatkovne strukture
CISC 121: Introduction to Computing Science - Uvod u oblikovanje i analizu algoritama, elementarno pretraživanje i razvrstavanje	- Oblikovati i konstruirati programsku potporu u uobičajenom proceduralnom programskom jez., - koristiti interaktivnu razvojnu okolinu za pisanje funkcija od oko 50 linija koda u konvencionalnom proceduralnom programskom jeziku (npr. Python), - implementirati osnovni algoritam za pretraživanje i razvrstavanje (linearno i binarno pretraživanje, razvrstavanje mjehurićima, ubacivanjem, izborom spajanje i brzo razvrstavanje), - demonstrirati posljedice predstavljanja cjelobrojnih i vrijednosti s pomičnim zarezom u digitalnom računalu (s obzirom na razne vrste pogrešaka)

IX. ZAKLJUČAK

Ishodi učenja osiguravaju snažan i potreban okvir sustavnom pristupu oblikovanju kurikuluma što ih čini njegovim sastavnim dijelom. Kako bi kurikulum bio cjelovit i dosljedan, preporučljivo je:

- jasno identificirati željene ishode učenja,
- oblikovati odgovarajuće strategije ocjenjivanja,
- planirati nastavne aktivnosti i iskustva učenja koje će moći osigurati ostvarivanje ishoda učenja [10]

Kod sastavljanja ishoda učenja potrebno je uzeti u obzir prirodu i razinu njihovih specifičnosti, ali ostaviti prostor razvoju mašte i kreativnosti, a kod implementiranja ishoda učenja u obzir treba uzeti i zahtjevano vrijeme i resurse.

Takav "Početak pri kojem na umu imamo kraj" [10], sličan je korištenju karte za putovanje pri čemu se učenicima daje poznata destinacija, očekivanje koje treba dostići. Ishodi učenja su destinacija, a karta za putovanje pri tome se koristi kako bi se planirao put i konačno pokazalo stižu li učenici na svoju destinaciju. Zato je potrebno unaprijed odgovoriti na pitanja kao što su:

- Koje važne koncepte i principe moraju učenici upamtiti? Koje metode i postupke bi trebali naučiti upotrebljavati? Koji su načini razmišljanja i praktične vještine koji učenici moraju razviti tijekom nastave?
- Kako će se znati da su učenici ovladali znanjem i vještinama koje se od njih očekuju? Što će biti prihvaćeno kao dokaz napretka?

- Koji su odgovarajući problemi, aktivnosti, slučajevi ili zadaci koji će razviti učenikovu sposobnost da dostigne ishode učenja?

Nastavnici predmeta u okviru novih strukovnih kurikuluma još uvijek se prilagođavaju ovakvom pristupu planiranja i realizacije nastave, čega je uspjeh usko vezan uz razvoj učinkovitih ishoda učenja vezanih uz specifične stručne kompetencije. I ovaj bi rad trebao pomoći prepoznavanju i jasnom postavljanju upravljivih ishoda učenja, dovoljno sažetih, dosegljivih, ali i značajnih na duže vrijeme.

Jer, "kada postoji usklađenost između onog što želimo, kako poučavamo i kako ocjenjujemo, poučavanje postaje učinkovitije."[11].

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Procjena zadovoljstva IKT obrazovnih alata učenika razredne nastave

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***Sažetak* - Postojeće metode i načini poučavanja nisu dostatni za ostvarenje matematičkih ciljeva u nekom razumnom vremenu, stoga su se neke zemlje i institucije okrenule IKT-u i istražuju načine kako IKT može pomoći u dostizanju obrazovnih ciljeva matematike. Jedna od obrazovnih prednosti tableta je korištenje matematičkih aplikacija u učenju matematike. Cilj rada bio je ispitati zadovoljstvo učenika korištenim obrazovnim IKT alatima i to obzirom na njihovu zanimljivost, lakoću korištenja i zabavnost. Istraživanje je provedeno početkom školske godine 2015./2016. i trajalo je cijelo prvo polugodište na ukupno 60 sati matematike. U istraživanju je sudjelovalo ukupno 127 učenika trećih i četvrtih razreda od 6 razrednih odjela. U istraživanju je korišteno pet edukativnih alata pomoću kojih su učenici, primjenom taktilne tehnologije, rješavali kvizove znanja i igrali edukativne matematičke igre. U uvodnom (motivacijskom) dijelu sata učenici su koristili Kahoot, Plickers i Matematičku igru za dvoje, dok su u završnom dijelu sata samostalno rješavali zadatke koristeći alate Socrative i Nearpod. Rezultati istraživanja pokazali su da je učenicima najzanimljivije raditi s aplikacijom Kahoot, a najmanje zanimljivo s aplikacijom Nearpod. Također, učenicima je i najzabavnije raditi s aplikacijom/alatom Kahoot, a najmanje zabavno s aplikacijom/alatom Math Duel, dok im je najlakše koristiti Plickers, a najteže aplikaciju Nearpod.**

Ključne riječi - IKT, nastava matematike, IKT alati, Socrative, Nearpod, Kahoot, Plickers

I. UVOD

Učenici 21. stoljeća žive svoje živote okruženi tehnologijama. Korištenje tehnologije u razredu dozvoljava učenicima da uče na njima zanimljiviji način te na taj način povećava njihovu angažiranost i aktivnost na satu. Najčešće reakcije učenika pri uvođenju novih tehnologija i implementaciji IKT-a u odgojno-obrazovni proces su entuzijazam i zadovoljstvo [4]. Učenici tehnologiju doživljavaju kao zabavnu i atraktivnu te smatraju kako uz pomoć tehnologije mogu više toga naučiti i lakše razumjeti složene koncepte te poboljšati i proširiti svoje osobne interese [3]. Pojedine zadatke koje odrađuju uz pomoć tehnologije učenici ne shvaćaju kao školsku obavezu već kao zabavu, čak i kada se radi o tradicionalnim školskim predmetima[1].

Dostupnost IKT-a promijenilo je način učenja i poučavanja u matematici. „Tehnologija je bitna u učenju i poučavanju matematike; utječe na matematiku koja se poučava i obogaćuje učeničko učenje“ (Nacionalno vijeće učitelja matematike, SAD, 2000). Nove tehnologije omogućuju učenicima rješavanje problemskih zadataka, istraživanje i razumijevanje veza između nastavnih cjelina te aktivan pristup matematičkim sadržajima [8]. U radu objavljenom u Centru za tehnologiju u učenju (2007) navode se dva osnovna razloga za uvođenjem tehnologije u nastavu matematike: fokus na učenikovom razmišljanju i veća opipljivost rezultata, čime se postiže bolje razumijevanje pojmova i povezivanje odnosa kako? i što? Pilgrim, Krekić i Ivanović (2013) navode važnost strategija, a osobito kreativnosti, u poučavanju matematike kod učenika nižih razreda osnovne škole [7].

Obzirom na kratku povijest tableta, istraživanja o matematičkim aplikacijama su još uvijek u počecima [2]. Wise, Toto i Lim, 2006 tvrde da su tableti u učionici lako usvojiva tehnologija koja ima pozitivne utjecaje na učenikovu pažnju i učenje [9]. Reins (2007) tvrdi da učenici koji koriste tablete postaju sastavni dio nastave, dok Tutty i White (2006) tvrde da su tableti učinkovitiji od tradicionalnih metoda poučavanja te da ta činjenica djelomično proizlazi zbog povećanog naglaska na socijalne aspekte učenja i procese koje učenici prolaze kada stvaraju obrazovne koncepte [5]. Svaki dan objavljuje se preko 300 aplikacija koje se mogu koristiti u različite svrhe [1]:

- informativne – pružaju informacije, učenik je pasivni konzument, a ne aktivan kreator
- interaktivne – pružaju neke elemente interakcije, mogućnost izbora i donošenje odluka od strane učenika

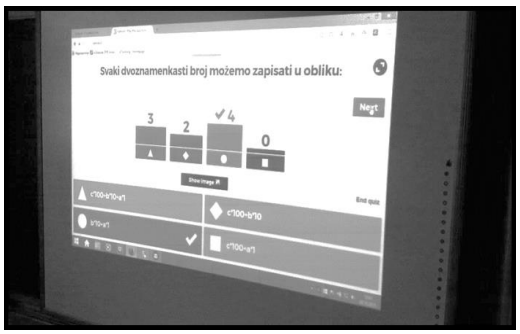
[1] Tekst uvoda i rezultati istraživanja preuzeti su iz doktorskog rada autorice: „Pavičić Zajec, T. (2017) *Učinkovitost korištenja informacijsko – komunikacijske tehnologije u nastavi matematike nižih razreda osnovne škole*“ [6].

- produktivne – učenici djeluju kao kreatori, a interakcija s aplikacijom rezultira nekim proizvodom

U istraživanju za potrebe ovog rada korišteno je pet edukativnih alata pomoću kojih su učenici, primjenom taktilne tehnologije, rješavali kvizove znanja i igrali edukativne matematičke igre. U uvodnom (motivacijskom) dijelu sata učenici su koristili Kahoot, Plickers i Math Duel jer ti alati, osim edukativne uloge, imaju i natjecateljski karakter (vremensko ograničenje, lista učenika poredanih po uspjehu) što dodatno doprinosti motivaciji učenika te njihovom interesu za matematičke zadatke. U završnom dijelu sata učenici su samostalno rješavali zadatke koristeći alate Socrative i Nearpod koji su ih vodili kroz cijeli kviz, dajući im detaljne upute i povratne informacije o točnosti njihova odgovora.

II. ALATI U ISTRAŽIVANJU

Kahoot[2] je besplatna platforma za učenje bazirana na igri. Učitelj kreira kvizove koji mogu biti napravljeni za bilo koji predmet i na bilo kojem jeziku. Kvizovi se sastoje od pitanja s mogućnošću višestrukog odgovora, a moguće je ubacivanje slika, videa i raznih dijagrama. Kahoot kvizove najbolje je primjenjivati na grupi učenika – u razredu. Pitanja su projicirana na velikom ekranu tako da mogu vidjeti svi učenici, a igrači odgovaraju na svojim tabletima birajući boju koja predstavlja točan odgovor.



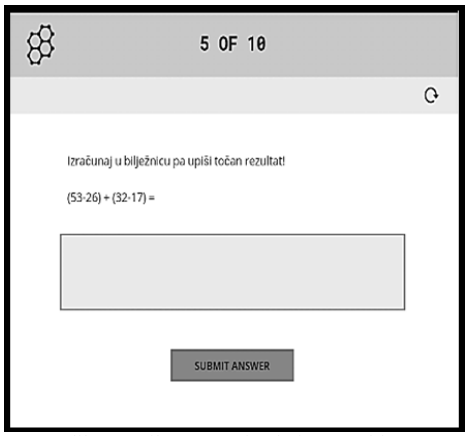
Slika 1. Prikaz pitanja napravljenog u kvizu Kahoot

Alat Plickers[3] namijenjen je jednostavnoj i inovativnoj provjeri znanja u razredu sa automatskim prikupljanjem podataka i analizom dobivenih rezultata. Za rješavanje ovog kviza učenicima su potrebne papirnate kartice koje su vrlo jednostavne za korištenje za svakog učenika unutar razreda, a svojim izgledom podsjećaju na QR kodove. Nakon postavljenog pitanja, svi učenici trebaju prikazati svoj odgovor pravilnim položajem svoje kartice, dok nastavnik sa svojim mobilnim uređajem skenira sve kartice i na taj način prikuplja rezultate.

Slika 2. Prikaz Plickers kartica

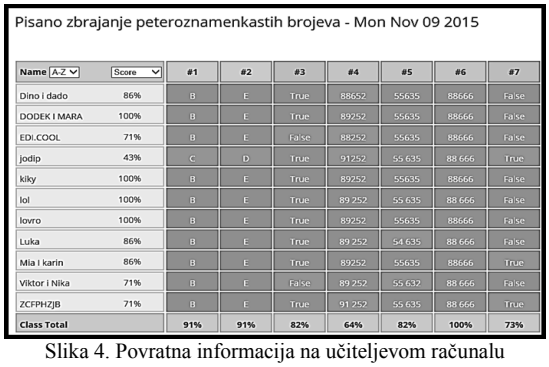
Socrative[4] je još jedan od besplatnih alata za procjenu učenikova znanja. Za razliku od kvizova izrađenih u Kahootu ili Plickersu, učenici kviz napravljen od strane učitelja rješavaju na tablet računalima.
Zadaci mogu biti:

- otvorenog tipa (učenici upisuju svoj odgovor),
- zatvorenog tipa s ponuđenim odgovorima,
- zadaci s mogućnošću odabira (točno/netočno).



Slika 3. Prikaz Socrative kviza na tabletu

Nakon što učitelj kreira kviz, učenici se logiraju pomoću koda koji se sastoji od brojeva i slova te počinju sa rješavanjem. Cijelo vrijeme tijekom rješavanja kviza, učitelj na svom računalu ima povratnu informaciju o njihovom napredovanju i točnosti riješenih zadataka.


Pisano zbrajanje peteroznamenkastih brojeva - Mon Nov 09 2015

Name	Score	#1	#2	#3	#4	#5	#6	#7
Dino i dado	86%	B	E	True	88652	55635	88666	False
DODEK I MARA	100%	B	E	True	89252	55635	88666	False
EDI.COOL	71%	B	E	False	88252	55635	88666	False
jodip	43%	C	D	True	91252	55 635	88 666	True
kiky	100%	B	E	True	89252	55635	88666	False
lol	100%	B	E	True	89 252	55 635	88 666	False
lovro	100%	B	E	True	89252	55635	88666	False
Luka	86%	B	E	True	89 252	54 635	88 666	False
Mia i karin	86%	B	E	True	89252	55635	88666	True
Viktor i Nika	71%	B	E	False	89 252	55 632	88 666	False
ZCFPHZJB	71%	B	E	True	91 252	55 635	88 666	True
Class Total		91%	91%	82%	64%	82%	100%	73%

Slika 4. Povratna informacija na učiteljevom računalu

[2] https://kahoot.com/
[3] https://www.plickers.com/
[4] https://www.socrative.com/

Nearpod[5] je alat koji omogućuje učitelju da od klasične nastave napravi prezentaciju koja traži od učenika da bude aktivni sudionik. Uz tekstualne i slikovne sadržaje jednostavno je ugraditi audio i video isječke kao i kompletne web stranice koje je moguće pregledavati unutar prezentacije. Aktivnost učenika potiče se dodavanjem interaktivnih elemenata kao što su pitanja otvorenog tipa, ankete, kvizovi ili rukom pisani odgovori i crteži. Odgovore i povratnu informaciju o riješenosti navedenih elemenata učitelj također dobiva u realnom vremenu. Uz navedeno, nastavnik u učionici upravlja tempom prezentacije sa svog računala dok učenici kod kuće putem linka mogu ponovno pregledavati istu prezentaciju ali svojim tempom.

Slika 5. Nearpod - početni zaslon

„Math Duel“[6] je matematička igra za dvije osobe uz pomoć koje učenici mogu vježbati osnovne matematičke operacija: zbrajanje, oduzimanje, množenje i dijeljenje. Igru može igrati najviše dvoje učenika koji se međusobno natječu u osvajanju bodova. Učenici dobivaju jednake zadatke, a onaj učenik koji prvi točno riješi deset zadataka postaje pobjednik. Učenici imaju mogućnost odabira razine koju žele rješavati, pa tako mogu dobiti lake, srednje teške, teške ili ekspert zadatke [6].

Slika 6. Matematička igra za dvoje – oduzimanje brojeva

III. METODOLOGIJA

Istraživanje je provedeno u I. osnovnoj školi Varaždin početkom školske godine 2015./2016. i trajalo je cijelo prvo polugodište na ukupno 60 sati matematike. Uzorak istraživanja činilo je 127 učenika trećih i četvrtih razreda I. osnovne škole u Varaždinu (N=127). Od ukupnog broja 52% učenika činili su učenici trećih razreda, a 48% učenici četvrtih razreda. Djevojčica je bilo 43,3%, a dječaka 56,7%. (Tablica 1).

TABLICA 1. PRIKAZ UZORKA – BROJ UČENIKA PREMA SPOLU (M – MUŠKO, Ž- ŽENSKO) I RAZREDU (R)

	m	**ž**	**UZORAK**
3.r	39	27	66
4.r	33	28	61
Uk.	72	55	127
%	56,7%	43,3%	100%

Cilj istraživanja bio je ispitati zadovoljstvo učenika korištenjem obrazovnih IKT alata i to obzirom na njihovu zanimljivost, lakoću korištenja i zabavnost. Učenici su bili podijeljeni u kontrolne i dvije eksperimentalne skupine, a za procjenu zadovoljstva korištenih aplikacija od strane učenika konstruiran je anketni upitnik koji se sastojao od tablice s pet korištenih aplikacija. Uz pomoć skale od 5 stupnjeva (1 –nimalo; 2- malo; 3 – osrednje; 4 – mnogo; 5 – izrazito mnogo) učenici su ocjenjivali aplikacije u odnosu na njihovu zanimljivost, zabavnost i lakoću korištenja.

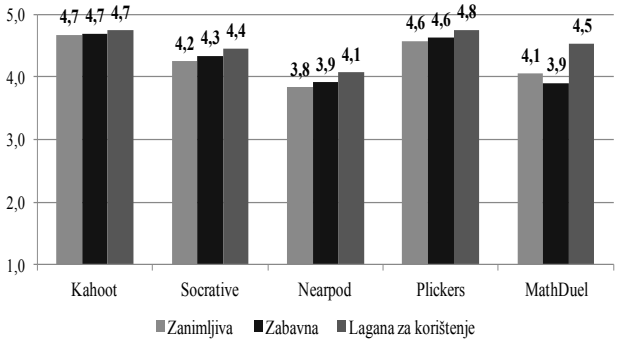
U istraživanju se polazilo od sljedećih hipoteza:

- Aplikacija Plickers je najlakša za korištenje većini učenika
- Aplikacija Kahoot je najzanimljivija većini učenika
- Aplikacija Socrative je teža za korištenje učenicima trećih razreda u odnosu na učenike četvrtih razreda

A Prikaz rezultata

Za testiranje statističke značajnosti razlika u prosječnim procjenama karakteristika svih 5 aplikacija/alata provedene su analize varijance za ponovljena mjerenja (za svaku karakteristiku po jedna analiza – grafikon 1.).

[5] https://nearpod.com/
[6] https://play.google.com/store/apps/details?id=com.mathduel2playersgame.mathgame&hl=hr



Grafikon 1. Prosječne procjene zanimljivosti, zabavnosti i lakoće korištenja alata

TABLICA 2. PROSJEČNE PROCJENE ZANIMLJIVOSTI

	Aritmetička sredina	Statistički značajne razlike uz p<,05
(1) Kahoot	4,67	1 > 2, 3, 5
(2) Socrative	4,25	2 < 1; 2 > 5
(3) Nearpod	3,84	3 < 1, 4
(4) Plickers	4,58	4 > 3, 5
(5) Math Duel	4,06	5 < 1, 2, 4

U prosječnoj procjeni **zanimljivosti** utvrđeno je da postoji statistički značajna razlika između aplikacija / alata (p<0,001). Učenicima je u prosjeku najzanimljivije raditi s aplikacijom Kahoot, a najmanje zanimljivo s aplikacijama Nearpod i Math Duel (Tablica 2). Naknadne usporedbe pomoću Tukeyevog HSD testa pokazuju da se srednja vrijednost ocjena za kategoriju zanimljivost alata Nearpod (M=3,84, SD=1,526) i Math Duel (M=4,06, SD=1,285) značajno razlikuju od srednjih vrijednosti ocjena alata Kahoot (M=4,67, SD=0,777), Socrative (M=4,25, SD=0,975) i Plickers (M=4,58, SD=1,039).

TABLICA 3. PROSJEČNE PROCJENE LAKOĆE KORIŠTENJA

	Aritmetička sredina	Statistički značajne razlike uz p<,05
(1) Kahoot	4,74	1 > 2, 3
(2) Socrative	4,44	2 < 1, 4
(3) Nearpod	4,07	3 < 1, 4
(4) Plickers	4,75	4 > 2, 3
(5) Math Duel	4,53	-

U prosječnoj procjeni lakoće korištenja također je utvrđeno da postoji statistički značajna razlika između aplikacija / alata (p<0,001). Učenicima je u prosjeku najlakše koristiti aplikaciju Plickers, a najteže aplikaciju Nearpod (Tablica 3). Posthoc Tukeyev HSD test pokazuje da se srednja vrijednost ocjena za lakoću korištenja alata Nearpod (M=4,07, SD=1,421) značajno razlikuje od srednje ocjene za lakoću korištenja preostalih alata (Kahoot: M=4,74, SD=0,657; Socrative: M=4,45, SD=0,945; Plickers: M=4,75, SD=0,785; Math Duel: M=4,53, SD=0,959).

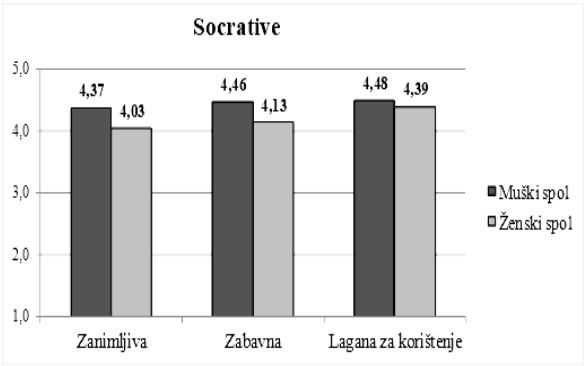
TABLICA 4. PROSJEČNE PROCJENE ZABAVNOSTI

	Aritmetička sredina	Statistički značajne razlike uz p<,05
(1) Kahoot	4,69	1 > 2, 3, 5
(2) Socrative	4,34	2 < 1, 4
(3) Nearpod	3,93	3 < 1, 2, 4, 5
(4) Plickers	4,64	4 < 1
(5) Math Duel	3,91	5 < 1, 2, 4

U prosječnoj procjeni **zabavnosti** utvrđeno je da postoji statistički značajna razlika između aplikacija / alata (p<0,001). Učenicima je u prosjeku najzabavnije raditi s aplikacijom Kahoot, a najmanje zabavno s aplikacijama Math Duel i Nearpod (Tablica 4). Rezultati Tukeyevog HSD testa ukazuju na postojanje statistički značajne razlike u ocjenama zabavnosti alata Math Duel (M=3,91, SD=1,306) i Nearpod (M=3,93, SD=1,395) u odnosu na ocjene kategorije zabavnosti u alatima Kahoot (M=4,69, SD=0,740), Socrative (M=4,34, SD=0,946) i Plickers (M=4,64, SD=0,857).

Detaljnijom statističkom obradom rezultata vidljivo je da je alat Kahoot izrazito zanimljiv, zabavan i lagan za korištenje gotovo svim učenicima. Obzirom na dob učenika, učenici trećih i četvrtih razreda izrazili su podjednako zadovoljstvo ocijenivši alat Kahoot zanimljivim i zabavnim. 20% učenika četvrtih razreda navodi Kahoot težim alatom za korištenje nego učenici trećih razreda, a uzrok tome mogu biti nešto kompliciraniji zadaci obzirom na gradivo koje se obrađivalo u četvrtom razredu. Alat Kahoot izrazito je i mnogo zanimljiv dječacima (77,8%), i tek nešto više djevojčicama (83,9%), dok je dječacima (85,2%) ipak malo zabavniji nego djevojčicama (74,2%). Lakoću korištenja navedenog alata podjednako su prepoznali i dječaci i djevojčice.

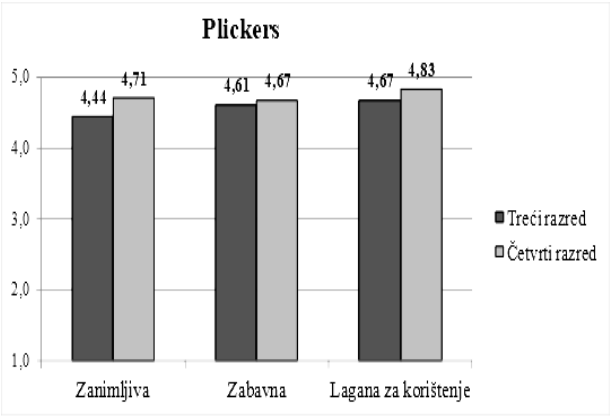
Alat Socrative mnogo je i izrazito mnogo zanimljiv za ukupno 81% učenika trećih razreda i 83% učenika četvrtih razreda, dok nije nimalo ili je vrlo malo zanimljiv za tek 9,3% učenika trećih i 7,1% učenika četvrtih razreda. Spomenuti alat nešto je zanimljiviji, zabavniji i lakši za korištenje dječacima nego djevojčicama. 61,1% dječaka procijenilo je alat izrazito zanimljivim, dok je istu procjenu dalo tek 35,5% djevojčica. Prema grafikonu 2. vidljivo je da veći broj dječaka (68,5%) alat smatra izrazito zabavnim nego djevojčica (41,9%).



Grafikon 2. Prosječne procjene zanimljivosti, zabavnosti i lakoće korištenja aplikacije Socrative prema spolu

U ocjeni zanimljivosti i zabavnosti alata Nearpod nisu utvrđene velike razlike u odnosu na dječake i djevojčice. Rezultati pokazuju da je alat izrazito lagan za korištenje za 70,4% dječaka i 45,2% djevojčica.

Aplikacija Plickers pokazala se kao manje zanimljivija za učenike trećih razreda (76,7%) od učenika četvrtih razreda (85,7%). Također, učenici četvrtih razreda (83,3%) ocijenili su ovu aplikaciju kao izrazito zabavnom, dok ju je kao takvu ocijenilo 76,7% učenika trećih razreda (grafikon 3). Analizom dobivenih podataka obzirom na spol učenika, rezultati pokazuju da je Plickers nešto zabavniji i zanimljiviji djevojčicama nego dječacima. Kao izrazito zabavan, ovaj alat je ocijenilo 87,1% djevojčica i 75,9% dječaka.



Grafikon 3. Prosječne procjene zanimljivosti, zabavnosti i lakoće korištenja aplikacije Plickers prema razredu

Matematička igra za dvoje pokazala se kao najmanje zabavna aplikacija od svih koje su učenici koristili tijekom eksperimenta. Ukupno 54,1% učenika ocijenilo je ovu aplikaciju kao izrazito zanimljivom, 47,1% kao izrazito zabavnom i 75,3% kao izrazito lakom za korištenje. Detaljnijom obradom rezultata, vidljivo je da je ova matematička igra za dvoje skoro podjednako zanimljiva učenicima trećih i četvrtih razreda, dok je četvrtim razredima ipak malo zabavnija (73,8%) nego učenicima trećih razreda (65,1%). Između učenika trećih i četvrtih razreda nisu utvrđene statistički značajne razlike u prosječnim procjenama zanimljivosti ($M_{3.raz}$=3,95, $SD_{3.raz}$=1,378, $M_{4.raz}$=4,14, $SD_{4.raz}$=1,201, t (82) = -0,675, p=0,501) i zabavnosti ($M_{3.raz}$=3,83, $SD_{3.raz}$=1,360, $M_{4.raz}$=3,95, $SD_{4.raz}$=1,268, t (82)=-0,415, p=0,679) aplikacije Math Duel no utvrđeno je postojanje statistički značajnije razlike u procjeni lakoće korištenja ($M_{3.raz}$=4,31, $SD_{3.raz}$=1,179, $M_{4.raz}$=4,79, $SD_{4.raz}$=0,565, t(82)=-2,361, p=0,022). Učenicima četvrtih razreda je korištenje aplikacije Math Duel lakše nego učenicima trećih razreda.

IV. ZAKLJUČAK

Da bi učenje uz pomoć novih tehnologija bilo učinkovito i produktivno, učitelj je taj koji mora posjedovati potrebne IKT kompetencije te znati odabrati vrstu tehnologije i najprikladnije IKT alate. U nastavi matematike najviše se upotrebljavaju tableti i pametne ploče koji učenicima omogućuju bolji i jasniji prikaz apstraktnih sadržaja te trenutnu povratnu informaciju o točnosti riješenih zadataka ili kvizova koji mogu biti natjecateljskog karaktera (Kahoot, Plickers, Socrative, GeoGebra, Matematička igra za dvoje, Nearpod).

Ovim se radom željela prikazati procjena zadovoljstva učenika razredne nastave korištenih IKT alata/ aplikacija u nastavi matematike. Učenici su pomoću Likertove skale od 5 stupnjeva ocjenjivali alate obzirom na njihovu zanimljivost, zabavnost i lakoću korištenja. U istraživanju je sudjelovalo 127 učenika trećih i četvrtih razreda I. osnovne škole Varaždin koji su bili podijeljeni u tri grupe: kontrolnu (rade na tradicionalan način, bez tableta), prvu eksperimentalnu (tableti u motivacijskom dijelu sata) i drugu eksperimentalnu (tableti u završnom dijelu sata).

Tijekom eksperimenta učenici su najčešće koristili ove alate: Kahoot, Plickers, Nearpod, Matematička igra za dvoje, Socrative. Procjenom učenika utvrđeno je da je učenicima u prosjeku najzanimljivije raditi s aplikacijom Kahoot, a najmanje zanimljivo s aplikacijom Nearpod što potvrđuju prvu hipotezu. Učenici trećih i četvrtih razreda izrazili su podjednako zadovoljstvo ocijenivši alat Kahoot zanimljivim i zabavnim. 20% učenika četvrtih razreda navodi Kahoot težim alatom za korištenje nego učenici trećih razreda, a uzrok tome mogu biti nešto kompliciraniji zadaci obzirom na gradivo koje se obrađivalo u četvrtom razredu. Alat Socrative mnogo i izrazito mnogo je zanimljiv za ukupno 81% učenika trećih razreda i 83% učenika četvrtih razreda, dok nije nimalo ili je vrlo malo zanimljiv za tek 9,3% učenika trećih i 7,1% učenika četvrtih razreda. Obzirom da nije utvrđena statistični značajna razlika u težini korištenja ovog alata između učenika trećih i četvrtih razreda, treća hipoteza nije potvrđena. Alat Nearpod izrazito je lagan za korištenje za 70,4% dječaka i 45,2% djevojčica, dok se davanje odgovora uz pomoć Plickers kartica pokazalo izrazito zanimljivim za ukupno 82,1% učenika, zabavnim za 80% učenika, te laganim za korištenje za 87,1% učenika obju grupa čime se potvrđuje i druga postavljena hipoteza. Matematička igra za dvoje pokazala se kao najmanje zabavna aplikacija od svih koje su učenici koristili tijekom eksperimenta. Obzirom da se radi isključivo i igri natjecateljskog karaktera koja se igra u parovima, iznenađuje podatak koji pokazuje da je čak

21,5% učenika druge eksperimentalne skupine ocijenilo ovu igru kao nimalo ili vrlo malo zabavnom.

Budući da je rad s tabletima i pametnim pločama u nastavi matematike relativno nova tema koja još nije dovoljno istraživana, autorica ovog rada samostalno je istraživala aplikacije i alate te odabrala one najprikladnije za djecu te dobi.[7]

Kako bi rad uz pomoć novih tehnologija i IKT alata rezultirao unaprijeđenjem odgojno – obrazovnog procesa pa onda i ostvarivanjem boljeg uspjega učenika, velika odgovornost stavlja se upravo na učitelje koji su moderatori svoje nastave. Da bi IKT alati imali smisao i svrhu u obrazovanju, učitelj je taj koji ih mora istražiti, pomno proučiti i znati kako, kada i zašto implementirati određeni alat u svoj rad.

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Utjecaj tehnologije na motivaciju nastavnika u srednjim školama (preliminarno istraživanje)

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***Sažetak* – Istraživanje je napravljeno na području Koprivničko-križevačke županije i Bjelovarsko-bilogorske županije kako bi se utvrdio utjecaj tehnologije na motivaciju nastavnika za rad u nastavi. Istraživanje je napravljeno kao preliminarno / početno istraživanje koji bi se moglo koristiti u daljnjem istraživanju utjecaja tehnologije na motivaciju i opći rad u nastavi. Istraživanje je napravljeno na četiri srednje škole, dvije srednje strukovne i dvije gimnazije iz tri grada koji gravitiraju jedan drugome (Koprivnica, Bjelovar i Đurđevac). Istraživanje je napravljeno kvantitativno (anketiranjem) i kvalitativno (intervjuiranjem). Istraživanje je napravljeno u siječnju, 2018. godine. Zaključci koji proizlaze iz podataka dobivenih u istraživanju pokazuju direktnu povezanost znanja o radu tehnologije s motiviranošću rada s tehnologijom.**

Ključne riječi – motivacija, utjecaj tehnologije, inovativna nastava, e-dnevnik

I. UVOD

A. Cilj istraživanja

Cilj ovog istraživanja je istražiti povezanost opće motivacije i znanja korištenja tehnologije s motiviranošću nastavnika za rad u nastavi (i školi općenito) koristeći se tehnologijom. Za ovo istraživanje pojam tehnologija se odnosi na svu digitalnu tehnologiju koja se može koristiti u nastavi od običnog računala za pristup Internet sadržaju, zapisivanju sata pa sve do stvaranja aktivnog sadržaja za rad s učenicima kroz različite analogno-digitalne uređaje. Sama tehnologija ima širi pojam, ali kako bi se skratilo korištenje uskog, ali višerječnog složenog pojma koristit će se pojam tehnologija.

B. Što je motivacija i zašto je važna

Motivaciju definiramo kao mentalni čimbenik koji nas vodi do djelovanja u svakoj od situacija i područja ljudskog života [1]. Amotivacija je nedostatak motivacije koja rezultira nesposobnošću za obavljanje zadaće zajedno s nedostatkom kontrole ponašanja [1]. Teorija samoodređenja navodi da je motivacija raspon koji osigurava višu ili nižu razinu samoodređenja. Motivacija se sastoji od tri čimbenika, a to su: ekstrinzična motivacija, amotiviranje i intrinzična motivacija [1]. Ekstrinzična motivacija definira se kao svaka situaciju koja stimulira neki vanjski poticaji (samostalno upravljani ili od drugih osoba), a osobe provode zadaće kako bi izbjegle krivnju, tjeskobu i povećale samopoštovanje. Intrinzična motivacija je potreba za istraživanjem okoline radi znatiželje i zadovoljstva s osjećajima sposobnosti i samospoznaje, čak i nakon što je postigla cilj bez potrebe za vanjskim zadovoljenjem [1].

Intrinzična motivacija je veća od ekstrinzične motivacije i amotiviranja te su utvrđene statistički značajne razlike u korist intrinzične motivacije. Intrinzična motivacija u nastavi je ono što pokreće i utječe na stupanj prihvaćanja, entuzijazma i zadovoljstva struke [1].

Istraživanje o radnoj motivaciji nastavnika uspoređuje relativne snage niza radnih motiva. Kao glavne motive nastavnici ističu: osjećaj društvene obaveze, osjećaj identifikacije s poslom koji rade, urođeni užitak povezan s radom i izazove koje im predstavlja rad. Specifične ciljeve neutralno rangiraju, a to su: osjećaj dužnosti, prestiž i materijalna korist [2].

C. Što je to motivacija nastavnika

Nastavnici svoje slobodno vrijeme vrlo često posvećuju školskim zadacima zato što su motivirani idejom da to "rade za učenike", a istodobno navode da „motivatori" poput plaće vezane uz uspješnost imaju malo utjecaja na motivaciju nastavnika [3]. Ukoliko nadređeni ili menadžeri žele dobro upravljati, osim praćenja, moraju razumjeti i koristiti tu motivaciju nastavnika jer je to za dobrobit nastavnika i njegovo zadovoljstvo poslom. Jedan od načina je suradničko vođenje i postavljanje zajedničkih ciljeva [3].

Sve češće nastavnici sudjeluju u virtualnim zajednicama i web mjestima društvenih medija kako bi dobili podršku i ideje za poboljšanje rada. U online istraživanju, sudionici iznose tri razloga, a to su: motivacija, osnaživanje i inovacija. Sudionici su motivirani na učenje kako bi poboljšali praksu, žele se osjećati spremniji za promjene u radu i vjeruju da mogu usvojiti inovativne ideje za rad s učenicima. Ograničena su istraživanja o tome kako sudjelovanja mogu utjecati na poučavanje i učenje [4].

Motiviranost nastavnika ima važnu ulogu u motiviranju učenika što je i svrha podučavanja. Teorija samoodređenja ukazuje na to da su učenici motivirani i imaju veća postignuća kada nastavnici podupiru svoje psihološke potrebe za autonomijom, kompetentnošću i povezanošću. Ukoliko nastavnici imaju problema s ispunjavanjem svojih psiholoških potreba to bi moglo utjecati na ispunjavanje učeničkih postignuća i njihovo zadovoljstvo [5].

Možemo zaključiti da će uspostavljanje osobne veze i rješavanje temeljnih psiholoških potreba naših učenika rezultirati pozitivnim stavovima prema poučavanju i razvijanju cjeloživotnog učenja. Važno je promicati konstruktivne odnose između učenika i nastavnika jer imaju značajan utjecaj na pristup učenika prema školi.

Povezanost je potreba učenika da se osjećaju povezani s drugima, da budu dio grupe, da imaju osjećaj zajedništva i da razviju bliske odnose s drugima. Kompetencija je vjerovanje da učenici mogu uspjeti. Važno je učenicima uvijek zadavati nove izazove i usaditi im vjeru u vlastiti uspjeh. Učenici moraju imati autonomiju koja uključuje razmatranje perspektiva učenika, pružanje relevantnih informacija te mogućnost izbora. Ovi ciljevi su važni jer ako su učenici inspirirani, motivirani i imaju pozitivne stavove prema učenju i poučavanju, napori nastavnika će ispuniti potencijal [6].

II. METODE ISTRAŽIVANJA

Metode ovog istraživanja podijeljene su u dva različita pristupa: kvantitativno istraživanje i kvalitativno istraživanje.

A. Kvantitativna metoda

Kod kvantitativnog istraživanja odlučeno je za anketno ispitivanje putem samoprocjene. Razlog leži u činjenici kako se takva ispitivanja mogu provesti relativno brzo i uspješno. Jednako tako, sama obrada nije zahtjevna, ali takav vid ispitivanja je isključivo vezan za makro razinu [7].

1) Osnovni podaci

Za kvantitativno istraživanje se postavio zadatak odabrati četiri reprezentativne škole, odabrati područje ispitivanja i setove pitanja.

Izabrane škole (ključ je bio blizina i mogućnost brze komunikacije): Gimnazija dr. Ivana Kranjčeva Đurđevac, Srednja strukovna škola Đurđevac, Gimnazija „Fran Galović“ Koprivnica i Komercijalna i trgovačka škola Bjelovar.

Za provjeru utjecaja tehnologije na motiviranost za nastavu postavljena su tri područja ispitivanja, s njima pridruženim pitanjima:

- opća motiviranost za nastavu ili rad u školi (OM)
- motiviranost i utjecaj na motiviranost u radu u nastavi pomoću tehnologije
- poznavanje tehnologije (PT)

Rezultate odgovora na pitanja za svako područje će se zasebno uspoređivati i obraditi, te će se odrediti utjecaj na njih. Dakle, prva i treća skupina su varijable koje su trenutno stanje, uz sva ograničenja koja samo procjena donosi (nezavisne varijable), a druga skupina su zavisne varijabla koja je pod utjecajem prve i treće. Tezu koja se provjerava je: Opća motiviranost nastavnika (prva skupina pitanja) i/ili Znanje korištenja tehnologije (treća skupina pitanja) utječe na Motiviranost nastavnika za rad u nastavi.

2) Istraživačka metoda

Osim prvog dijela anketnog obrasca – koji sadrži osnovne podatke – samoprocjenjujući dijelovi obrasca koristili su se Likertovom ljestvicom samoprocjene.

3) Obrada podataka

Prikupljeni podaci su obrađeni u dvije faze

- osnovna pretvaranja vrijednosti iz znakovnih u vrijednosne i korištenje osnovne statističke metode (standardna devijacija, aritmetička sredina)
- viša razina korištenja statističkih metoda (traženje poveznica, uspoređivanje grupa)

B. Kvalitativna metoda

Kao što je već navedeno, kvantitativna istraživanja nam mogu dati veliki broj podataka ali se ona isključivo odnose na makro razinu, pa je pri samom planiranju istraživanja odlučeno kako je potrebno određene pojavnosti istraživati na mikro razini putem jedne od kvalitativnih metoda. Pošto su nastavnici dostupni i ne zahtijeva veliki vremenski ili ikakav drugi napor, a može biti fleksibilan i dati dobre mikro rezultate odlučeno je da se koristi intervju kao kvalitativna metoda[7].

1) Osnovni podaci

Za intervju odabrano je 3 (ako se uvidi tijekom istraživanja potreba za većim brojem odabrat će se još jedna ili dvije) osobe i intervju je, kao anketa, potpuno anoniman. U intervjuu nisu traženi osobni podaci ispitanika, ali se ostalo pri podjeli na tri dijela samoprocjene.

2) Istraživačka metoda

Intervju će se bazirati prema prikupljenim i obrađenim podacima koji su proistekli iz kvantitativne metode, tj. nakon postavljanja H0 hipoteze će se ispitati postoji li razlog zbog te hipoteze. Razlog tome je dvojak:

- provjera ispravnosti donesene teze
- produbljivanje teze na (barem) dvije podteze (H1 i H2)

Intervju je polustrukturiran te se snima audio zapis. Za vrijeme intervjuiranja zapisuju se određena zapažanja u obrazac koji je napravljen isključivo za ovo istraživanje. U obrazac se unose sljedeći podaci: trajanje intervjua, spol ispitanika, te zapažanja prije, za vrijeme i nakon intervjuiranja.

3) Obrada podataka

Sama obrada podataka će se koncentrirati na ključne, ponavljajuće pojmove koje ispitanik koristi te će ih se staviti u kontekst s provedenim kvantitativnim istraživanjem.

III. REZULTATI ISTRAŽIVANJA I ANALIZA

A. Kvantitativno istraživanje

1) Rezultati

Istraživanje je na četiri škole (Gimnazija dr. Ivana Kranjčeva Đurđevac, Srednja strukovna škola Đurđevac, Gimnazija „Fran Galović“ Koprivnica i Komercijalna i trgovačka škola Bjelovar). Anketa je anonimna i dobrovoljna. Anketi je pristupilo 100 nastavnika (N=96 ispravno popunjeni anketni upitnici) od 210 nastavnika koji rade u tim školama što čini 46% mogućih ispitanika što zadovoljava kriterije ispitivanja za valjanost uzorka [7] s preciznošću od 0,05.

Anketa je provedena obrascem internetskog servisa Google.docs i sadržavala je opće podatke i upitnik sastavljen po dijelovima navedenim u A. 1).

Anketa se provodila u vremenskom intervalu od 22. do 29. siječnja 2018. godine. Uz poziv na ispunjavanje ankete poslano je i pismo u kojem se objašnjavaju razlozi ispunjavanja ankete, trajanju ispunjavanja ankete te

Tablica 1. Motiviranost za rad s tehnologijom

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	77,230[a]	54	1,430	5,150	,000
Intercept	283,134	1	283,134	1,020E3	,000
OM	4,435	12	,370	1,331	,238
PT	21,412	13	1,647	5,931	,000
OM * PT	6,833	25	,273	,984	,506
Error	11,664	42	,278		
Total	1312,768	97			
Corrected Total	88,894	96			

a. R Squared = ,869 (Adjusted R Squared = ,700)

korištenju podataka, tj. zaštitu osobnih podataka. Kako bi se omogućilo što bolje ispunjavanje ankete, anketa je posložena tako da se ispunjava u što kraćem vremenskom roku – do 10 min.

2) Analiza

Za analizu (Tablica 1.) dobivenih podataka anketom koristila se statistička metoda Two-Way ANOVA s dvije nezavisne varijable i jednom zavisnom. Analiza je pokazala da OM ima p vrijednost od 0,238 što je veće od 0,05 te da kao takva ne utječe statistički relevantno na motiviranost rada s tehnologijom, tj. da utjecaj tehnologije na motivaciju nije podložan općoj motivaciji.

Kod nezavisne varijable PT (poznavanje tehnologije) vrijednost p je 0,000 što je manje od 0,05 pa kao takva utječe statistički relevantno na motiviranost s tehnologijom, tj. da utjecaj poznavanja tehnologije statistički signifikantno utječe na motiviranost rada s tehnologijom.

Kombiniranje dviju nezavisnih varijabli ne daje nikakvu statističku značajnost (OM*PT p=0,506).

Ispravnost modela pokazuje R^2 koji je vrijednosti 0.869 i s time pokazuje model koji dobro opisuje dobivene rezultate.

B. Kvalitativno istraživanje

Nakon dobivenih rezultata postavljena je hipoteza: „H0 - Nedovoljno poznavanje rada tehnologije dovodi do smanjivanja motivacije za rad s tehnologijom“ što nam potvrđuje prethodno kvantitativno istraživanje. Kroz intervju se je željelo doznati zašto ta H0 hipoteza dovodi do smanjenja motivacije.

1) Rezultati

U intervjuu izabrane su nasumično tri osobe koje su se razlikovale i po spolu (ž=2, m=1) i po struci (2 su iz STEM područja, a jedna iz društveno-humanističkog) te po poznavanju tehnologije (2 imaju malo ili srednje poznavanje tehnologije, a 1 ima visoko ili ekspertno poznavanje tehnologije).

Nakon analize intervjua doneseni su slijedeći zaključci o ispitanicima:

- visoke su osnovne motivacije
- stručni i odgovorni u svojem području
- koriste tehnologiju u nastavi (u većini slučajeva – pasivno)
- voljni su se educirati dalje za nastavu pomoću tehnologije
- smatraju da nastava pomoću tehnologije nema alternativu i da bi nastava bez korištenja tehnologije kao didaktičkog pomagala bio korak unazad
- odgovorni su prema svojim učenicima, školi u kojoj rade i struci koju predstavljaju

2) Analiza

Analizom intervjua kod postavljanja pitanja o frustraciji do koje dolazi kod korištenja tehnologije ispitanici su istakli ove čimbenike:

- neispravan rad tehnologije – nemogućnost potpunog povjerenja
- neadekvatna podrška
- neiskorištena tehnologija uslijed nedovoljnog znanja

Intervju je pokazao kako uz znanje o radu tehnologije postoje i dodatni faktori, a to su: neispravan rad tehnologije i neadekvatna podrška. Ako povežemo ova dva nova faktora s dobivenim iz ankete i potvrđenim intervjuom može se doći do sljedećeg zaključka:

H0 - Nedovoljno poznavanje rada tehnologije dovodi do smanjivanja motivacije za rad s tehnologijom

H1 - Neispravan rad tehnologije dovodi do nepovjerenja i u krajnjem slučaju nekorištenja tehnologije u nastavi (smanjivanja motivacije)

H2 - Neadekvatna podrška ne omogućava uklanjanje problema s tehnologijom, a to dovodi do nekorištenja tehnologije u nastavi (smanjivanja motivacije).

Nadalje se može zaključiti da bi H1 i H2 bili u većinu slučajeva rješivi ili ne bi stvarali veliku frustraciju kada bi razina znanja u korištenju tehnologije bila veća (H0), a s time H1 i H2 možemo prikazati kao podhipoteze hipotezi H0.

C. *Dodatna analiza svih dobivenih podataka i zaključak preliminarnog istraživanja*

Kako bi se provjerili drugi (potencijalni) utjecaji na motiviranost nastavnika analizirani dodatni podaci i dobiveni su slijedeći zaključci:

- na motiviranost ne utječe spol, dob, razina stručnosti, područje stručnosti niti godine staža

Analizirana je i opća motiviranost i uspoređene su motiviranosti po školama, a dobiveni su slijedeći zaključci koji se mogu koristiti u daljnjim istraživanjima:

- visoko bazično motivirani (prosječna ocjena 4,35 od 5)
- nastavnici u gimnazijama i srednjim školama su jednako motivirani

IV. ZAKLJUČAK I DALJNJI RAD

Ovo istraživanje je pokazalo kako na motivaciju nastavnika za rad u nastavi utječe tehnologija, tj. da znanje o tehnologiji pozitivno utječe znanje na motivaciju jer smanjuje frustraciju u korištenju, bilo to zbog neispravne tehnologije ili neadekvatne podrške ili znanja korištenja svih mogućnosti tehnologije.

Ovo istraživanje je preliminarno i kao takvo ne bi se trebalo uzeti kao konačno već samo kao istraživanje koje je pokazalo rezultate s ovom metodologijom na ovim ispitanicima u ovim školama.

Sljedeći bi korak trebao biti ponavljanje još jednom takvog istraživanje na sličnom uzorku (slične veličine i sličnih ispitanika) kako bi se utvrdilo razlikuju li se podaci i odgovara li model. Ako se potvrdi da su podaci statistički jednaki trebalo bi se provesti veliko istraživanje koje bi moglo dovesti do generalizacije.

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Utjecaj korištenja micro:bit tehnologije na učenje programiranja u sklopu nastave informatike u osnovnoj školi

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***Sažetak* - Učenje programiranja najčešće je učenicima teško i apstraktno, no upotreba micro:bit računala trebala bi im omogućiti da na jednostavan način shvate načela programiranja te da ujedno postanu stvaraoci novih alata s kojima će moći unaprijediti učenje, riješiti problem ili samo se zabaviti. Cilj istraživanja ovog rada bio je ispitati postoji li utjecaj micro:bit tehnologije na učenje programiranja kod učenika šestih, sedmih i osmih razreda osnovne škole koji pohađaju izbornu nastavu informatike i prethodnih su godina učili programirati na klasičan način koristeći programski jezik QBASIC. Na uzorku od 164 učenika utvrđeno je da programirati voli njih 69,5% a više programirati uz upotrebu micro:bitova želi 76,2,% učenika. Da je zanimljivije programirati uz upotrebu micro:bitova potpuno se slaže 41,5% učenika, a da je jednostavnije smatra 45,1% učenika. Dobiveni rezultati pokazuju pozitivan utjecaj korištenja micro:bit tehnologije na učenje programiranja u sklopu nastave informatike u osnovnoj školi, no analizirajući odgovore po spolu može se zamijetiti puno veći interes za programiranjem kod dječaka, nego kod djevojčica.**

Ključne riječi – učenje programiranja, micro:bit, nastava informatike, osnovna škola

I. UVOD

Programiranje je računalom potpomognuto rješavanje problema, otklanjanje grešaka, razvijanje logičkog i računalnog razmišljanja [1], samopouzdanja, upornost i preciznost u ispravljanju pogrešaka te sposobnost komunikacije i zajedničkoga rada usmjerenoga prema postizanju određenoga cilja [2].

Prema prijedlogu nacionalnog kurikuluma nastavnog predmeta Informatike važnost poznavanja temeljnih informatičkih koncepata kao što su programiranje, algoritmi ili strukture podataka postaje neophodno kako učenici ne bili samo korisnici informacijsko-komunikacijske tehnologije (IKT) nego i stvaratelji [2].

No, programiranje je samo po sebi potpuno apstraktno i samim time teško za razumijevanje [3], a nastavni sadržaji iz programiranja učenicima su zahtjevni, ponekad i nezanimljivi jer ne vide odmah jasno njihovu stvarnu primjenu u svakodnevnom životu [4].

Današnji učenici smatraju programske jezike poput BASIC-a vizualno neprivlačnima, a čest izvor frustracija i demotivirajući faktor za učenje programiranja je to što takvi jezici zahtijevaju potpuno sintaktički (i semantički) ispravno napisan program [1]. Učenici više ne žele programirati samo zato da bi programirali, već radije kreiraju stvarne aplikacije npr. igre [5].

Većina učenika se prvi puta s programiranjem susreće u osnovnoj školi na nastavi informatike, pa se od učitelja informatike očekuje da pronađu najbolji način kako motivirati učenike i olakšati im učenje programiranja. Jedna od mogućnosti koja im se trenutno pruža je podučavati programiranje uz upotrebu micro:bit računala.

II. MICRO:BIT-NOVI PRISTUP PROGRAMIRANJU

BBC micro:bit je nova suvremena tehnologija koju su zajednički razvili tvrtke: BBC, Microsoft, Amazon, Samsung i drugi partneri s ciljem masovne uključenosti u osnovnim školama, ne samo u STEM[1] području, nego i u dizajnu, umjetnosti i ostalim predmetima. To je edukativni i kreativni alat čija svrha inspirirati mlade ljude i pomoći im steći znanje i sposobnosti da prerastu iz konzumenata digitalne tehnologije u dizajnere i stvaraoce novih alata s kojima će moći unaprijediti učenje, rješavati probleme ili jednostavno se zabaviti [6].

Micro:bit računalo je kompatibilno s naprednim programskim jezicima poput Pythona i C++, a Microsoft donosi i dva dodatna programa, Microsoft TouchDevelop[2] za tekstualno programiranje i za lakše kodiranje grafički programski jezik Microsoft Blocks. Nije potrebna posebna instalacija programskog jezika, programira se putem web preglednika, a može se programirati i putem mobilnih aplikacija za Android i iOS [7]. Zaslon micro:bita se sastoji od 25 LED-ova, dva programibilna gumba, te se može napajati putem USB-a ili eksternog baterijskog paketa [8]. Korištenjem svih navedenih značajki u znatno

[1] Akronim: Science, Technology, Engineering and Mathematics. Podrazumijeva područja znanosti, tehnologije, inženjerstva i matematike.
https://loops.hr/ict-pojmovnik-koristenih-termina/
[2] https://www.touchdevelop.com/

kraćem vremenu nego inače učenici savladaju sve bitne algoritamske koncepte, a onda klikom na jedan gumb dobiju uvid u kod u programskom jeziku JavaScript [9].

Djeci je takav način programiranja interesantan budući da više ne moraju „znati“ sintaksu programskog jezika, već intuitivno slažu programske naredbe koje koriste logiku puzzla. Ovo posebno dolazi do izražaja kada treba objasniti da program, odnosno računalo mora sam izvršiti zadatak, a ne onaj tko program izrađuje. To su situacije poput objašnjavanja kako varijabla pamti vrijednosti, ponavljanja dijelova programa, uvjetne situacije, ponavljanja naredbi s određenim brojem, itd.

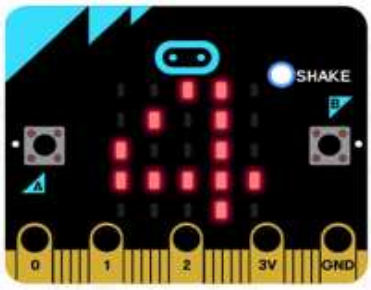
Primjeri zadataka sa upotrebom micro:bita:

1) Bacanje kocke[3] – igra „Čovječe ne ljuti se“

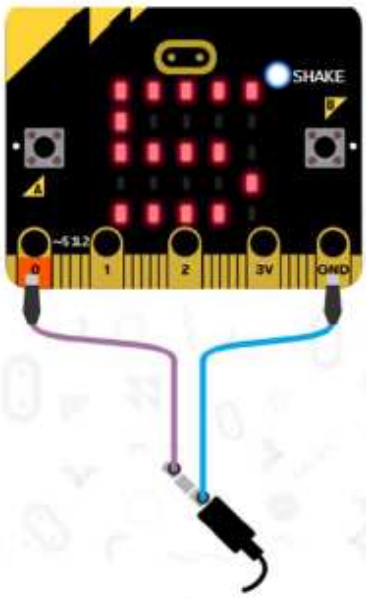
- Prepoznati da kocka ima samo brojeve od 1 – 6, a svaki broj na kocki dobiva se slučajnim ishodom („odabirom”).
- Rabeći micro:bit tehnologiju prilagoditi slučajni odabir brojeva od 1 do 6.
- Pokazati dobiveni broj kao rezultat „bacanja kocke” i primijeniti ga kao preduvjet ponavljanja reprodukcije tona onoliko puta koliko je dobiveni broj (vrijednost varijable).

Primjerom se želi objasniti veza vrijednosti varijable s naredbom za ponavljanje. Vrijednost koja je dobivena i pridružena varijabli uvjet je broju ponavljanja naredbe za reprodukciju tona (Slika 1., Slika 2a. i 2b.)

Slika 1. Bacanje kocke – KOD



Slika 2a. Simulator na webu koji prikazuje/simulira uređaj (micro:bit) – slučajni broj 4



Slika 2b. Simulator na webu koji prikazuje/simulira uređaj (micro:bit) – slučajni broj 5 (reprodukcija tona 5 puta)

2) Kviz[4] – „Miljunaš“ (četiri ponuđena odgovora)

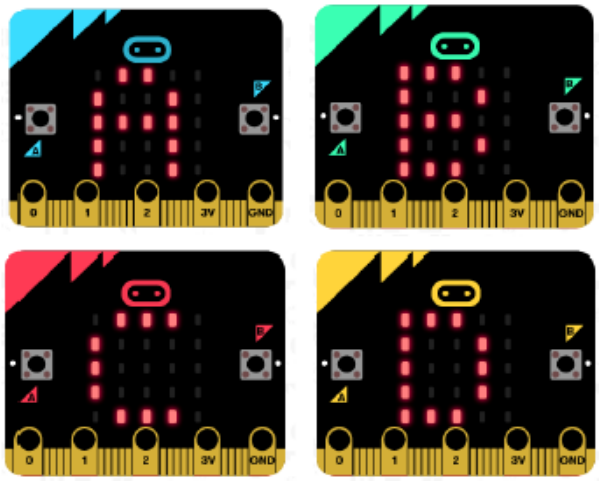
- Povezati da je ispunjenost uvjeta na početku ponavljanja preduvjet za početak igre. (Učitelj šalje radio – vezom stanje uvjeta).
- Utvrditi da vrijednost varijable utječe na njihov odabir odgovora (A, B ,C, D), kao rezultat ispitivanja uvjeta naredbom „if then“.
- Rezultat odabira se prikazuje na učiteljskom micro:bitu u obliku ispisa imena učenika i njihovih odgovora redoslijedom kako su ih poslali radio – vezom.

  U ovom primjeru učenici upoznaju naredbu ponavljanja (petlju) kako bi očitali vrijednosti varijable koju koriste kao „okidač“ kada njihovi micro:bit-ovi mogu slati odgovore. Naredbom za ispitivanje uvjeta odlučuju na temelju koje pritisnute tipke micro:bita treba poslati odgovor kao odabir kviz pitanja (Slika 3. i Slika 4.).

[3] Početna ideja preuzeta sa mrežne stranice: http://izradi.croatianmakers.hr/project/kockica/

[4] Ideja preuzeta sa mrežne stranice: http://izradi.croatianmakers.hr/project/kviz-uz-microbit/

Slika 3. Kviz – KOD



Slika 4. Simulator na webu koji prikazuje/simulira uređaj (micro:bit) – odgovor A, B, C ili D [10]

O pozitivnom utjecaju BBC mikro:bita na učenike i učitelje govore i akademska istraživanja provedena u Velikoj Britaniji [11].

- 90% učenika kaže da im je micro:bit dokazao da svatko može programirati.
- 86% učenika kaže da im je micro:bit učinio računalnu znanost zanimljivijom.
- 70% više djevojčica kaže kako će odabrati računalstvo kao predmet u školama nakon što su isprobale micro:bit.
- 85% nastavnika se slaže da je micro:bit njihovim učenicima IKT/računalstvo učinio zabavnijim.

Sentence, Waite, Hodges, MacLeod, Yeomans u svom su radu [12] intervjuirali 15 nastavnika i 54 učenika u školama u Engleskoj o njihovim iskustvima s BBC micro:bitom obzirom na jednostavnost upotrebe, fizički doživljaj uređaja, kreativnost i vještinu programiranja. Rezultati pokazuju da micro:bitovi učenike potiču na kreativnost te da lako stvaraju poveznicu između učenja programiranja i kreiranja digitalnih proizvoda. To im omogućuje da uoče važnost kodiranja i povežu to sa stvarnim svijetom.

A. Micro:bit – STEM revolucija

Udruga IRIM (Institut za Razvoj i Inovativnost Mladih) pod nazivom Croatian Makers dovodi STEM aktivnosti u hrvatske škole nizom inicijativa. U siječnju 2017. pokrenuli su *crowdfunding* [5] kampanju STEM revolucija za masovno uvođenje micro:bit tehnologije u škole i druge ustanove [13]. Kako bi korisnicima olakšali rad sa micro:bitovima razvili su bogati web edukacijski sadržaj podijeljen u više kategorija: osnovni i napredni edukacijski materijali, predmetni materijali za nastavnike, dodatne poveznice na vanjske stranice s mnoštvom primjera te učenički projekti s micro:bitovima [14]. Ovim projektom udruga IRIM - Croatian Makers želi stvoriti aktivnu zajednicu nastavnika, edukatora i svih ostalih koji rade s djecom, ali i šire: pravo civilno društvo, angažirano i aktivno u promjeni i poboljšanju školstva i obrazovanja u Hrvatskoj [13]. Konačni cilj projekta je da se svakom učeniku 6. ili 7. razreda osnovnih škola u Hrvatskoj osigura korištenje BBC micro:bit računala [6].

Početkom veljače 2017. udruga IRIM - Croatian Makers otvorila je natječaj za uključenje osnovnih i srednjih škola, udruga, knjižnica i drugih ustanova koje rade s djecom u STEM revoluciju, s ciljem besplatne donacije BBC micro:bitova. Na natječaj su se javili i učitelji informatike III. i IV. osnovne škole Varaždin te tako osigurali po 20 micro:bit računala za svoje učenike. Kroz jednodnevnu edukacijsku radionicu u organizaciji udruge „Mis" [6] učitelji su upoznali osnove rada s micro:bitovima, a nakon toga nastavili su ih koristiti u sklopu izvannastavne aktivnosti iz informatike. Zbog velikog odaziva učenika od školske godine 2017./2018. micro:bitove koriste na izbornoj nastavi informatike kao zamjenu za QBASIC „stari" programski jezik.

III. METODOLOGIJA ISTRAŽIVANJA

Cilj istraživanja opisanog u ovome radu bio je ispitati postoji li utjecaj korištenja micro:bit tehnologije na učenje programiranja u sklopu nastave informatike u osnovnoj školi kod onih učenika koji su prethodnih godina učili programirati na klasičan način koristeći programski jezik QBASIC, obzirom da su sada mogli usporediti novi način učenja programiranja sa starim.

[5] Crowdfunding je proces traženja javnih donacija za dobivanje početnog kapitala za nove pothvate
http://ekonomskiportal.com/crowdfunding/
[6] Udruga „Mis" Strahoninec
http://www.udruga-mis.hr/

Istraživanje je provedeno školske godine 2017./2018. na uzorku od 164 učenika (47,6% ženskih i 52,4% muških ispitanika) šestih, sedmih i osmih razreda III i IV. osnovne škole Varaždin nakon što su učenici nastavnu cjelinu programiranja obradili uz korištenje micro:bitova.

Za potrebe istraživanja kreiran je online anketni upitnik koji se sastojao od pitanja zatvorenog tipa kojima se ispitivalo vole li učenici uopće programirati, koriste li mico:bitove i na nekim drugim predmetima te žele li više koristiti micro:bitove na nastavi informatike, a Likertovom skalom od 5 stupnjeva se kod ispitanih učenika željela utvrditi zanimljivost i jednostavnost upotrebe micro:bitova u programiranju.

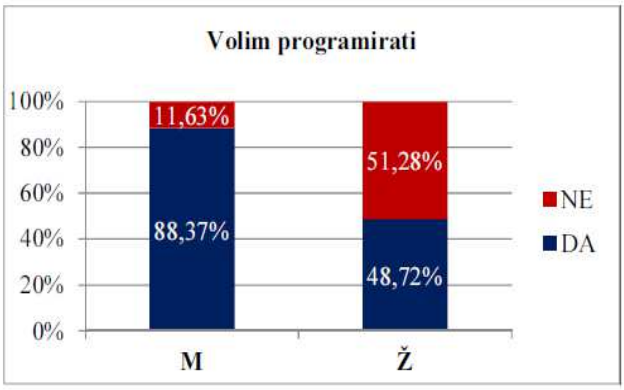
U radu se polazi od sljedećih hipoteza:

1. (H1) Dječaci i djevojčice podjednako vole programirati
2. (H2) Učenici žele više programirati sa micro:bitovima na nastavi informatike
3. (H3) Učenicima je koristeći micro:bitove zanimljivije i jednostavnije programirati

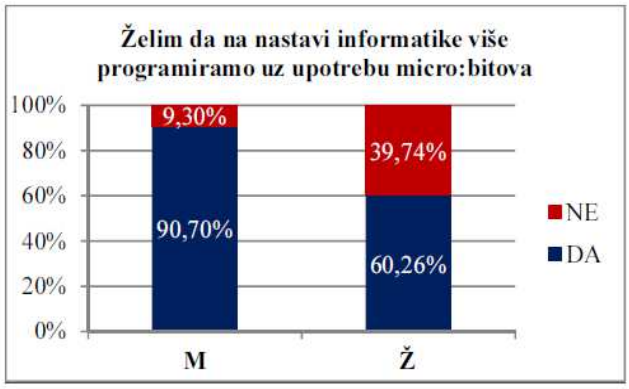
A. Rezultati istraživanja

Pri odgovaranju na tvrdnju da li vole programirati čak 69,5% učenika izjasnilo se potvrdno, a 30,5% negiralo je ovu tvrdnju. No, analizirajući odgovore po spolu utvrđeno je da od ukupnog broja ispitanih dječaka njih 88,4% vole programirati, dok od ukupnog broja ispitanih djevojčica programirati voli samo 48,7% (Slika 5.). Obzirom na statistički značajnu razliku između muških i ženskih ispitanika ovi podaci opovrgavaju prvu hipotezu (H1).

Obzirom da se na tvrdnju „Želim da na nastavi informatike više programiramo uz upotrebu micro:bita“ 76,2,% učenika izjasnilo potvrdno, a samo 23,8% navelo je kako to ne žele, dobiveni rezultati potvrđuju drugu hipotezu (H2). Ako analiziramo podatke prema spolu tada 90,7% dječaka i samo 60,3% djevojčica želi više koristiti micro:bitove u programiranju (Slika 6.).



Slika 5. Postotak učenika prema spolu koji su odgovorili vole li programirati, N=164



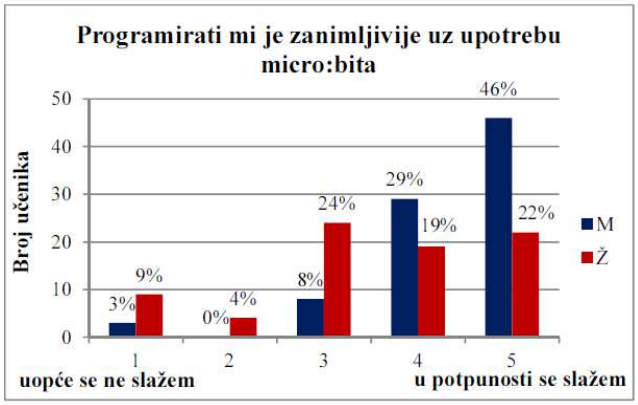
Slika 6. Postotak učenika prema spolu koji su odgovorili žele li na nastavi informatike više programirati uz upotrebu micro:bita, N=164

Detaljnijom analizom utvrđena je međusobna ovisnost između prve dvije tvrdnje:

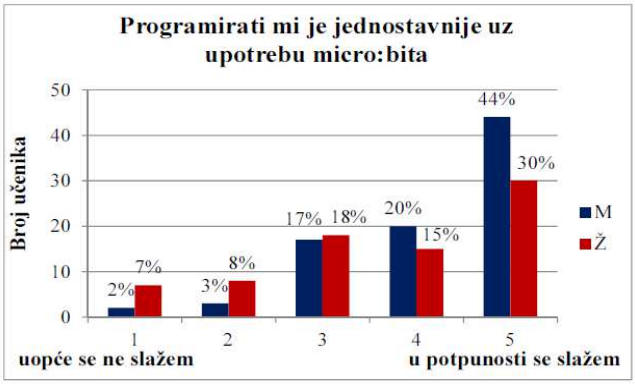
- Programirati voli 64% učenika (41% djevojčica i 84,9% dječaka) i ujedno želi da na nastavi informatike više programiraju uz upotrebu micro:bita
- Programirati voli 5,5% učenika (7,7% djevojčica, 3,5% dječaka), ali ne želi da na nastavi informatike više programiraju uz upotrebu micro:bita
- Iako ne vole programirati žele da na nastavi informatike više programiraju uz upotrebu micro:bita 12,2% (19,2% djevojčica, 5,8% dječaka).

Ovdje dobiveni podaci pokazuju da iako je prethodno utvrđeno kako je više djevojčica od dječaka koje ne vole programirati, njih čak 19,2% želi na nastavi informatike više programirati uz upotrebu micro:bitova, pa stoga zaključujemo da micro:bitovi imaju pozitivan utjecaj na želju za učenjem programiranja kod djevojčica.

Likertovom skalom od 5 stupnjeva (1 - uopće se ne slažem; 5 - u potpunosti se slažem) učenici su ocjenjivali zanimljivost i jednostavnost programiranja uz upotrebu micro:bitova u sklopu nastave informatike. Dobiveni rezultati pokazuju da 41,5% učenika (28,2% djevojčica, 53,5 dječaka) u potpunosti se slaže da je zanimljivije programirati uz upotrebu micro:bitova, dok se 7,3% učenika (11,5%, djevojčica, 3,5% dječaka) s ovom tvrdnjom uopće ne slaže. Da je jednostavnije programirati uz upotrebu micro:bitova smatra 45,1% učenika (38,5% djevojčica, 51,2% dječaka) (Slika 7.), a 5,5% učenika (9% djevojčica, 2,3% dječaka) se s time uopće ne slaže (Slika 8.). Ovi rezultati potvrđuju treću hipotezu (H3) da je učenicima koristeći micro:bitove zanimljivije i jednostavnije programirati. Ovdje kao i kod prethodne dvije tvrdnje može se zamijetiti veći interes za programiranjem kod dječaka, nego kod djevojčica.



Slika 7. Slaganje s tvrdnjom da li je programirati zanimljivije uz upotrebu micro:bita, N=164



Slika 8. Slaganje s tvrdnjom da li je programirati jednostavnije uz upotrebu micro:bitova, N=164

IV. ZAKLJUČAK

Obzirom da učenici smatraju stare programske jezike vizualno neprivlačnima i najčešće ne vide jasno njihovu stvarnu primjenu u svakodnevnom životu [4] mogućnost unapređenja učenja programiranja prepoznata je upotrebom micro:bitova. Jednostavnost, svestranost i pristupačan način korištenja te mogućnost bežičnog spajanja čine ovaj uređaj laganim i zabavnim polazištem za ulazak djece u digitalni svijet [13].

U ovome radu ispitan je utjecaj korištenja micro:bit tehnologije na učenje programiranja u sklopu nastave informatike u osnovnoj školi, a posebice postoji li u tome značajna razlika između ženskih i muških ispitanika. Uzorak se sastojao o 164 učenika šestih, sedmih i osmih razreda III. i IV. Osnovne škole Varaždin gdje se od 2017./2018. školske godine micro:bitovi koriste kao zamjena za QBASIC „stari“ programski jezik na izbornoj nastavi informatike.

Dobiveni rezultati istraživanja u potpunosti opovrgavaju postavljenu hipotezu da dječaci i djevojčice podjednako vole programirati, jer analizirajući odgovore utvrđeno je da od ukupnog broja ispitanih dječaka njih 88,4% vole programirati, dok od ukupnog broja ispitanih djevojčica programirati voli samo 48,7%. No, rezultati obrađenih anketa potvrđuju drugu postavljenu hipotezu kojom je utvrđeno da 76,2%, učenika želi više programirati sa micro:bitovima na nastavi informatike, a obzirom da se čak 41,5% učenika u potpuno se slaže da je zanimljivije programirati uz upotrebu micro:bitova, a 45,1% učenika smatra da je jednostavnije programirati uz upotrebu micro:bitova potvrđuje se i treća postavljena hipoteza. Detaljnijom analizom i ovdje se primjećuje razlika u odgovorima između dječaka i djevojčica, gdje dječaci više pokazuju interes za programiranjem. Vjerujemo da će učestalija upotreba micro:bitova s vremenom to promijeniti, pa će želja da nauče programirati podjednako biti prisutna kod djevojčica i kod dječaka.

Učenici su također ispitani koriste li micro:bitove i na drugim predmetima. Tek 13,4% ispitanika odgovorilo je potvrdno, dok se njih 88,6% izjasnilo da micro:bitove ne koristi. No, obzirom na mogućnost široke primjene micro:bitova u različitim područjima, nadamo se da će dobiveni podaci u ovom istraživanju o pozitivnim iskustvima učenika vezano za njihovu upotrebu na nastavi informatike, potaknuti i druge nastavnike da ih počnu koristiti u sklopu svojih predmeta i izvananstavnih aktivnosti.

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BYOD u obrazovanju

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Sažetak

Činjenica da su pametni telefoni, tableti i prijenosna računala sastavni dijelovi života svakog čovjeka, a posebno mladih ljudi omogućuje aktivno prihvaćanje tih uređaja za obrazovanje. Škole i sveučilišta širom svijeta isprobavaju BYOD (Bring Your Own Device) kao dinamičnije okruženje za učenje, gdje učenici donose i koriste svoj izbor pomoćnih uređaja u učionici s kojima mogu raditi i kod kuće. BYOD u obrazovanju nudi mnoge nove mogućnosti učenja i prednosti s povećanom angažiranošću učenika u učenju kao i poboljšanim uključivanjem u nastavne aktivnosti. Međutim, BYOD također zahtijeva nove pristupe učenju i poučavanju. Važno je razmotriti pedagogiju, spremnost nastavnika te politiku škole. Dopuštenje učenicima da ponesu sa sobom u učionicu svoje pametne telefone omogućuje također neophodan pomak u kulturi škole.

Postoji više oblika modela BYOD-a koji se analiziraju prema scenarijima primjene odnosno prema odabiru uređaja koje će učenici i nastavnici koristiti. Budući da svi učenici trebaju imati jednak pristup uređajima koji se koriste u procesu učenja, škola mora imati na raspolaganju dodatne uređaje koji se mogu posuditi pojedinim učenicima.

U radu je analizirana anketa provedena u siječnju 2018. godine među učenicima Tehničke škole u Požegi, vezana za primjenu mobilnih uređaja u nastavi i učenju. Učenici su naglasili da će BYOD povećati njihovu angažiranost u nastavi, omogućiti brži pristup informacijama istraživanja te digitalnim resursima.

Ključne riječi – BYOD; telefoni; tableti; prijenosna računala; mobiteli; politika škole; modeli BYOD-a; sigurnost; vlastiti uređaj

I. UVOD

Pojam BYOD (skraćenica engleskog izraza Bring Your Own Device – donesi svoj vlastiti uređaj) ušao je u uobičajenu uporabu 2009. godine zahvaljujući tvrtki Intel koja je prepoznala sve veću tendenciju među svojim zaposlenicima da donesu vlastite uređaje (npr. pametne telefone, tablete i prijenosna računala) te s njima rade i povezuju ih s korporacijskom mrežom [1]. Poslodavci u svijetu i Republici Hrvatskoj sve više koriste ovaj način rada zbog fleksibilnosti zaposlenika, povećanja produktivnosti, uštede, veće konkurentnosti, podržavanja rada na daljinu te praćenja trendova u tehnologiji. Koncept se je iz poslovnog svijeta prenio u obrazovne ustanove.

Unatoč pojedinim nedostacima, prednosti koje BYOD nudi daju mu sve veću popularnost i očekuje se njegova integracija u mnogim obrazovnim ustanovama širom svijeta. BYOD postaje nadolazeća revolucija koju će svijet obrazovanja uskoro doživjeti.

Današnja generacija učenika odrasla je s tehnologijom i želi ju koristiti u svakom aspektu svakodnevnog života - uključujući školu. Očekuju da će ista tehnologija koju koriste kod kuće biti dostupna i u školi. Škole omogućuju učenicima da koriste osobne uređaje za aktivnosti vezane uz nastavni plan i program Mnogi vide upotrebu tehnoloških sredstava u učionici kao prirodni način za kretanje naprijed uz praćenje novih tehnologija jer jedan od ključeva uspjeha škole je svijest o potrebi da bude na vrhu tehnoloških trendova. Unatoč očiglednim prednostima, priljev mobilne tehnologije u obrazovnim sustavima izazvao je reakciju roditelja i nastavnika.

II. PREDNOSTI UPORABE BYOD-A U OBRAZOVANJU

BYOD čini proces obrazovanja jeftinijim, jer škole ne moraju instalirati svoje tehnološke uređaje odnosno štedi se novac zbog stalnog ulaganja u nove tehnologije. Osobni mobilni uređaji učenika obično su najsuvremeniji, tako škole lakše prate trendove u tehnologiji. Učenici postaju organiziraniji sa svim svojim bilješkama i zadaćama. Neograničen im je pristup informacijama i resursima. U nastavnom procesu oni i nastavnici razmjenjuju svoje uloge.

Najvažnija prednost koju BYOD nudi je zasigurno udobnost korištenja vlastitog uređaja. Kada učenici donose svoje uređaje u školu, donose uređaj koji dobro poznaju. Mogu ga koristiti bez poteškoća i lakše se usredotočiti na nastavu jer ne moraju razmišljati o upravljanju potpuno nepoznatim uređajima. Učenici su već upoznati s tehnologijom i aplikacijama koje koriste. Preuzimaju kontrolu kako bi osigurali da njihov uređaj pravilno radi, a pri tome se potiče njihov osjećaj odgovornosti.

Većina učenika voli svoje uređaje više nego bilo što drugo, zbog čega ostaju vezani za njih tijekom cijelog dana. Motivirani su većom brigom o njihovim uređajima nego što bi imali kod uređaja u vlasništvu škole. Korištenje tih uređaja u nastavi je odličan način kako iskoristiti učeničku ljubav prema svojim uređajima. Očekuje se da će to biti učinkovitije od tradicionalne metode podučavanja. Učenici vole tehnologiju čime ih BYOD više angažira, stvara entuzijazam, izazov i uzbuđenje u učenju uz brojne zanimljive obrazovne aplikacije. Omogućeno je personalizirano učenje gdje učenici uče vlastitim tempom [2].

Napredak na području tehnologije pomogao je uvođenju velikog broja uređaja pri čemu mnogi od njih imaju svojstva koja ubrzavaju nastavni proces, olakšavaju rad učenicima i pomažu da što dulje budu uključeni u aktivnosti nastave. Učenici uz pravilnu uporabu vlastitih uređaja uče

učinkovitije. Učitelji mogu koristiti određene aplikacije kako bi bili više povezani s učenicima i roditeljima.

Učenici će također vjerojatnije nastaviti učiti ili dovršiti zadaće na svom uređaju izvan nastave, što povećava produktivnost, dok se suradnja i izvan učionice poboljšava upotrebom dodatnih aplikacija kao što su Google Apps for Education ili Office 365. BYOD može pružiti učenicima daleko veće mogućnosti za međusobnu komunikaciju s nastavnicima i rad s drugim učenicima na zadacima, projektima i stvaranju sadržaja.

Korištenje aplikacija koje nadopunjuju postojeću nastavnu pedagogiju može uštedjeti vrijeme. Nastavnici mogu pratiti rad učenika u stvarnom vremenu i lako zadavati nove aktivnosti i projekte. Te aplikacije omogućuju nastavnicima prilagodbu učenja prema sposobnosti svakog učenika, pri čemu oni povećavaju životne vještine radeći s najnovijim tehnologijama koje će koristiti u budućnosti. Ugrađivanje mobilnih računalnih uređaja u vlasništvu učenika u nastavni plan i program pomaže transformirati izravne metode poučavanja u učenje temeljeno na istraživanju [3].

III. NEDOSTACI I IZAZOVI UPORABE BYOD-A U OBRAZOVANJU

Kako smanjiti distrakciju tijekom nastave? Čak i ako je nekoliko web stranica blokirano, nekoliko učenika će ih možda uspjeti deblokirati i posjetiti ako to žele. Važno je osigurati da učenici koriste svoj uređaj za učenje, a ne za osobnu upotrebu unutar nastave. S uređajima u vlasništvu škole, to se može postići pomoću alata za filtriranje i praćenje kako biste ograničili i provjerili sadržaje koje učenici mogu tražiti. Međutim, s uređajima u vlasništvu učenika, problem je izraženiji. Škola mora razviti snažnu politiku e-sigurnosti, koja je usko povezana s roditeljima, pri čemu informira i poučava učenike da se zaštite na internetu. Postoje proizvodi za upravljanje mobilnim uređajima koji školama omogućuju postavljanje različitih profila koji provode online ograničenja prilikom ulaska učenika u školsko okruženje. Neki od ovih proizvoda također imaju roditeljske portale kako bi roditeljima omogućili pregled djetetova korištenja interneta.

Budući da učenici potencijalno koriste širok spektar uređaja, nastavnici bi morali postati stručnjaci za svaku vrstu uređaja kako bi im pomogli te omogučili rad resursa i aplikacija na različitim operacijskim sustavima. Ako škola može ograničiti broj različitih uređaja i operacijskih sustava onda je upravljanje tim uređajima mnogo jednostavnije.

BYOD predstavlja nekoliko sigurnosnih problema. Razmjena velike količine podataka može rezultirati krađom. Ovo je važno pitanje u poslovnim uredima i trgovačkim organizacijama, međutim, također je važno poduzeti potrebne korake kako bi se osigurala sigurnost pri implementaciji BYOD-a u obrazovnim ustanovama [4].

Brojni mobilni uređaji mogu preopteretiti školsku bežičnu mrežu. Otvara se mogućnost za varanje. Tehnologija može postati statusni simbol za učenike čime se uzrokuje podjela učenika. Roditelji možda nisu zadovoljni idejom plaćanja mobilnih uređaja za korištenje u školi [2]. Ako je u lokalnoj zajednici poznato da učenici donose svoje uređaje u školu, mogućnost krađe je veća. Odgovornost je na školama u smislu osiguravanja da njihovi učenici budu sigurni sa svojim fizičkim uređajima.

Mnogi od ovih nedostataka mogu se izbjeći ili riješiti s određenim pravilima, aplikacijama, ispravnom mrežnom infrastrukturom i upravljanjem mobilnim uređajima.

IV. MODELI IMPLEMENTACIJE BYOD-A

Brojne škole u svijetu istražuju i analiziraju načine uvođenja BYOD politike u školske programe. Važno je pružati podršku i obuku nastavnicima te instalirati široku Wi-Fi mrežu. Školski odbori proučavaju i prihvaćaju prijedloge kako bi omogućili promjene koje će pomoći učenicima i nastavnicima integrirati tehnologiju u učionice.

Škole koje su uvele BYOD program, razvile su pravila, odnosno dokumente o digitalnom građanstvu koji opisuju očekivana ponašanja i društvene norme online društva. To pomaže učenicima razumjeti i regulirati ponašanje na internetu u školi.

Škole moraju biti osjetljive na potrebe i mogućnost vlasništva uređaja kod svih učenika. Ako neki od njih ne posjeduju vlastiti uređaj, treba osigurati da preuzmu školski pri čemu bi škole trebale posjedovati malu količinu vlastitih uređaja.

Primjena BYOD-a u školama može se razmatrati kroz tri scenarija. Najednostavniji je onaj u kojem pojedini nastavnici u školi dopuštaju učenicima da donose svoje pametne telefone u učionice te u suradnji traže načine kako ih koristiti kao podršku učenju. Pri tome su nastavnici motivirani i željom da pokušaju aktivirati i doprijeti do svih učenika, posebno onih koji nisu zainteresirani za nastavu. Nastavnik će svojim odlukama možda raditi protiv službene školske politike. Međutim svoja iskustva može prenijeti ostalim nastavnicima i potaknuti ih da isprobaju BYOD, koji se time postupno širi u školi.

U drugom scenariju ravnatelj škole odlučuje dopustiti starijim učenicima da koriste mobilne uređaje za nastavne aktivnosti. Nastavnici se potiču, ali nisu dužni dopustiti korištenje mobilnih uređaja na njihovoj nastavi. Ako su zainteresirani, mogu pohađati radionice o pedagoškom korištenju mobitela. Neki učenici neće donijeti uređaje u školu i pojedini nastavnici neće dopustiti koristiti ih u svojim učionicama odnosno neće u potpunosti iskoristiti potencijal učenika kako bi unaprijedili nastavu i učenje.

Treći scenarij je planirani i kontrolirani školski pristup primjene BYOD-a. Ravnatelji odlučuju, u dogovoru s nastavnicima, zahtijevati od svih roditelja financiranje tableta za učenike kako bi ih koristili u nastavi i učenju kod kuće. Kako bi se pružila što lakša tehnička podrška školskom osoblju, te izbjegle brige roditelja i škole o potencijalnoj nejednakosti uređaja koje koriste učenici, odlučeno je da svi uređaji budu jednaki. Škola ulaže sredstva u poboljšanu širokopojasnu mrežu i nadograđuje Wi-Fi mrežu kako bi zadovoljila planirano povećanje internetskog prometa [6].

S tehničkog kao i pedagoškog razmatranja, ne postoji jedno BYOD rješenje za sve škole koje ga žele primjeniti. Jedna srednja tehnička škola koja ima nekoliko zgrada u jednom gradu imati će različite potrebe od male osnove škole u ruralnoj sredini. Postoje mnogi čimbenici koji utječu na tehničke zahtjeve BYOD-a, time na izbor i odluke škole [7].

Čimbenici koji utječu na izbor tehničkog modela BYOD-a su: lokacija poučavanja/učenja, veličina obrazovne ustanove, tip ustanove kao građevine, postojeća infrastruktura, organizacija tehničke podrške, broj i vrsta mobilnih uređaja, pristupi kurikulumu, ambicija organizacije, pravila uporabe i pristupa, dob učenika (slika 1).

Slika 1. Čimbenici koji utječu na tehničke zahtjeve BYOD-a u školi [7]

Školske vlasti mogu upravljati BYOD modelima na različite načine, od visokih standardizacija (ograničavajući uređaje na određene modele) do velike fleksibilnosti (dopuštajući bilo koji uređaj koji se može povezati na internet). Važno je imati jasnu viziju željenih

obrazovnih ishoda i dizajn modela za njihovo postizanje s obzirom na različite potrebe učenja.

Postoji niz izazova u provedbi BYOD-a, uključujući:

• Povećani mrežni promet. Dok učenici koriste svoje uređaje, broj uređaja koji istodobno pristupaju mreži značajno se povećava. Škola mora imati odgovarajuće kapacitete i širinu pojasa za potporu učenicima u učenju s ovim uređajima.

• Digitalna pravednost: ne mogu si sve obitelji priuštiti osobne uređaje ili pristup internetu kod kuće.

• Odgovorni/prikladni ugovori o korištenju: važno je osigurati da su s politikom korištenja BYOD-a upoznati nastavnici, učenici i roditelji.

• Pedagogija/spremnost učitelja: prije i tijekom provedbe BYOD programa, potrebno je omogućiti profesionalni razvoj nastavnika, redizajniranje učenja i podršku programima koji razvijaju digitalno građanstvo[8].

Prema odabiru uređaja koje će učenici i nastavnici koristiti za BYOD razlikujemo slijedeće modele:

1) Učenici/roditelji odabiru uređaj koji donose u školu. Ovaj model je najmanje opterećenje roditeljima koji su već kupili uređaj za svoje dijete za kućnu upotrebu jer nema potrebe za kupnju dodatnog uređaja posebno za školu. Model može biti problematičan za školu jer školska mreža možda ne podržava sve različite uređaje. Nastavnici i tehničko osoblje moraju biti upoznati s nekoliko operacijskih sustava i različitim uređajima. Većina programa ili aplikacija nije dostupna preko svih operacijskih sustava. Širok raspon uređaja i funkcionalnosti uređaja izaziva znatnu složenost u učionici.

2) Škola određuje uređaje koje učenici mogu donijeti u školu. Ovaj model pretpostavlja da će škola usmjeravati roditelje na kupnju određenog uređaja koji je kompatibilan sa školskom mrežom. To osigurava da svi uređaji koji se unose u školu imaju iste mogućnosti i dobru komunikaciju sa školskom mrežom. Osim toga, ovaj model osigurava da su uređaji koje učenici koriste slični i kompatibilni s nastavničkim uređajem.

3) Škola uspostavlja kriterije za odabir uređaja koje će učenici koristiti. Ovaj model daje roditeljima fleksibilnost pri kupnji uređaja. Učenici ili roditelji mogu već posjedovati uređaj koji odgovara kriterijima ili mogu biti dostupni roditeljima po različitim cijenama.

Bez obzira na odabrani model, škole moraju osigurati da svi učenici imaju pristup uređaju tijekom boravka u školi. Očekuje se da neki učenici, iz bilo kojeg razloga, možda neće moći donijeti vlastiti uređaj u školu. Važno je da škola ima na raspolaganju dodatne uređaje koji se mogu posuditi tim učenicima. Svi učenici trebaju imati jednak pristup uređajima koji se koriste u procesu učenja [9].

V. BYOD U ŠKOLAMA EUROPE

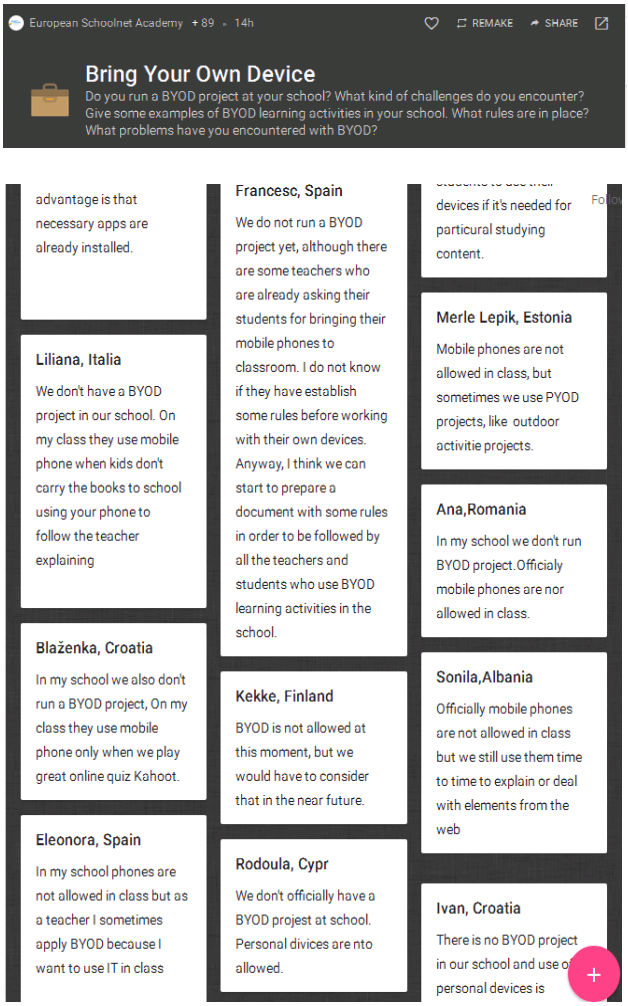
U većini zemalja mobiteli su zabranjeni u školi. Učenici u principu imaju mobitele, ali ih tijekom nastave ne smiju koristiti. To se odnosi i na učenike i na nastavnike. U Republici Hrvatskoj „Pravilnikom o kriterijima za izricanje pedagoških mjera“, korištenje mobitela u školi spada pod ‘‘lakše neprihvatljivo ponašanje’’. Objavljivanje snimki koje uključuju nasilje se kažnjava. Negativnosti mobitela te ne priznavanje njihova doprinosa kvaliteti nastavnog procesa, nastavnici i škole procjenjuju na osnovu negativnih iskustava u kojima su učenici zlorabili mogućnosti mobitela. Francuska vlada najavila je zabranu mobilnih telefona u osnovnim školama. Djeci će i dalje biti dozvoljeno donositi mobitele u školu, ali ih neće smjeti koristiti sve do završetka nastave, pa čak ni za vrijeme odmora. Ova zabrana stupiti će

na snagu početkom sljedeće školske godine, točnije u rujnu 2018., te će se odnositi na sve učenike od 6 do 15 godina starosti.

Postoje brojne aplikacije koje su nastavnicima u radu dobro došle, ali za mnoge škole problem je kako ograničiti druge funkcije kojima učenici ometaju nastavu. Učenici mobitelima razmjenjuju poruke oko zadaća, zadataka. Razmjena sadržaja pomoć je učenicima koji nisu bili u školi.

Mnogi nastavnici, svjesni mogućnosti koje pruža BYOD, pokušavaju samostalno, unatoč zabrani uporabe mobitela, uvesti njihovu primjenu u nastavu. Vidljivo je to iz aktivnosti razmjene iskustava polaznika online tečaja „Administering School ICT infrastructure: developing your knowledge and skills (2nd edition)“, u organizaciji European Schoolnet Academy. Polaznici/nastavnici komentirali su primjenu BYOD-a u svojoj školi, izazove na koje nailaze, primjere aktivnosti učenja putem BYOD-a, pravila i probleme na koje nailaze (slika 2) [10].

U Europi se povećava interes za BYOD u školama zbog visoke razine posjedovanja mobilnih uređaja kod učenika i nastavnika, sveprisutnosti javne Wi-Fi mreže, te brze širokopojasne mreže i povećanja dostupnosti mobilnog interneta. Strategija BYOD obično se provodi u bogatijim



Slika 2. Komentari polaznika online tečaja „Administering School ICT infrastructure: developing your knowledge and skills (2nd edition)“ na Padlet online zidu o iskustvima primjene BYOD-a u školi [10]

zajednicama u kojima je vlasništvo mobilnih uređaja među mladim ljudima gotovo sveprisutno.

Iz dijagrama na slici 3. vidljivo je da među 20 prikazanih europskih zemalja, u samom vrhu, koji prelazi prosječnu vijednost od 75% škola koje primjenjuju BYOD su: Danska, Portugal, Rumunjska, Švedska, Španjolska, i Estonija. Najveći postotak škola u Danskoj, Portugalu i Švedskoj također pružaju usluge podrške primjene BYOD-a [6].

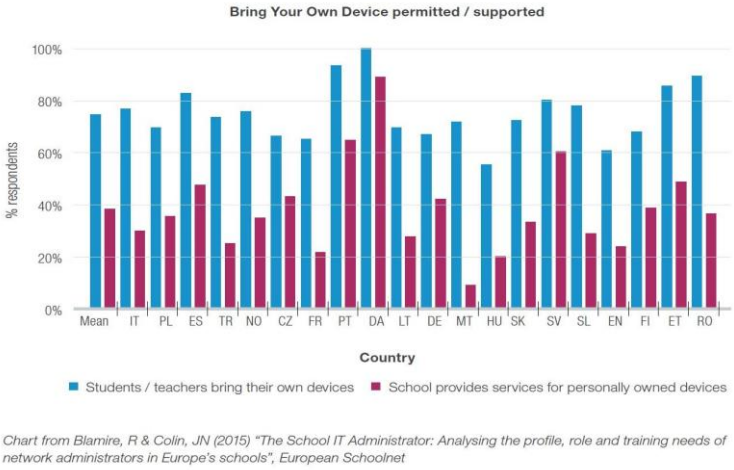


Chart from Blamire, R & Colin, JN (2015) "The School IT Administrator: Analysing the profile, role and training needs of network administrators in Europe's schools", European Schoolnet

Slika 3. Dijagram 20 europskih zemalja čije škole imaju veći postotak primjene BYOD-a [6]

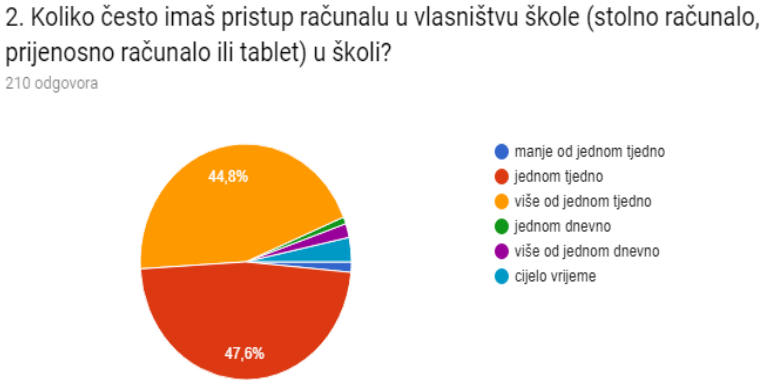
VI. ANALIZA ANKETIRANJA UČENIKA

Mobiteli su prerasli u snažne multimedijske alate koje je moguće koristiti na nastavi u svrhu motivacije, razvoja kreativnog i kritičkog mišljenja učenika te razvijanja vještina suradničkog rješavanja problema.

U cilju istraživanja povratnih informacija učenika o dopuštenju da donose vlastite uređaje za aktivnosti povezane sa školom kao što su bilježenje, istraživanje, rad na projektima, komuniciranje s učenicima i nastavnicima, provela sam među učenicima škole anketiranje.

Anketa je provedena tijekom siječnja 2018. godine na prigodnom uzorku od 210 učenika Tehničke škole u Požegi. Za potrebe istraživanja izrađen je online anketni upitnik s 13 pitanja. Slijedi prikaz analize nekoliko pitanja iz ankete.

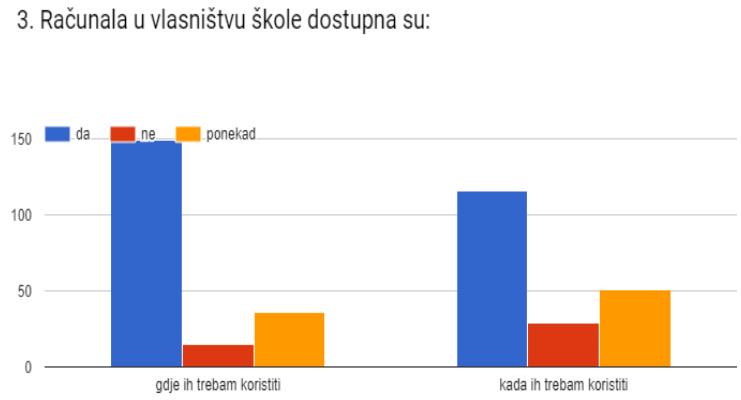
Slika 4. prikazuje koliko često učenici imaju pristup školskim računalima. Većina je odgovorila jednom tjedno ili



Slika 4. Dijagram prikaza učeničkog pristupa školskim računalima (online anketa)

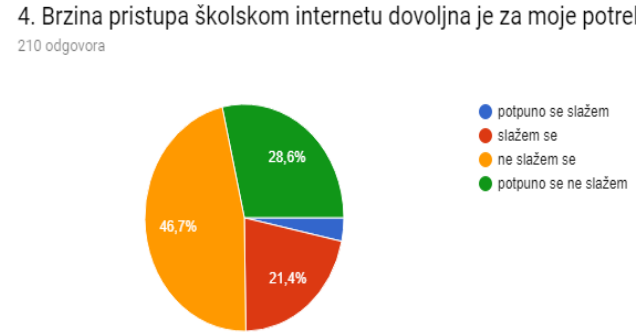
više od jednom tjedno, ovisno o nastavnim predmetima (informatika ilil stručni predmeti) dok opcije jednom dnevno ili više od jednom dnevno su vrlo rijetke.

U pitanju vezanom za primjenu školskih računala kada i gdje ih trebaju koristiti, učenici su većinom zadovoljni pristupom njima, više gdje ih trebaju koristiti (vježbe) nego kada ih trebaju koristiti (slika 5.).



Slika 5. Dijagram prikaza uporabe školskih računala kada i gdje ih učenici trebaju (online anketa)

Brzinom pristupa internetu dok su u školi većina učenika nije zadovoljna (slika 6.).

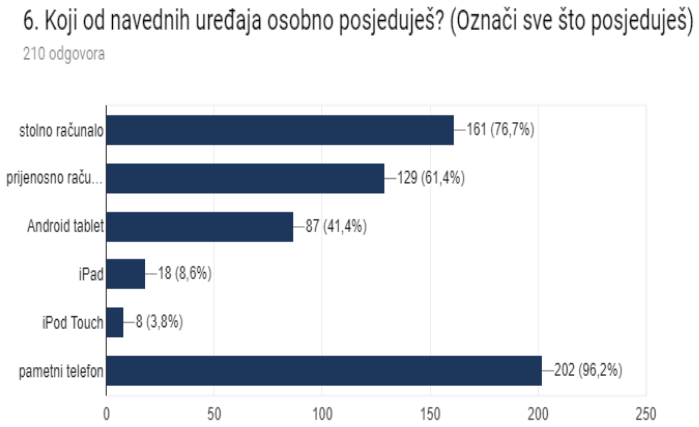


Slika 6. Dijagram prikaza reakcije učenika na brzinu školskog interneta (online anketa)

Gotovo svi anketirani učenici posjeduju pametne telefone, a uz njih, većina učenika ima stolno i/ili prijenosno računalo (slika 7.).

Učenici su mogli izabrati više razloga zašto bi koristili vlastite uređaje u školi:

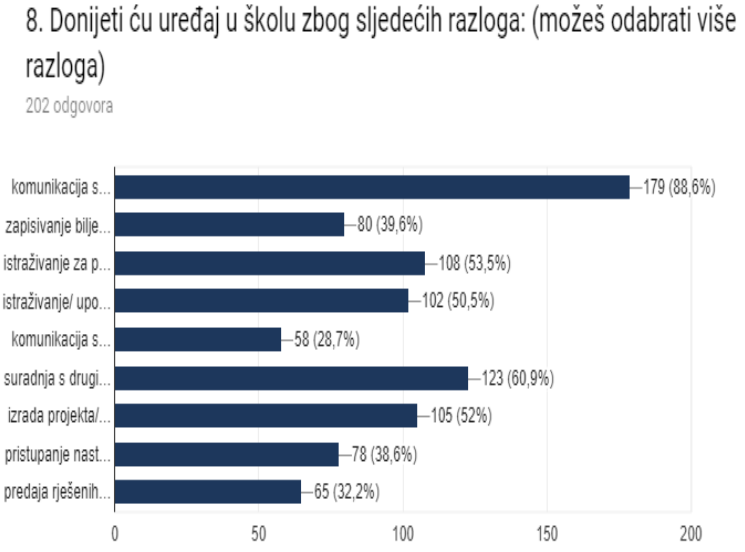
- komunikacija s prijateljima
- zapisivanje bilješki na nastavi
- istraživanje za projekt



Slika 7. Dijagram prikaza posjedovanja uređaja informatičke tehnologije kod učenika (online anketa)

- istraživanje/ uporaba web resursa za aktivnosti na nastavi
- komunikacija s nastavnikom
- suradnja s drugim učenicima u timskom rješavanju zadatka
- izrada projekta/ rješavanje zadatka
- pristupanje nastavnim sadržajima na nastavnikovoj web stranici ili sustavu za upravljanje učenjem
- predaja rješenih zadataka na nastavnikovoj web stranici ili sustavu za upravljanje učenjem.

Prema većem broju glasova učenika, komunikacija s prijateljima ima prednost, a potom slijedi suradnja s drugim učenicima u timskom rješavanju zadatka, te istraživanje za projekt (slika 8.)

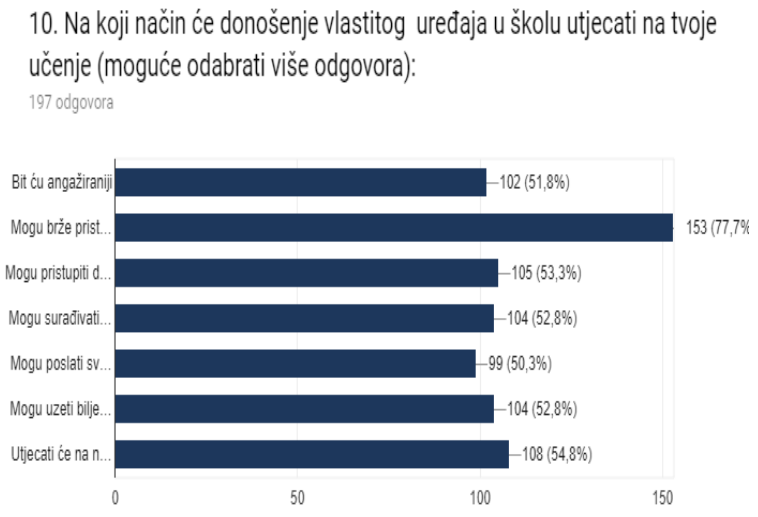


Slika 8. Dijagram prikaza učeničkih razloga za donošenje vlastitith uređaja informatičke tehnologije u školu (online anketa)

Učenici su mogli odabrati više odgovora u pitanju na koji način će donošenje vlastitog uređaja u školu utjecati na njihovo učenje. Među njima su:

- bit ću angažiraniji
- mogu brže pristupiti informacijama istraživanja
- mogu pristupiti digitalnim resursima
- mogu surađivati sa svojim kolegama, kao i stručnjacima
- mogu poslati svoj rad nastavnicima digitalno
- mogu uzeti bilješke i podijeliti ih s mojim razrednim kolegama
- utjecati će na način mog učenja.

Naglasak kod učenika je brži pristup informacijama istraživanja (slika 9.).



Slika 9. Dijagram prikaza učeničkih razloga na koji način će donošenje vlastitog uređaja u školu utjecati na njihovo učenje (online anketa)

Polovina anketiranih učenika (48%) potvrdilo je da bi u slučaju da nemaju svoj uređaj, preuzeli mobilni uređaj u vlasništvu škole kako bi ga koristili tijekom nastave.

VII. ZAKLJUČAK

S pravilnim planiranjem i pravilnom infrastrukturom možemo očekivati sve veći broj škola u svijetu koje u nekom obliku usvajaju BYOD, kao dio šireg plana za smanjenje troškova, uštedu vremena i povećanje angažmana učenika.

BYOD, kao i svaki drugi sustav, treba sistematski planirati, implementirati, nadzirati i poboljšavati. Važno je razviti svjesnost učenika o sigurnosnim prijetnjama koje dolaze kao posljedica korištenja vlastitih uređaja.

Učenicima i nastavnicima BYOD pruža dinamično iskustvo učenja iz dana u dan. Nastavnici kroz organizirane edukacije mogu upoznati osnovne pojmove vezane uz BYOD te jednostavne i besplatne programe za mobilne uređaje, kao što su aplikacije za kameru i audio aplikacije, pomoću kojih će dodatno utjecati na razvoj jezičnih vještina svojih učenika. S mobilnim uređajima mogu izrađivati zadatke za razvoj usmenog i pismenog izražavanja. Učenici mogu koristiti aplikacije kako bi prikupili i analizirali podatke a na nastavi stranih jezika uključuju se u razgovor putem svojih telefona.

Dopuštenje učenicima da mogu ponijeti sa sobom u učionicu svoje pametne telefone omogućiti će također neophodan pomak u kulturi škole. Nastavnici ne moraju više paziti na učenike koji šalju poruke iz hodnika ili se skrivajući igraju svojim mobitelima, jer se oni sada koriste za obrazovne svrhe što pomaže oblikovanju kulture u školi. Te promjene vjerojatno će se postići postupno u fazama.

U školama gdje uvođenje BYOD-a ima jasan cilj, to može biti podrška značajnim promjenama u nastavnim metodama kako bi se poboljšao angažman učenika i njihovo postignuće. Postizanje takvog cilja uključuje tehnologiju koja je u potpunosti integrirana u svakodnevno učenje tijekom cijele nastavne godine.

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Učenje u ozračju međunarodne suradnje i igre

Iva Naranđa
Osnovna škola Vladimira Nazora Pribislavec, Pribislavec, Republika Hrvatska

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***Sažetak* - Rad opisuje primjer iz prakse u kojem se uvođenjem eTwinninga kao izvannastavne aktivnosti za četvrti razred osnovne škole stvorilo ozračje za učenje u kojem su učenici bili izuzetno motivirani, zainteresirani za sadržaje i s puno entuzijazma izvršavali projektne zadatke. eTwinning projekt Zero-One proveden je tijekom školske godine 2016./2017. u Osnovnoj školi Vladimira Nazora Pribislavec, a u njemu su uz navedenu školu sudjelovale dvije škole iz Grčke i dvije škole iz Turske. Svih pet partnera dobilo je Europsku oznaku kvalitete koju dodijeljuje Središnja služba za podršku eTwinningu iz Brisela. Početkom studenoga 2017. Agencija za mobilnost i programe EU iz Zagreba predstavila je projekt Zero-One u rubrici Projekt mjeseca na mrežnim stranicama za hrvatske korisnike eTwinninga. Radom na projektu Zero-One učenici su na zabavan način upoznali jedan od osnovnih pojmova u informatici, binarnu znamenku. Najznačajniji rezultati projekta su kratki filmovi o projektnim aktivnostima, rezultati inicijalnog upitnika i evaluacije projekta, edukativni materijali, učenički radovi kao što su logo, infografike, aure, online igre i zajednička priča o planetu iz mašte.**

Ključne riječi - eTwinning, projekt, bit, binarni zapis, QR kôd, Web 2.0 alati, proširena stvarnost, digitalna priča, učenje kroz igru

I. UVOD

Tijekom školske godine 2016./2017. u Osnovnoj školi Vladimira Nazora Pribislavec proveden je međunarodni eTwinning projekt Zero-One u kojem su sudjelovali učenici četvrtih razreda, polaznici izannastavne aktivnosti eTwinneri. U projektu su sudjelovale dvije škole iz Grčke (1st Primary School of Metamorfosi, učiteljica Georgia Lascaris i 8o Dimotiko Kifissias, Kifisia, učiteljica Irene Papadopetraki), dvije škole iz Turske (100. Yıl Atatürk Ortaokulu, Köşk, učiteljica Bilge Varel i Tekkeköy İmam Hatip Ortaokulu, Tekkeköy, učiteljica Elif Şimşek) i Osnovna škola Vladimira Nazora Pribislavec iz Hrvatske. Koautorice projekta su učiteljice informatike Iva Naranđa i Georgia Lascaris.

U projektu je sudjelovalo ukupno 65 učenika, aktivnih članova TwinSpacea, od toga 13 učenika iz Hrvatske, 27 učenika iz Grčke i 25 učenika iz Turske. (Slika 1)

U Osnovnoj školi Vladimira Nazora Pribislavec projekt je integriran u školski kurikulum kao izvannastavna aktivnost za četvrte razrede, jedan sat tjedno, 35 sati godišnje.

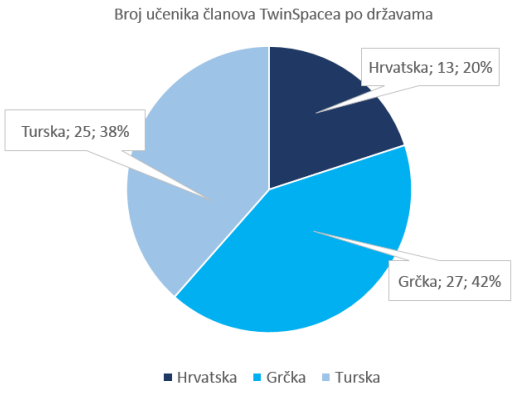
Radom na projektu Zero-One učenici su na zabavan način upoznali jedan od osnovnih pojmova u informatici, binarnu znamenku (bit). Surađujući s partnerima, učeći kroz igru i zabavne aktivnosti, učenici su razvijali ključne kompetencije prema eTwinning publikaciji „Developing pupil competences through eTwinning“ [1], naročito komunikaciju na stranom jeziku i digitalnu kompetenciju, te razumjeli značenje i važnost bita. Učenici su stjecali znanja, iskustva, vještine i stavove prema pet ključnih područja iz Europskog okvira za digitalne kompetencije za građane (The European Digital Competence Framework for Citizens – DigComp) [2].

Kako bi bio pedagoški smislen, pojam digitalne kompetencije osim sasvim tehničkog značenja proširen je na koncept koji sadrži kognitivne i etičke dimenzije, te poznavanje društvenih implikacija vezanih uz korištenje informacijsko-komunikacijske tehnologije, kao u [3]. Radom na ovom projektu i integracijom tehnološke, kognitivne i etičke dimenzije digitalne kompetencije iskorišteni su potencijali tehnologije i međunarodnom suradnjom izgrađivano je znanje naših učenika.

Učenike se željelo od rane dobi poticati na sigurno i kreativno korištenje računala i interneta u dobre svrhe. Stvaranjem privlačnog okruženja za učenje preobraženo je iskustvo učenja naših učenika, zaintrigirani su i razvijane su njihove vještine uporabe informacijsko-komunikacijske tehnologije korištenjem Web 2.0 alata i alata za proširenu stvarnost.

Osim glavne teme projekta, tijekom projektnih aktivnosti među učenicima je podizana svijest o važnosti prijateljstva i suradnje između različitih država i kultura.

Prateći obrazovne trendove radom na projektu Zero-One korištene su suvremene pedagoške metode koje su usmjerene na potrebe, interese i motive učenika, potiču



Slika 1: Broj učenika članova TwinSpacea po državama

kreativnost, komunikaciju, samostalnost i kritičko mišljenje te u poučavanju koriste elemente igre i zabave, kao u [4]. Primjenjivano je istraživačko učenje, suradničko učenje i igrifikacija u interdisciplinarnim aktivnostima u kojima su učenici razvijali znanja i stavove o više tema. Učenike se poticalo na samostalno zaključivanje, razvijalo se njihovu radoznalost, kreativnost i osposobljavalo ih se za samostalni rad. Znanje stečeno na ovaj način učenicima je razumljivije i trajnije i moći će ga primjenjivati u daljnjem radu i životu. Učenike se usmjeravalo da suradnjom i kroz zajednički rad otkrivaju rješenja problema i izrađuju uratke. Suradničko učenje omogućilo je aktivan angažman i uključivanje svih učenika u rad, što je pozitivno utjecalo na samopouzdanje učenika, pripremalo ih za prihvaćanje različitosti i drugačijih mišljenja, te u konačnici doprinijelo boljim odnosima među učenicima.

U svim projektnim aktivnostima vidljiva je suradnja škola, osnivačice projekta postavile su glavne ciljeve, ali svi partneri su predlagali rješenja, ideje, alate i iznosili svoja mišljenja na Twinspace forumu.

II. PROJEKTNE AKTIVNOSTI

A. Uvodne aktivnosti – upoznavanje i inicijalni upitnik

Prvi zadatak obuhvaćao je upoznavanje učenika s projektom i predstavljanje partnerskih škola te provedbu inicijalnog upitnika kojim se željelo saznati jesu li naši učenici već čuli za pojam bit i neke s njime povezane pojmove.

Učenici su pogledali prezentacije partnerskih škola, te napisali svoje dojmove i komentare na TwinSpace forumu.

Učenici su na TwinSpaceu ispunili inicijalni upitnik putem Google obrasca. Upitnik se sastojao od sedam pitanja zatvorenog tipa. Učenici su najprije ispunili upitnik na hrvatskom jeziku, ispisan na papiru, a nakon toga unijeli svoje odgovore u Google obrazac s istim pitanjima na engleskom jeziku.

Prema rezultatima inicijalnog upitnika za pojam bit čulo je šest učenika Osnovne škole Vladimira Nazora Pribislavec, dok je njih sedam odgovorilo da još nije čulo za ovaj pojam. Za izraz digitalni svijet čulo je deset naših učenika, a troje učenika nije. Troje učenika iz Pribislavca odgovorilo je kako misli da sve brojeve možemo predstaviti koristeći samo nule i jedinice, dok je njih deset odgovorilo kako misle da to nije moguće. Na pitanje je li moguće napisati ime naše države koristeći samo nule i jedinice, samo jedan učenik odgovorio je potvrdno.

S obzirom na dob učenika i činjenicu da još nisu pohađali nastavu informatike, odgovori nisu iznenađujući. Preostala pitanja i odgovori učenika, kao i zajednički rezultati za svih pet škola nalaze se na TwinSpaceu projekta.

U sklopu uvodnih aktivnosti učenici su potaknuti na upoznavanje binarnog zapisa pomoću infografike napravljene alatom Canva, u inačicama na hrvatskom, grčkom i turskom jeziku. Zadatak je bio otkriti što računalo kaže, odnosno otkriti kratku poruku u ASCII kôdu.

B. Logo projekta

Drugi zadatak bio je kreiranje loga projekta i biranje najboljeg loga između učeničkih radova svih partnerskih škola.

Putem foruma na TwinSpaceu učiteljice su razmijenile ideje o tome kako realizirati ovaj zadatak. Učenici su najprije ukratko upoznati s pojmom loga i njegovim osnovnim svojstvima, te im je naglašeno da logo treba biti jednostavan, lako pamtljiv i atraktivan. Usuglašeni su elementi koje bi trebao sadržavati logo našeg projekta: eTwinning, prijateljstvo, suradnja, Europa, programiranje i računala, strojni jezik, ime projekta.

Za izradu loga projekta učenici su koristili drvene bojice, flomastere i kolaž te skenirali svoje radove. Osim toga, učenici su napravili logoe projekta pomoću alata Online Logo Maker.

Kada su sve škole objavile logoe koje su izradili učenici, pristupilo se odabiru najboljeg loga. Na forumu unutar TwinSpacea dogovorena su pravila natjecanja: svaka škola može glasovati samo za logoe iz drugih škola i svaka škola može dati 10 glasova. Učenicima su pokazani radovi partnerskih škola i zatim su glasovali za logo koji je po njihovom mišljenju najbolji. Glasovanje je najprije izvršeno na papiru, a zatim su glasovi unijeti pomoću alata Tricider. Ovom aktivnošću učenike smo ujedno uveli u poštivanje demokratskih vrijednosti.

Slika 2: Logo projekta, rad učenika iz Turske, škola 100. Yıl Atatürk Ortaokulu Köşk/Aydın, 6 glasova

Slika 3: Logo projekta, rad učenika iz Grčke, škola 8o Dimotiko Kifissias, Kifissia, 6 glasova

Radovi učenika iz Turske i Grčke dobili su jednak broj glasova (Slika 2 i Slika 3), pa je konačan logo projekta nastao kao kombinacija ova dva učenička rada što je napravila koautorica projekta, učiteljica Georgia Lascaris iz Grčke (Slika 4). Najveći broj glasova koji je dobio logo iz Hrvatske bio je četiri, za rad napravljen u kombiniranoj tehnici kolaž i flomaster (Slika 5).

Slika 4: Konačan logo eTwinning projekta Zero-One

Slika 5: Logo projekta, rad učenika iz Hrvatske koji je dobio najviše glasova, OŠ Vladimira Nazora Pribislavec, 4 glasova

C. Code Bucket Challenge – međunarodni timovi učenika

Tijekom prosinca 2016. škole su surađivale na trećem zadatku pod nazivom Code Bucket Challenge.

Svaka škola podijelila je svoje učenike u četiri tima s nazivima KiloByte Team, MegaByte Team, GigaByte Team i TeraByte Team. Svaki tim pripremio je po četiri zadatka za istoimene timove učenika iz partnerskih škola i postavio ih na zajedničkom Cacoo dijagramu. (Slika 6) Zatim su učenici rješavali izazove koje su za njih pripremili partneri. Osnove rada u alatu Cacoo učenici su stekli izradom prvog zajedničkog dijagrama na kojem su oformljeni međunarodni timovi učenika. Zadaci su se sastojali od kratkih poruka za čije kreiranje su učenici koristili binarni zapis, Morseov kôd, QR kôd i bitmape, a koje su se odnosile na temu projekta, osnovne podatke o našim državama, čestitke i dobre želje. Učiteljice su pripremile sve dijeljene Cacoo dijagrame tako da je

Slika 6: Code Bucket Challenge, zajednički Cacoo dijagram (GigaByte tim)

učenicima bilo jasno gdje trebaju postaviti svoje zadatke, a gdje rješenja.

Radom na ovom zadatku učenici su na zabavan način upoznali binarni zapis, Morseov kôd, QR kôd i bitmape. Za potrebe ovog zadatka kreiran je i zajednički Symbaloo webmix. Učenici su napravili čestitku za partnere koristeći ASCII kôd, Morseov kôd, QR kôd i bitmape.

D. Proširena stvarnost – Aurasma

Tijekom siječnja i veljače 2017. učenike se upoznalo s proširenom stvarnošću i alatom Aurasma.

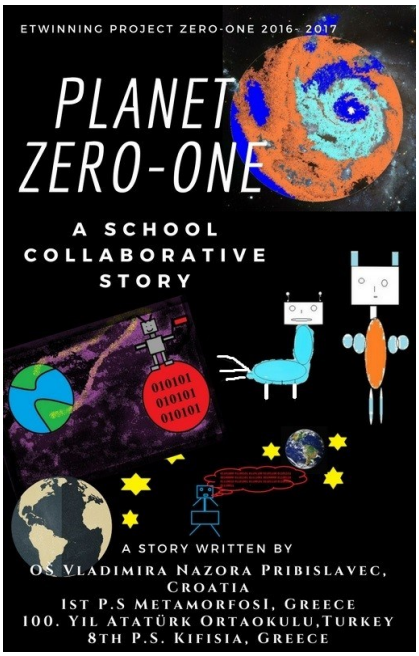
Učenici su najprije pripremili animacije napravljene programom FotoMorph. Teme su bile vezane uz našu školu (Vladimir Nazor, Feštetići i dvorac Feštetić), a povodom Dana sigurnijeg interneta osvrnuli smo se i na problematiku objavljivanja fotografija na internetu i digitalne tragove.

Pripremljen je motivirajući primjer za učenike, aura o međimurskom konju čime smo ujedno partnerima pokazali našu autohtonu pasminu konja. Učenici su upoznati s osnovnim mogućnostima alata Aurasma u kojem su kreirali aure.

Napravljena su dva kratka vodiča s uputama za pregledavanje auri, na engleskom, grčkom i hrvatskom jeziku. Krajem veljače partnerske škole objavile su učeničke radove i tada smo pogledali zanimljive aure koje su napravili naši partneri.

E. Zajednička priča o planetu iz mašte

Tijekom ožujka i travnja 2017. škole su surađivale na izradi zajedničke digitalne priče o planetu iz mašte „Planet Zero-One“ (Slika 7). Obzirom na dob učenika, u izradi priče vodilo ih se potpitanjima. Ilustracije priče naši učenici napravili su u programu IrfanView, a partnerske škole koristile su druge programe i alate.



Slika 7: Naslovnica priče Planet Zero-One

Učenici su bili izuzetno zainteresirani za izradu digitalne priče, slobodno su izražavali svoje ideje i pritom razvijali vještinu organiziranja vlastitih ideja u smislene dijelove priče te samokritičnost, kao u [5].

Na pripremi priče škole su surađivale pomoću kolaborativnog alata RealTimeBoard, a priča je objavljena kao e-knjiga. Početkom lipnja 2017. eTwinneri su iznenadili svoje razrednice i školsku knjižničarku darovavši im tiskane verzije priče o planetu Zero-One.

F. Online igre i eTwinning Live Eventi

Krajem travnja 2017. počelo se s izradom online igri koje su podijeljene s partnerima putem TwinSpacea tako da su naše igre igrali učenici iz partnerskih škola. Napravljena su i dva Kahoot! kviza na hrvatskom jeziku te su prevedena na engleski jezik kako bi ih mogli igrati i naši partneri. Nadalje, napravljene su online igre vješala, osmosmjerka i nekoliko Jigsaw puzzle igri, za što se koristio alat ProProfs Brain Games. Nekoliko učenika napravilo je Jigsaw puzzle s logoima koje su napravili učenici iz Grčke i Turske te su ih samostalno objavili na projektnom dnevniku TwinSpacea.

Posebno zanimljivi bili su eTwinning Live Eventi, online događanja tijekom kojih su učenici iz Grčke, Turske i Hrvatske zajedno igrali natjecateljski Kahoot! kviz "Zero-One". Ovaj kviz nastao je uslijed suradnje svih pet partnerskih škola, svaka škola pripremila je po tri pitanja za zajednički kviz. Pitanja su bila jednostavna i prilagođena dobi učenika, npr. *Can we write the name of our country using only 0 and 1?* (ponuđeni odgovori: *yes* i *no*) i *What's in the picture?* (uz pitanje je prikazana slika QR kôda, a ponuđeni odgovori bili su *QR Code, labyrinth, Morse code, bitmap*). Tijekom susreta odlično smo se zabavili i uz igru provjerili znanje naših učenika o temi projekta.

Interaktivni web alat Kahoot! izvrstan je za poticanje učenika i uvođenje dinamike u nastavu, koristi elemente učenja kroz igru u realnom vremenu, a u učenicima potiče i natjecateljski duh, što je bilo posebno izraženo tijekom ovih online susreta.

eTwinning Live Eventi realizirani su pomoću Adobe Connecta i trajali su približno jedan sat. Naše iskustvo podijelili smo i s eTwinnerima izvan ovog projekta putem eTwinning Live Eventa pod nazivom "We Love Kahoot" gdje su škole mogle razmijeniti materijale putem Padleta.

G. Diseminacija projekta

Tijekom cijelog projekta radilo se na njegovoj diseminaciji, a diseminacijske aktivnosti su također koordinirane s partnerima. Sve škole su redovito objavljivale materijale o napretku projekta na nekoliko načina, na mrežnim stranicama škola, putem predstavljanja aktivnosti u školama, uređivanja eTwinning kutka i objavljivanjem članaka na portalima u Hrvatskoj, Grčkoj i Turskoj. Na taj način pregled projektnih aktivnosti bio je dostupan i na našim materinskim jezicima.

Polaznici izvannastavne aktivnosti eTwinners predstavili su ostalim učenicima četvrtih razreda i

učenicima trećih razreda aktivnosti na eTwinning projektu Zero-One provedene tijekom listopada i studenoga 2016. godine. Predstavljanje projekta održano je 8. prosinca 2016. uz prikladno uređen pano u holu škole. Kratke tekstove o pojedinim projektnim aktivnostima pročitali su pojedini učenici, a nakon toga svi eTwinneri podigli su svoje radove s porukom koju su dekodirali s prethodno spomenute infografike - YOLO. Učenici su razgledali pano na kojem su izloženi radovi učenika iz svih pet partnerskih škola i zajednički rezultati inicijalnog upitnika.

Krajem ožujka 2017. u OŠ Vladimira Nazora Pribislavec održana je druga po redu prezentacija projektnih aktivnosti. Učenicima trećih i četvrtih razreda predstavljene su aktivnosti provedene u razdoblju od prosinca 2016. do kraja veljače 2017., Code Bucket Challenge i proširena stvarnost. Prezentaciju su pratile razrednice i školska pedagoginja.

Na samom kraju nastavne godine, prilikom Dana škole 13. lipnja 2017., eTwinnerima su za uspomenu na projekt podijeljene projektne kartice s pregledom svih aktivnosti, QR kodovima i aurom. (Slika 8)

Krajem srpnja 2017. godine izašao je sedmi newsletter grupe „Visibility of eTwinning Projects“ u kojem je objavljen članak „Collaboration and dissemination in the eTwinning project Zero-One“ kojeg su napisale koautorice projekta Iva Naranđa i Georgia Lascaris. Ovaj newsletter je zbirka članaka o eTwinning projektima u kojima autori članaka dijele svoja iskustva u promicanju eTwinning projekata i ideje za korištenje eTwinninga u nastavi. Nizom zanimljivih članaka na atraktivan način predstavljene su informacije o provedenim projektima i korištenim alatima. Newsletter povezuje učitelje diljem Europe, otkriva eTwinning široj javnosti i nastoji potaknuti interes novih korisnika eTwinning portala te jačati osjećaj pripadnosti europskoj mreži škola.

U listu Općine Pribislavec „Pribislav“ objavljenom u kolovozu 2017. izašao je članak o eTwinning projektima

Slika 8: Projektna kartica s pregledom aktivnosti

realiziranima tijekom školske godine 2016./2017. u OŠ Vladimira Nazora Pribislavec u kojemu se spominje i projekt Zero-One.

Diseminacija projekta nastavljena je nakon dodjeljivanja Europske oznake kvalitete putem lokalnih portala i CARNetovog Portala za škole, te članaka u digitalnom časopisu Pogled kroz prozor i u tiskanom izdanju Školskih novina, u prosincu 2017.

H. Evaluacija projekta

Nakon provedenog projekta, u lipnju 2017. godine provedena je ex-post evaluacija projekta među projektnim partnerima. Učenici i učiteljice ispunili su online upitnike za evaluaciju projekta pomoću alata SurveyMonkey, a rezultati evaluacije objavljeni su na TwinSpaceu projekta.

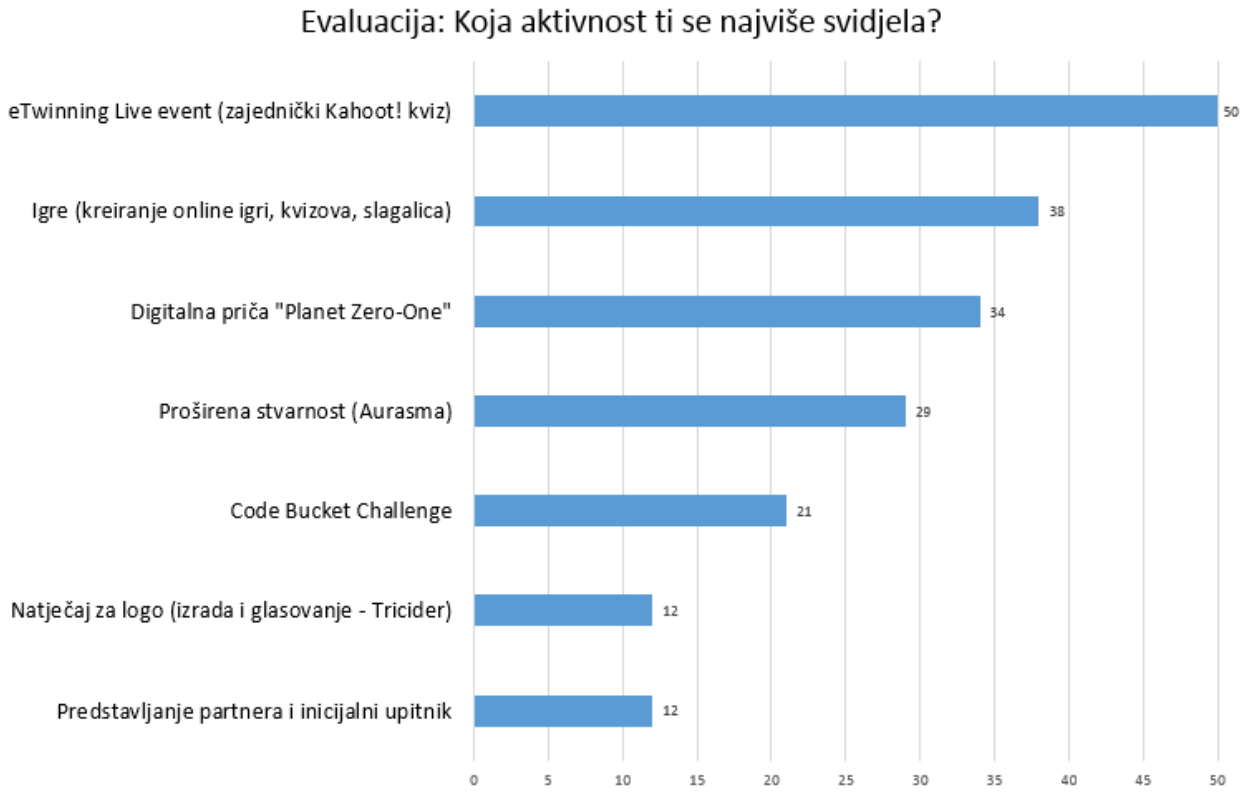
Evaluacijski upitnik za učiteljice sastojao se od sedam pitanja, od toga šest pitanja zatvorenog tipa i jedno pitanje otvorenog tipa.

Rezultati evaluacijskog upitnika za učiteljice pokazali su da svih pet učiteljica smatra da su projektne aktivnosti bile dobro planirane, da su očekivani rezultati ostvareni u potpunosti, da su radom na ovom projektu stekle znanja i vještine koje će moći koristiti u budućem radu i životu te ih je sudjelovanje u ovom projektu motiviralo za rad na budućim eTwinning projektima. Na pitanje jesu li projektne aktivnosti bile relevantne za kurikul njihovog razreda, četiri učiteljice odgovorile su potvrdno, a jedna učiteljica odgovorila je da su aktivnosti bile umjereno relevantne. Kao najveću poteškoću u provođenju projekta dvije učiteljice istaknule su nedovoljno vremena za provođenje svih projektnih aktivnosti, jedna učiteljica istaknula je nedovoljnu opremljenost škole informatičkom opremom, a dvije učiteljice odgovorile su da nije bilo nikakvih poteškoća u provođenju projekta. Učiteljicama se tijekom rada na ovom projektu najviše svidjela raznolikost aktivnosti i korištenih Web 2.0 alata, pouzdanost partnera, izvrsna suradnja i eTwinning Live eventi s Kahoot! kvizovima.

Evaluacijski upitnik za učenike ispunio je šezdeset jedan učenik, a sastojao se od četiri pitanja zatvorenog tipa.

Na pitanje jesu li uživali u sudjelovanju u eTwinning projektu Zero-One šezdeset učenika odgovorilo je potvrdno, a jedan učenik negativno. Na pitanje jesu li naučili nešto o državama i školama partnera šezdeset učenika odgovorilo je potvrdno, a jedan učenik negativno. Pedeset devet učenika odgovorilo je da bi iduće školske godine željelo sudjelovati u nekom drugom eTwinning projektu, a dvoje učenika to ne bi željelo.

Učenicima je postavljeno i pitanje koja od projektnih aktivnosti im se najviše svidjela, te su na ovo pitanje mogli odabrati više odgovora. (Slika 9)



Slika 9: Rezultati evaluacije – pitanje broj 3, odgovori učenika iz svih pet partnerskih škola

Rezultati su pokazali da su učenicima najzanimljiviji bili eTwinning Live eventi tijekom kojih su igrali zajednički natjecateljski Kahoot! kviz, slijedi stvaranje online igri i zajedničke digitalne priče „Planet Zero-One“ te proširena stvarnost i Code Buckett Challenge. Predstavljanje partnera, inicijalni upitnik i izrada te odabir najboljeg loga učenicima su bili manje zanimljivi.

III. ZAKLJUČAK

Prema rezultatima evaluacijskih upitnika možemo zaključiti da je projekt Zero-One kvalitetno osmišljen i proveden te da je ostvario pozitivan učinak na sve projektne partnere.

Surađujući s partnerima u interdisciplinarnim aktivnostima i učeći kroz igru, učenici su razvijali ključne kompetencije te stjecali znanja, iskustva, vještine i stavove prema pet ključnih područja iz Europskog okvira za digitalne kompetencije za građane.

Projekt je imao pozitivan učinak na učenike, učiteljice i škole. Učenici su imali mogućnost komunicirati i surađivati s vršnjacima iz drugih država, pokazati svoju kreativnost i vještine, stjecati digitalne vještine potrebne u daljnjem životu te razvijati analitičko i kritičko razmišljanje kroz rješavanje problemskih zadataka. Upoznali su rad s nekoliko Web 2.0 alata koji olakšavaju suradnju i uklanjaju prostorno-vremenska ograničenja, istodobno razvijajući svijest o sigurnosti na internetu i digitalnom građanstvu. Rad na ovom projektu imao je pozitivan učinak i na profesionalni razvoj učiteljica, omogućujući razmjenu informacija i iskustva između triju država. Kontinuiranom diseminacijom projekta i atraktivnim aktivnostima zainteresirali smo i druge učitelje naših škola za eTwinning, što je još jedan pozitivan učinak ovog projekta na školu, ali i lokalnu zajednicu.

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Korištenje programima otvorenoga koda u nastavi informatike

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***Sažetak* - U ovome se radu analiziraju dostupni besplatni programi otvorenoga koda (engl. Open source) koji se mogu koristiti u nastavi informatike te za druge potrebe nastavnika u školi. Programi se otvorenoga koda mogu koristiti za različite nastavne svrhe: H5P se koristi za izradu obrazovnih igara, od kojih će neke biti prikazane na stranici Informatičke igre (www.informatickeigre.com), VirtualBox za emulaciju drugih operacijskih sustava, GIMP za obradu digitalnih slika, Inkscape za izradu vektorske grafike, Visual Studio Code za kodiranje mrežnih stranica te rad s programskim jezicima, draw.io za izradu dijagrama, sustav Moodle za izradu obrazovnih tečajeva te program iTALC za nadzor nad radom učenika na drugim računalima. Nekim od tih programa mogu se koristiti nastavnici za izradu nastavnih materijala te za poboljšanje vođenja nastave, što dovodi do uspješnijega poučavanja učenika. Prikazat će se primjena nekih od tih programa na satu informatike u Školi za medicinske sestre Vrapče te će se s pomoću ankete prikazati zadovoljstvo učenika vezano za rad u određenim programima. Na temelju rezultata donijet će se zaključci vezani za primjenu određenih programa otvorenoga koda u školi.**

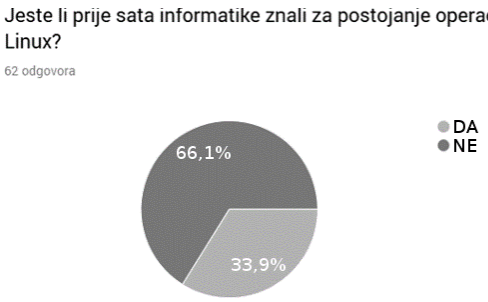
Ključne riječi - obrazovanje, programi otvorenoga koda, poučavanje, nastava, informatika u školi

I. UVOD

Programi otvorenoga koda (engl. Open source) omogućuju korisnicima pristup cijelome programskom kodu. Programeri mogu izmijeniti ili proširiti njihove funkcionalnosti. Poznati su primjeri takvih programa operacijski sustav Linux, uredski paketi LibreOffice i OpenOffice, program za obradu slika GIMP i sustav za izradu i održavanje mrežnih stranica Wordpress [1]. Na nastavi informatike uglavnom se koriste Microsoftovi komercijalni programi. Više bismo se mogli koristiti programima otvorenoga koda zbog njihovih mogućnosti i dostupnosti. Škole se mogu legalno koristiti Microsoftovim programima zbog licencije koja je dana učenicima i nastavnicima. Sve osobe s AAI@EduHr računom mogu preuzeti Microsoftove proizvode i koristiti se njima određeno vrijeme [2]. Osobe koje ne rade u obrazovnim ustanovama poput škola i fakulteta često rade u ustanovama ili tvrtkama koje nemaju pravo besplatnoga korištenja Microsoftovim proizvodima, pa se koriste drugim dostupnim programima. Važno je zato učenicima napomenuti da postoje različiti besplatni programi otvorenoga koda koji mogu zamijeniti funkcionalnosti različitih poznatih komercijalnih programa. Neki od besplatnih programa otvorenoga koda mogu se naći na stranici SourceForge, na kojoj svatko može izdati svoj besplatni program otvorenoga koda za preuzimanje [3].

II. UPOZNAVANJE UČENIKA SA SUSTAVOM LINUX

Poznati operacijski sustav otvorenoga koda Linux ima različite inačice. Trenutačno su najpopularnije inačice Debian, Ubuntu i Mint. Sučelje tih operacijskih sustava na sličan se način koristi kao i sučelje operacijskog sustava Windows. Računalni podatci također su organizirani s pomoću mapa koje sadržavaju datoteke, postoje izbornici slične funkcionalnosti kao kod Windowsa te postoje različiti alternativni programi za Microsoftove programe. Uz instalaciju jedne od inačica operacijskoga sustava Linux moguće je dodatno instalirati druge programe otvorenoga koda za različite namjene. Programski paketi LibreOffice i OpenOffice sadržavaju programe slične MS Officeu, koji se mogu koristiti za obradu teksta (Writer), rad s proračunskim tablicama (Calc), izradu prezentacija (Impress) i dizajniranje baza podataka (Base). Ti su programi po svojoj funkcionalnosti slični Microsoftovim programima, jedino sučelja tih programa ne sadržavaju kartične izbornike s ikonama nego padajuće izbornike na jednoj vrpci. Dizajn sučelja tih program sličan je dizajnu sučelja starijih inačica MS Office programa koji su se koristili od 1997. do 2003. [4]. Učenicima prvih razreda Škole za medicinske sestre Vrapče tijekom obrade nastavne cjeline vezne za programsku podršku ponuđeno je da isprobaju rad na sustavu Linux Mint. Sustav je bio emuliran s pomoću programa VirtualBox, koji je također otvorenoga koda te omogućuje da se istodobno koriste dva operacijska sustava na jednome računalu [5]. Učenici su imali zadatke slične onima koje rade u sustavu Windows kad uče osnove rada u sustavu. Trebali su stvoriti mapu, u njoj datoteke, provjeriti svojstva datoteka te podesiti njihovu sigurnost, podesiti vrijeme koje se prikazuje na računalu, stvoriti nove korisničke račune, instalirati te deinstalirati programe. S učenicima bi se moglo više obraditi i istražiti da prvi razredi nemaju samo jedan sat informatike tjedno, što je ukupno 35 sati u školskoj godini. Nakon rješavanje zadataka 62 učenika iz tri prva razreda dobrovoljno je ispunilo anketu vezanu za dojmove koje su imali pri radu u sustavu Linux. Treba uzeti u obzir da su učenici kratko i prvi put radili sa sustavom Linux, ali su prije toga bili upoznati s radom sustava Windows za vrijeme prethodnih sati informatike te su sustavi Android njihovih mobilnih uređaja izrađeni na temelju Linux kernel jezgre [6]. Učenike se pitalo jesu li čuli za Linuxe prije nastave informatike u srednjoj školi (rezultati prikazani na Sl. 1), čini li im se grafičko sučelje sustava složenijim za osnovno korištenje od Windowsa i imaju li želju instalirati Linuxe na kućno računalo.

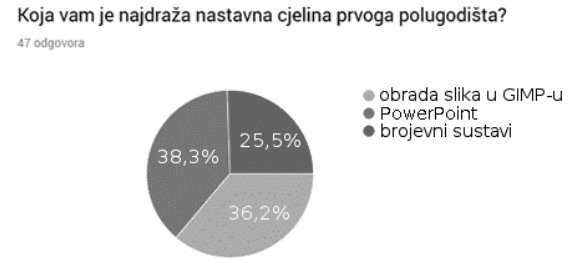


Slika 1. Broj učenika prvog razreda srednje škole koji znaju za operacijski sustav Linux

Od 62 učenika samo ih je 21 (33,9%) znalo za postojanje Linuxa prije nastave informatike u srednjoj školi. 42 učenika (67,7%) odgovorilo je da im se grafičko sučelje sustava Linux ne čini složenijim za korištenje od sustava Windows. Učenici su spomenuli da im sučelje izgleda slično kao i kod sustava Windows, a neki da im se čini jednostavnijim zbog strukturiranja programa po kategorijama unutar izbornika. Većina učenika (41 učenik, 66,1%) ipak je odgovorilo da nemaju želju instalirati Linux na svoja računala. 18 učenika (29%) odgovorilo je da bi možda instaliralo Linux, a ostali učenici su odgovorili da imaju želju instalirati Linux.

III. RAD S PROGRAMOM GIMP

Za obradu fotografija može se koristiti program GIMP, koji ima slične funkcionalnosti kao Adobe Photoshop program [7]. U Školi za medicinske sestre Vrapče prvi je put u nastavni plan i program informatike za druge razrede za 2017./18. uveden GIMP. Učenici su učili obrađivati fotografije koristeći se slojevima, alatima za retuširanje i označavanje te načinima spremanje fotografija u različitim formatima, od kojih neki služe za objavu ili daljnje uređivanje. Zadatci su bili osmišljeni tako da učenici dizajniraju reklame, plakate, posjetnice te uređuju slike poznatih glumaca koje su na internetu označene za slobodno korištenje s izmjenama. Na kraju polugodišta u kratkoj anketi pitalo se učenike drugih razreda koja je njihova najdraža nastavna cjelina te da ukratko objasne zašto (rezultati prikazani na Sl. 2). U prvome polugodištu 2017. godine obrađivalo se gradivo iz GIMP-a, PowerPointa i brojevnih sustava. Od 47 učenika koji su dobrovoljno ispunili anketu, 17 njih je odabralo GIMP kao najdražu cjelinu. Drugih 18 učenika odabralo je PowerPoint kao najdražu cjelinu, a ostalih 12 brojevne sustave. Prema rezultatima provedene ankete rad u GIMP-u i rad u PowerPointu podjednako su dragi učenicima. Učenici koji su naveli PowerPoint kao najdražu nastavnu cjelinu obrazložili su da je to zato što imaju najbolju ocjenu iz te cjeline ili da im je ta cjelina najlakša.

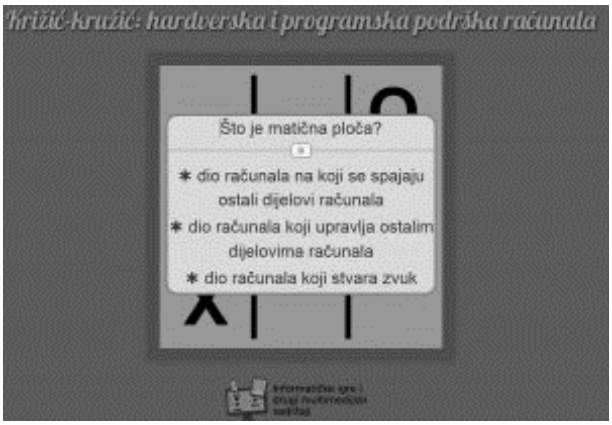


Slika 2. Mišljenje učenika o najdražoj nastavnoj cjelini u prvome polugodištu

Učenici koji su kao najdražu cjelinu odabrali obradu slika u GIMP-u napisali su da je to zbog toga što je to novo gradivo koje nisu učili u osnovnoj školi, jer mogu obrađivati svoje fotografije i jer je obrada fotografija po njihovim riječima *cool*. Više učenika za vrijeme drugoga polugodišta primijenilo je naručeno gradivo iz GIMP-a te izradilo promotivne materijale za projekt razmjene mladih *Be healthy, stay active* koji je vezan za podržavanje zdravog načina života [8]. To dokazuje da osnovno znanje iz obrade digitalnih slika može povremeno biti potrebno i učenicima strukovnih škola koje nisu u prvome redu informatički usmjerene.

IV. OBRAZOVNE IGRE ZA UČENJE INFORMATIKE

Učenje utemeljeno na igrama (engl. game based learning) proces je učenja s pomoću videoigara. Taj način učenja počinje se sve više razvijati zbog veće dostupnosti i primjene informacijsko-komunikacijske tehnologije u školama. Poželjno je povremeno se koristiti igrama tijekom nastave jer su zabavne te lako zaokupljaju pažnju učenika. Stranica *Informatičke igre i multimedijski i prikaz znanja* rezultat je ideje da se naprave mrežne stranice na kojima učenici mogu igrati različite igre iz kojih mogu na zabavan način naučiti činjenice vezane uz informacijsku i komunikacijsku tehnologiju. Igre su različite poput kvizova s različitim tipovima pitanja, križića i kružića (igra prikazana na Sl. 3), tetrisa te križaljka [9]. Sve te igre, koje se igraju na poznati način, imaju ugrađena pitanja na koja igrač mora odgovoriti kako bi mogao nastaviti s igrom. Te se igre mogu koristiti na početku sata u svrhu podizanja učeničkoga interesa za nastavni sadržaj te na kraju sat za ponavljanje gradiva. Sve igre sa stranice mogu se također igrati i na mobilnim uređajima, pa ih učenici mogu koristiti izvan nastave tijekom svakodnevnih aktivnosti poput vožnje autobusom ili tramvajem ili čekanja u redu. Stranice su izrađene s pomoću sustava za izradu mrežnih stranica (engl. CMS) Wordpress, koji je također otvorenoga koda. Igre sa stranice poput kvizova i igre memori napravljene su s pomoću platforme H5P [10]. H5P nudi različita besplatna programska rješenja otvorenoga koda za izradu obrazovnih igara poput kvizova s različitim tipovima pitanja, igre memori i igre dovlačenja (engl. drag-n-drop). Moguće je izraditi i ostale obrazovne sadržaje poput vremenskih lenta, slika s anotacijama, kolaža te interaktivnih videozapisa koji mogu prikazati pitanja te druge multimedijske sadržaje u određenoj vremenskoj točki videozapisa. Svi sadržaji izgrađuju se s pomoću grafičkog sučelja koje nudi mnogo opcija, koje uključuju i lokalizaciju teksta, pa stvaratelji sadržaja ne trebaju imati programersko znanje ili znanje vezano za mrežni dizajn. Izrađeni sadržaji spremljeni su na serverima H5P stranice te se mogu ugrađivati na druge stranice s pomoću iframe oznake na isti način kao i videozapisi na YouTubeu. Ugrađeni sadržaji s H5P stranice nemaju vodeni žig na sebi, pa većina korisnika neće primijetiti da je riječ o sadržaju koji je izrađen s pomoću drugoga servisa. Na spomenutoj stranici *Informatičke igre i multimedijski i prikaz znanja* nalazi se i vremenska lenta koja prikazuje razvoj računala. Ta vremenska lenta izrađena je s pomoću alata Timeline JS, koji omogućuje izradu, oblikovanje te ugradnju responzivnih vremenskih lenta na druge stranice [11]. Cijeli kod vremenske lente može se preuzeti te po potrebi izmijeniti.



Slika 3. Igra križić-kružić u kojoj igrač mora odabrati točan odgovor na pitanje kako bi mogao staviti svoju oznaku na polje

Ostale igre sa stranice poput igara križić-kružić, tetris, memori te simulacije za logičko sklopovlje napravljene su s pomoću dostupnih programskih kodova sa stranice CodePen [12]. Ti javno dostupni programski kodovi zaštićeni su MIT licencom, koja dopušta slobodno korištenje i izmjene [13].

A. Istraživanje vezano za korištenje obrazovnih igara u nastavi informatike

Među učenicima Škole za medicinske sestre Vrapče provedena je anketa vezana za korištenja igara s prethodno spomenute stranice. Uzorak obuhvaća 115 učenika prvih i drugih razreda. Prva skupina ispitanika bila je ispitana 2016./17. školske godine te je uključila sva tri razredna odijela prvih i drugih razrede. Školske godine 2017./18. jedino su prvi razredi bili ispitani jer su drugi razredi prethodne godine već ispunili anketu. Rezultati prvog ispitivanja predstavljeni su u radu *Creation and Use of Game-Based Learning Material* za konferenciju INFuture 2017. [14]. Pitalo se učenike sviđa li im se korištenje obrazovnih igara tijekom nastave, jesu li se koristili igrama za ponavljanje prije ispita (rezultati prikazani na Sl. 4), koja je njihova najdraža igara sa stranice te koju bi vrstu obrazovne igre htjeli vidjeti u budućnosti. 93 učenika (81%) reklo je da im se sviđa korištenja igara tijekom nastave. 51 učenik (44%) rekao je da je koristio igre za ponavljanje prije pisane provjere znanja. Oni koji se nisu koristili igrama za ponavljanje, naveli su da je to zbog toga što se nisu sjetili da se mogu koristiti tim igrama za ponavljanje te da su se navikli učiti iz knjiga ili profesorovih prezentacija. Za najdražu igru stranice odabrali su križić-kružić s pitanjima zato što tu igru mogu igrati protiv drugih igrača. U budućnosti su rekli da bi htjeli vidjeti obrazovne igre koje nalikuju popularnim komercijalnim igrama poput Call of Duty, Sims i GTA. To su skupe 3D igre koje je teško izraditi bez velikoga razvojnog tima.

Slika 4. Korištenje obrazovnim igrama pri ponavljaju gradiva prije provjere znanja

S pomoću programa gDevelop mogu se izraditi obrazovne inačice 2D popularnih igrica poput Angry birds i Super Mario. gDevelop omogućava s pomoću grafičkog sučelja učitavanje vlastitih grafičkih resursa te podešavanje logike igre s gotovim programerskim blokovima slično kao u programu Scratch ili Construct 2 [15]. Neki učenici spomenuli su manje igre koje se mogu lakše napraviti poput vješala ili *Čovječe ne ljuti se!*, pa bi se neka od tih igara u obrazovnoj inačici uskoro mogla pojaviti na stranici.

V. OSTALI PROGRAMI OTVORENOGA KODA KOJI SE MOGU KORISTITI U ŠKOLAMA

A. Programi za nadzor nad učionicom

Postoje mnogi drugi programi koji mogu pomoći nastavnicima u ostalim poslovima vezanim za pripremu nastave, administraciju, obradu podataka te izradu promotivnih materijala za različita školska događanja. Nastavnici informatike trebaju voditi brigu o informatičkoj učionici, a za to je važan nadzor nad učenicima. Nastavnici mogu dobiti bolji pregled i nadzor nad učeničkim računalima s pomoću programa poput Veyona ili iTALC-a. Ti programi spadaju u programe za nadzor nad učionicom (engl. Classroom Management Software). Ti se programi instaliraju na glavno (nastavničko) računalo te učenička računala. Nastavnik s pomoću svojega računala stvara virtualnu učionica unutar programa. Unutar te virtualne učionice dodaju se računala tako da se upišu njihove IPv4 adrese i MAC adrese te se računalu dodijeli ime. Nastavnik na svojem računalu u realnom vremenu može nadgledati rad učeničkih računala te ih po potrebi ugasiti ako je unesena MAC adresa za računalo. Također može zaključati računala, prikazivati rad svojeg ili tuđeg učeničkog računala na ekranima ostalih računala. S pomoću toga programa može se preuzeti i potpuni nadzor nad određenim učeničkim računalom [16]. Nažalost, u Školi za medicinske sestre Vrapče učenici se različitih razreda koriste različitim prijenosnim računalima i sjede na različitim mjestima. Zbog toga je svaki put računalu dodijeljena nova IPv4 adresa kad se spaja s pomoću mrežnog kabela na internet. Taj bi problem bio riješen da se svaki put prijenosno računalo spaja na istu mrežnu točku, ali je to teško ostvariti kad se radi s više učenika iz različitih razreda koji dijele računala.

B. Program Inkscape za rad s vektorima

Drugi je koristan program otvorenoga koda za crtanje u vektorima Inkscape, koji se može koristiti za izradu promotivnih materijala. Program osim mogućnosti za crtanje, određivanje veličine ispisa, grupiranje objekata, uvoz fotografija te izvoz crteža nudi mogućnost rada sa slojevima, ravnalo za poravnanje objekata te mogućnost prebacivanja fotografija u vektore [17]. Inkscape se koristio dvije uzastopne godine za izradu božićnih čestitaka te jednu veliku reklamu (engl. roll up) za događaj *Dođi osmaš* na kojem se predstavljaju zagrebačke srednje škole osmim razredima. Rad s vektorima podrazumijeva da se ne radi s fotografijama nego s crtežima i drugim oblicima koji se lako mogu prikazati ispunjenim geometrijskim oblicima i linijama ili Bezierovim krivuljama te se zbog toga grafika promotivnih materijala može lako prilagoditi računalnom formulom za ispis u različitim veličinama, a da se ne izgubi oštrina slike.

C. Program Scribus za izdavaštvo

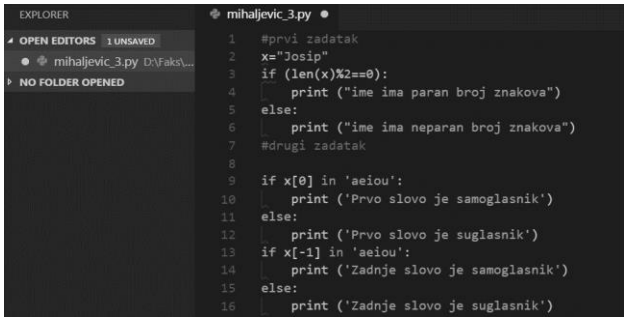
Scribus je program koji se koristi za izradu knjiga, časopisa, brošura, letaka te drugih materijala koji se pripremaju za tisak. Ovaj program radi slično kao komercijalni alat Adobe InDesign [18]. Trenutačno se profesor zajedno s učenikom koristi programom Scribus za izradu i prelamanje školskoga časopisa. Program se također koristio za dizajniranje i izradu dnevnika učeničke prakse u inozemstvu. Iako je Scribus dobra zamjena za InDesign, ti programi učenicima nisu dovoljno poznati i jednostavni za korištenje kao MS Word te se zbog toga većina učenika njima ne koristi za izradu školskih časopisa i novina.

D. Program draw.io za crtanje dijagrama

draw.io je mrežni softver koji služi za izgradnju, izmjenu, spremanje i pohranu dijagrama na osobnim računalima ili oblačnim sustavima poput Google Drivea, OneDrivea i DropBoxa. Unatoč tomu što je riječ o mrežnome programu, razvojni je kod dostupan na stranicama GitHuba te postoji inačica za izvanmrežno korištenje [19]. Velika je prednost ovoga besplatnog program što omogućuje svim korisnicima rad sa svim opcijama i nema ograničenja poput potrebe za registracijom prije početka korištenje ili dopuštenja da se izgradi samo određeni broj dijagrama. Također nudi opciju za pohranu i dijeljenje dijagrama putem različitih oblačnih programa. Dijagrami se spremaju u XML datoteci koja može biti učitana putem programa na bilo kojem računalu i omogućiti daljnji rad ili izmjenu nad spremljenim dijagramom. Kad su dijagrami gotovi, mogu se izdati kao slika u PNG formatu, vektorska grafika u SVG formatu, html ili PDF dokument. Izrađeni materijal na sebi nema vodeni žig. Povremeno su se programom učenici i nastavnik koristili za izradu dijagrama tijeka i logičkih sklopova.

E. Tekstni urednici i IDE programi za pisanje koda

Besplatni IDE programi i tekstni urednici poput programa Brackets, Notepad++ i Atom uglavnom se upotrebljavaju za dizajniranje mrežnih stranica, ali s dostupnim dodatcima mogu se nadograditi za pisanje programskoga koda u različitim programskim jezicima poput Pythona, C# i Jave. U drugim razredima uči se programiranje u Pythonu. Za pisanje koda koristi se program Visual Studio Code umjesto Python IDLE-a. Riječ je o besplatnoj inačici programa Visual Studio koja je otvorenoga koda (prikazan na Sl. 5). Razlog je za korištenje Visual studija taj da program učenicima nudi mnogo ljepše i funkcionalnije sučelje za rad te podržava različite tipkovničke prečice i dodatke koji olakšavaju pisanje te preglednost koda u Pythonu [20].



Slika 5. Programiranje u programu Visual Studio Code

F. Sustavi za upravljanje učenjem

Sustavi za upravljanje učenjem ili engleski LMS (Learning Management System) softverski su sustavi koji omogućuju stvaranje, organiziranje i izdavanje e-tečajeva. Često se dijele na dvije vrste od kojih se prva poput Moodla instalira i pokreće serverom slično kao sustavi Wordpress ili Joomla, a druga se poput Canvasa i Schoologya u potpunosti podešava i pokreće na proizvođačevu serveru. Ti su sustavi namijenjeni bilo kojoj ustanovi koja želi obrazovati određenu kategoriju polaznika – učenike, studente ili zaposlenike neke tvrtke. Sustavi za upravljanje učenjem vrlo su robusni, pa nude različite alate za učenje i vrednovanje polaznika te mnogo opcija za nadzor nad različitim aktivnostima korisnika i mogućnosti za postavljanje ovlasti rada korisnika u sustavu. Postoji mnogo različitih popularnih sustava za učenje poput sustava Blackboard, Sakai, Latitude Learning, Dokeos i Schoology, koji većinu opcija nude besplatno, ali neke naplaćuju [21]. Sustavom Moodle koriste se mnoge škole te druge obrazovne ustanove jer omogućuje lako stvaranje virtualnih predmeta ili kolegija te virtualnih učionica unutar kojih se mogu stavljati nastavni materijali, predavati zadaće, rješavati kvizovi te pisati mrežni ispit s mješovitim tipom pitanja. Nažalost, neke škole poput Škole za medicinske sestre Vrapče nemaju mrežnu bazu podataka dostupnu na serveru škole s pomoću koje bi mogli instalirati sustave poput Moodla. Moguće je koristi se drugim sustavima poput Canvasa, koji je također otvorenoga koda, koji nude neke od osnovnih usluga za korištenje na svojim serverima, ali imaju ograničene opcije za rad u odnosu na Moodle, koji se dulje razvija te ima bolju korisničku i programsku podršku [22]. CARNetov Loomen sustavom, koji je razvijen iz Moodlea, omogućuje nastavnicima s AAI@Edu.hr računom da zatraže od CARNeta otvaranje e-tečaja na njihovim stranicama [23].

VI. ZAKLJUČAK

Programi otvorenog koda postaju popularniji te se njihove mogućnosti unaprjeđuju do razine koja može konkurirati određenim komercijalnim programima. S obzirom na namjenu postoje različiti tipovi programa otvorenoga koda poput operacijskih sustava te različitih aplikacijskih programa za obradu teksta, rad s tablicama, izradu prezentacija, izradu mrežnih stranica, izradu mrežnih igara, 3D modeliranje, prelamanje itd. Zato bi ih nastavnici mogli više primjenjivati na nastavi informatike te time podržati korištenje besplatnih programa otvorenoga koda. Također, postoje mnogi dobri programi otvorenoga koda koji mogu pomoći nastavnicima u održavanju nastave te izradi multimedijskih i interaktivnih obrazovnih materijala poput igara s kojima mogu zainteresirati učenike za nastavno gradivo.

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Nadzorna ploča analitike učenja: upotreba podataka i analitike za podršku procesu učenja i poučavanja

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Sažetak - **U ovom radu prikazan je jedan od načina izvještavanja učenika, učitelja i obrazovnih institucija o procesu učenja i poučavanja korištenjem nadzorne ploče analitike učenja. Korištenje informacijske i komunikacijske tehnologije u obrazovanju rezultira stvaranjem velikih količina obrazovnih podataka i na taj način omogućava razvijanje polja analitike učenja. Jako je bitno odgovoriti na pitanja što prikupiti, zašto, kako, te na kraju, tko su sudionici analitike učenja. Navedeni su zahtjevi kojih bismo se trebali držati pri izradi nadzornih ploča, a osim toga, pokazani su primjeri korištenja nadzorne ploče u svijetu. Istraživanja pokazuju kako nadzorna ploča analitike učenja pozitivno utječe na učenike kao korisnike sustava. Pri izradi nadzorne ploče moramo biti oprezni po pitanju zaštite podataka koji pripadaju učeniku, što pokreće raspravu o etičkim načelima.**

Ključne riječi – veliki skupovi podataka, analitika učenja, nadzorna ploča, etika

I. UVOD

U ovom trenutku možemo zaključiti kako su prošli dani uzbuđenja zbog online tečajeva, iPada u učionicama, sustava za upravljanjem učenja ili sustava za preporuke koji točno znaju ono što učenik zna i ono što učenik ne zna. Polagano, ali sigurno, ulazimo u fazu složenosti u kojoj se sustav obrazovanja mijenja neprestano. Naime, korištenjem sustava za poučavanje, trajno ostaju podaci koji zasigurno obećavaju razumijevanje različitih ponašanja učenika [1]. Svi ovi podaci spadaju u velike skupove podataka (eng. Big data), tehnologija nam omogućava da prikupimo podatke, a potom ih iskoristimo na različite načine. Odgovor na pitanje *„Na koji način se mogu iskoristiti dobiveni podaci?“* implicira pojavu novog polja nazvanog analitika učenja (eng. Learning analitics). Usvajanjem tehnologija u obrazovne ustanove razvija se više mogućnosti za prikupljanje i analizu podataka, polje analitike učenja predstavlja jedan od najnovijih trendova u obrazovanju, a osim kao trenda obrazovanja, Horizon izvješće [2] 2013. opisuje analitiku učenja kao pravi potencijal za poboljšanje iskustava učenika. Povijesno gledano, analitika je korištena u ekonomiji, gdje je imala prediktivnu funkciju, primjenjivala su je razna poduzeća kako bi predvidjeli ponašanje potrošača i na taj način se mogla organizirati kampanja. Ubrzo, nakon toga, obrazovne institucije kreću sa korištenjem analitike, a krajnji cilj je veća uspješnost učenika. Osnovni cilj i svrha sustava za e-učenje je uspjeh i zadovoljstvo učenika, a na ovaj način je moguće prepoznati faktore koji omogućavaju isto. Elias [3] naglašava kako veće količine podataka već postoje u većini obrazovnih institucija, a tečajevi obrazovanja na daljinu posredovani računalom sve više stvaraju tragove učenikovih podataka. Analizom tih podataka aplikacije za analitiku mogu predvidjeti izazove koji predstoje, kako za ustanovu tako i za učenike. Na ovaj način otvaraju se vrata inovativnom učenju i poučavanju uz pomoć novih tehnologija i otvorenih obrazovnih resursa, jasno je kako pomoću analitike učenja mogu nastati nove metode podučavanja usmjerene više na učenika, jer se napredak učenika koji redovito koriste informacijsko-komunikacijsku tehnologiju može lakše pratiti, nastavnici mogu znati točne rezultate učenja svakog pojedinog učenika te identificirati potrebe za dodatnom pomoći.

II. ANALITIKA UČENJA

Obrazovne institucije sve su više zainteresirane za analitiku raspoloživih skupova podataka kako bi poboljšale rezultate učenika. Korištenje analitike u akademske svrhe proteže se najmanje 50 godina, ali je postala značajnija posljednjih godina, jer su skupovi podataka veći i lakše dostupni za analizu. 2007. godine Campbell i Oblinger [4] opisuju akademsku analitiku (eng. Academic Analytics) kao "motor“ za donošenje odluka ili usmjeravanje akcija. Mora se sastojati od pet koraka: hvatanje, izvještavanje, predviđanje, djelovanje i preciziranje. Akademska analitika odnosi se na prikupljanje, prikazivanje i analizu podataka učenika i studenata. Analitika akcija ili djelovanja (eng. Action Analytics) je srodni pojam kojeg predlažu Norris i sur. [5], kako prikupljeni podaci mogu utjecati na individualizaciju procesa učenja i poučavanja, bilo da se radi o učeniku ili grupi učenika.

Ideja analitike učenja dolazi od činjenice kako učenik ili student pri komunikaciji sa svojom obrazovnom

institucijom uvijek ostavlja digitalni trag (prijava u virtualno okruženje za učenje, odlazak u knjižnicu ili jednostavno pristup forumu) koji u ovom slučaju pripada velikom skupu podataka. U svakom slučaju, sustavi za poučavanje sadrže brojne podatke o aktivnostima učenika, a svrha analitike učenja je iskoristiti dobivene podatke kako bi što bolje razumjeli proces učenja i poučavanja. Greller i Drachsler [6] zaključuju kako analitika učenja ima potencijal učenicima pružiti uvid u vlastite navike učenja, uz samoprocjenu podataka koji su ključni za stvaranje informacija o svom znanju.

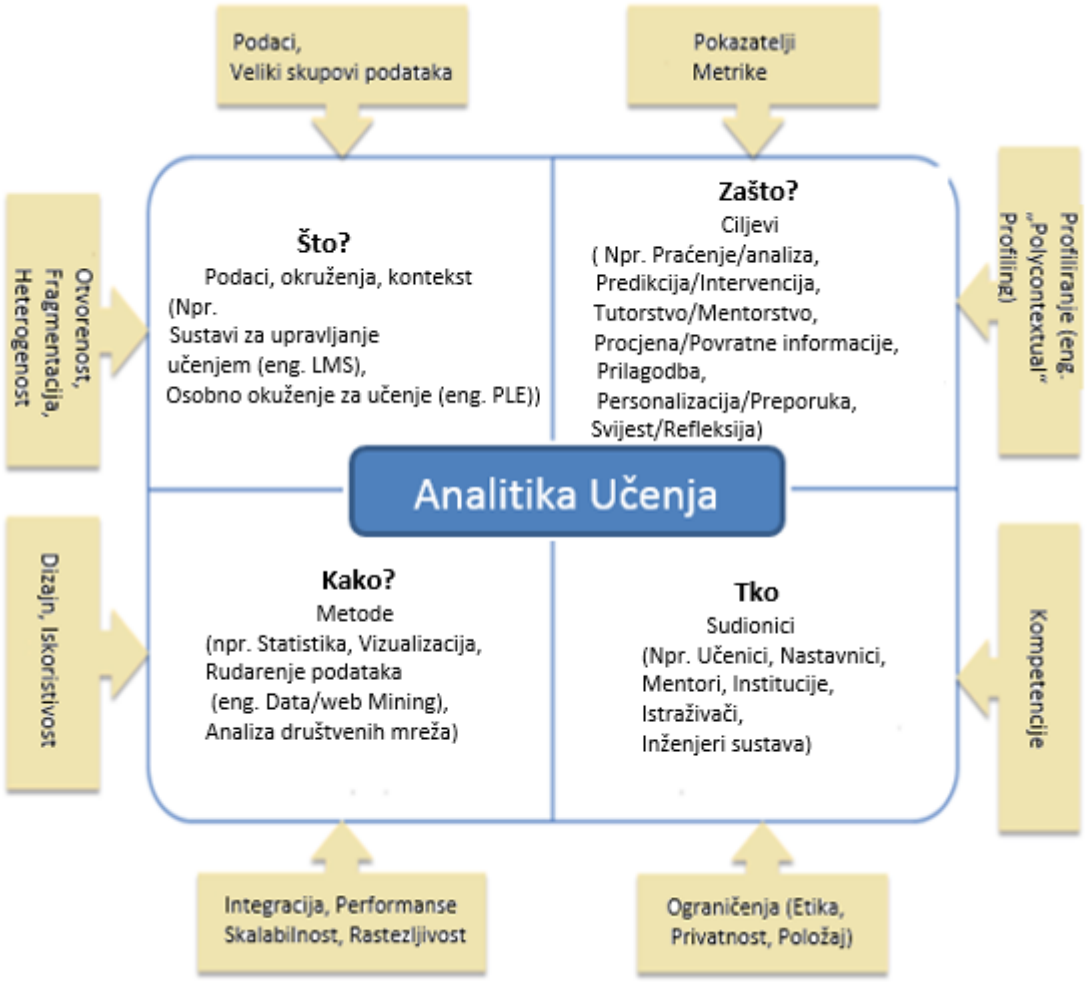
Vrlo je bitno imati na umu kakve podatke možemo prikupiti, a potom definirati strategije na koji način ćemo iskoristiti podatke. Različiti alati i pristupi upotrebljavaju se u analitici učenja kako bi pomogli donošenju odluka o učenju učenika.

Prema prvoj međunarodnoj konferenciji LAK (eng. Learning analytics and knowledge) [7] analitika učenja je *„mjerenje, prikupljanje, analiza i priprema izvještaja o učenicima i njihovim kontekstima, u svrhu razumijevanja i optimiziranja učenja i sredine u kojoj se učenje odvija“*. Svaki klik mišem, svaka interakcija, svaki posjet web stranici, svaka upotreba različitih aplikacija ostavlja informaciju koja može biti pospremljena, predstavljajući digitalni otisak. Upravo na ovaj način dolazimo do mnoštva podataka sa kojima možemo manipulirati na razne načine. Četiri područja analitike učenja mogu biti od interesa za obrazovne institucije [8], [9].

1) Deskriptivna analitika (eng. Descriptive Analytics) želi odgovoriti na pitanje „ Što se dogodilo?“. Obično ima za cilj analizirati podatke o učeniku i izraditi nadzorne ploče koje prikazuju smislene obrasce ili uvide koji dolaze iz tih analiza, vizualizacijama kao što su grafikoni, tablice, mreža i sl. Ova se vrsta analitike može koristiti na različitim razinama unutar obrazovanja :
   - Učenicima da postignu svoj položaj u smislu naučenog, radnog opterećenja ili angažmana u odnosu na druge;
   - Nastavnicima da dobiju ideju o utjecaju svog poučavanja temeljem rezultata testova ili temeljem vremena koje učenici trebaju za realiziranje određene aktivnosti;
   - Instituciji da dobije realnu sliku o odustajanju učenika.
2) Dijagnostička analitika (eng. Diagnostic Analytics) želi odgovoriti na pitanje „Zašto se to dogodilo?“, pregledavajući podatke ili sadržaj kako bi bolje razumjeli događaje ili utjecaje koji mogu objasniti trenutnu situaciju. Odgovor na to pitanje pokušava dobiti tehnikom otkrivanja podataka ili koristeći statističke korelacije. Dijagnostička analiza omogućuje razumijevanje događaja ili kombinacije događaja koji vode do trenutne situacije. Također, i ova se vrsta analitike može koristiti na različitim razinama unutar obrazovanja:
   - Učenicima ova vrsta analitike može dati odgovore na pitanja zašto su uspješni ili neuspješni u savladavanju nastavnog gradiva;
   - Nastavnicima bi mogla ukazati na bolje načine poučavanja i usporediti s prvobitnom shemom koju su imali na umu za poučavanje;
   - Instituacijama, kako bi mjerili učinke pojedinih akcija na postignuća učenika.
3) Prediktivna analitika (eng. Predictive Analytics) želi odgovoriti na pitanje „Što će se dogoditi?“. Obično ima za cilj predvidjeti buduće trendove u napretku učenika i obično se koristi za prepoznavanje učenika koji bi mogli postati "rizični" u smislu niskih performansi ili niskih angažmana. Prediktivna analitika je obećavajuće polje, za sve sudionike procesa učenja:
   - Učeniku ukazuje radi li u pravom smjeru kako bi postigao svoj cilj učenja;
   - Nastavnik koristi prediktivnu analitiku kako bi utvrdio koji su učenici rizični, a zatim intervenira kad još uvijek ima mogućnosti utjecati na njihov uspjeh.
   - Institucijama ukazuje koji su programi bolji ili lošiji te pomaže donijeti odluke o stvaranju novih programa.
4) Propisana analitika (eng. Prescriptive Analytics) želi odgovoriti na pitanje „Kako omogućiti željeno?“. To se može postići generirajući preporuke za proces učenja i poučavanja. Propisana analitika, na temelju pregledanih podataka i digitalnih sadržaja, želi odrediti realne i ispravne radnje za postizanje zadanog cilja. Ovakva vrsta analitike omogućuje:
   - Učenicima stvoriti indiviudalne staze učenja;
   - Nastavnicima, da svojim učenicima predloži aktivnosti koje ih vode prema postavljenim ciljevima;
   - Institucijama, da identificira trendove odustajanja i da ih spriječi prije nego se dogode.

Chatti i sur. [10] predstavljaju referentni model analitike učenja koji sadrži četiri dimenzije, koje možemo opisati sa sljedeća četiri pitanja:

1. ŠTO - koje vrste podataka moraju biti prikupljene, upravljane i korištene;
2. TKO – tko će biti obuhvaćen, tko će primiti rezultate
3. ZAŠTO – koji je cilj analize podataka;
4. KAKO – koje metode koristiti za analizu podataka?



Slika 1 Referentni model analitike učenja [10]

III. VELIKI SKUPOVI PODATAKA

Analitika učenja je pristup koji se temelji na podacima koji su dobiveni iz okruženja za učenje. Velike količine obrazovnih podataka sada se mogu pohraniti, analizirati i dijeliti. Postoje tjedni, ako ne i dnevni izvještaji o korištenju velikih skupova podataka. Što je još važnije, obrada velikih podataka može pomoći obrazovanju da postigne značajan napredak u poboljšanju procesa učenja i poučavanja. Veliki skupovi podataka predstavljaju područje koje se koristi u mnogim poljima istraživanja, a o važnosti razumijevanja pišu Mayer-Schonberger i Cukier [11] i naglašavaju kako veliki skupovi podataka predstavljaju revoluciju koja će transformirati kako živimo, radimo i mislimo mijenjajući način poslovanja i obrazovanja, ali i upravljanje našim osobnim životima.

Nadalje, kako kaže West [12] , "Veliki podaci mogu podupirati klasični obrazovni sustav koji pomaže nastavnicima da analiziraju ono što učenici znaju i koje su tehnike najučinkovitije za svakog učenika". Na taj način i učitelji mogu primijeniti nove tehnike i metode o svom obrazovnom radu. Dakle, osim što novi tipovi podataka mogu omogućiti personalizirano i uspješnije učenje, nove vrste podataka pomažu istraživačima da uče o učenju. Svi ti podaci dolaze iz online tečajeva ili drugih platformi za učenje temeljenih na tehnologiji.

Cope i Kanatzis [13] sugeriraju da su istraživači podijeljeni u pogledu na velike skupove podataka u obrazovanju na one koji ih prihvaćaju i na one koji ih kritiziraju S jedne strane, tvrdi se da veliki podaci obećavaju učiteljima i učenicima novu eru personalizirane nastave, aktivnu pedagogiju i suradničko učenje. S druge strane, kritičari se brinu o pitanjima kao što su privatnost učenika ili učinak profiliranja učenika. Bez obzira na to je li orijentacija optimistična ili ne, svi se slažu da su promjene značajne

Velike skupove podataka u obrazovanju čine administrativni podaci i podaci o procesu učenja. Sampson [14] definira profil učenika kao skup atributa i njihovih vrijednosti koje mogu opisati učenika. Upravo ti atributi predstavljaju prethodno spomenute administrativne podatke i podatke o procesu učenja, a klasificira ih na sljedeći način:

- Statički podaci – odnose se na osobne i akademske osobine učenika koji mogu ostati nepromijenjeni u velikim vremenskim razdobljima (dob, nacionalnost, postignute edukacije, prošlost akademskog uspjeha izvannastavne aktivnosti);
- Dinamičke podatke – odnose se na aktivnosti učenika tijekom procesa učenja i podložni su promjenama (angažiranost učenika u aktivnostima

učenja, ponašanje učenika tijekom aktivnosti učenja, izvedba učenika)

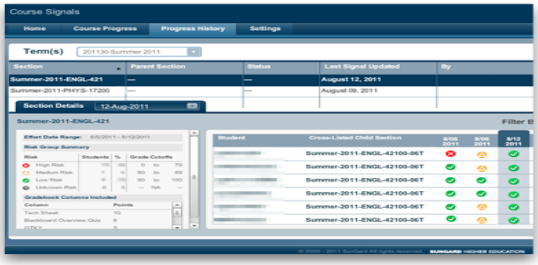
Osim ove dvije klasifikacije, grupa autora [15] navodi kako vrlo važnu ulogu imaju podaci postignuća. Naime, sustavi za učenje i poučavanje često sadržavaju bogatu riznicu podataka o učenikovim postignućima. Najčešće se tu nalaze ocjene koje su učenicima dodijeljene na temelju riješenih ispita ili završenih vježbi. Ova grupa podataka je „rizična“, jer bismo pri promatranju ocjene, također trebali promatrati težinu ispita, inače možemo doći do kontradiktornih rezultata. Veliki podaci mogu uključivati informacije o demografskim podacima, upisima, sustavu upravljanja učenjem, anketama, korištenju knjižnice, izvedbi učenika i vanjske skupove podataka [16].

IV. NADZORNA PLOČA ANALITIKE UČENJA

Jedan od načina predstavljanja rezultata u vizualnom obliku je koristeći nadzornu ploču analitike učenja (eng. Learning Analytics Dashboard). Zbog utjecaja informacijske tehnologije i digitalnih uređaja, nadzorne ploče zahtijevaju sve više pažnje u profesionalnom svijetu i u svakodnevnom životu, a osnovna ideja je omogućiti korisnicima praćenje svojih aktivnosti kako bi se omogućila samoanaliza i usporedba s drugim korisnicima, te kako bi učenici, nastavnici i savjetnici poduzeli odgovarajuće radnje [17] implicirajući kako su vizualizacija i izvješćivanje elementi koji čine analitiku učenja zaista djelotvornom. Općenito, nadzorna ploča s podacima je alat za upravljanje informacijama koji vizualno prati, analizira i prikazuje ključne pokazatelje uspješnosti. Nadzorna ploča prikazuje sve ove podatke u obliku tablica, linija i grafikona, što učenicima predstavlja povratne informacije.

Verbert i sur. [18] navode kako nadzorne ploče obično bilježe i vizualiziraju tragove aktivnosti učenja kako bi se promicala svijest i refleksija, te kako bi se učenicima omogućilo definiranje ciljeva i praćenje napretka prema tim ciljevima. Konkretnije, područje analize učenja usmjereno je na praćenje aktivnosti učenja i konteksta u kojem se te aktivnosti događaju, radi promicanja svijesti i refleksije kroz algoritamsku analizu ili vizualizacije informacija.

U svijetu postoje brojni primjeri dobre prakse korištenja nadzornih ploča u nastavnom procesu. Na Slika 2 prikazan je djelić raznoraznih mogućnosti kako se može iskoristiti nadzorna ploča.



Slika 2 Purdue University's Signals Course Signals, , otkriva znakove ranog upozorenja i osigurava intervenciju učenicima prije nego što dođu do kritične točke [19]

Siemens i sur. [20] kažu kako se nadzorna ploča sastoji od četiri pogleda: *učenik, nastavnik, istraživač i institucija.* Učenici će moći vidjeti svoj napredak u odnosu prema napretku svojih vršnjaka (imena će biti isključena kada je to prikladno). Nastavnici će moći vidjeti razne prikaze aktivnosti učenika, napredak u osvajanju osnovnih pojmova. Nadzorna ploča će pružiti analitiku na razini institucija za praćenje uspjeha i napredovanja učenika. Na primjer, ako učenik pokazuje loše shvaćanje određenog područja na temelju loše riješenog kviza, nadzorna ploča može predložiti učeniku da pristupi određenom skupu aktivnosti kako bi poboljšao svoje razumijevanje. Ako učenik počinje zaostajati, sustav bi preporučio strategije o tome kako nadoknaditi ostatak. Na slika 3 prikazan je pogled učenika na nadzornu ploču koja se koristi na sveučilištu Nottingham Trent .

Slika 3 Kumulativni angažman učenika u usporedbi s prosjekom kolegija. Ovo gledište učenicima pruža dobar pregled cjelokupnog angažmana za godinu dana [23]

Few [21] daje definiciju nadzorne ploče na sljedeći način: *„vizualni prikaz najvažnijih informacija potrebnih za postizanje jednog ili više ciljeva koje se nalaze na jednom mjestu“.*

Postojeće nadzorne ploče za učenje prikazuju podatke kao što su društvene interakcije, upotreba resursa, provedeno vrijeme i rezultate ispita. Ti se podaci mogu prikazati na mnogo načina. Dyckhoff i sur. [22] navode zahtjeve za stvaranje općenitog alata za analitiku učenja:

- Upotrebljivost: pripremiti razumljivo korisničko sučelje, odgovarajuće metode za vizualizaciju podataka i voditi korisnika kroz proces analitike.
- Korisnost: osigurati relevantne, smislene pokazatelje koji pomažu nastavnicima i učenicima da uče ponašanje učenika u učenju i podupiru ih u razmišljanju o njihovom učenju.
- Interoperabilnost: osigurati kompatibilnost za bilo koju vrstu okruženja za učenje dopuštajući integraciju različitih izvora podataka.
- Proširivost: dopustiti povećanje proširenja funkcionalnosti analitike nakon što je sustav implementiran bez ponovnog pisanja koda.
- Ponovna upotrebljivost: cilj za pristup izgradnji blokova kako bi se osiguralo da ponovno korištenje jednostavnijih mogu implementirati složenije funkcije.
- Rad u stvarnom vremenu: pobrinuti se da alat može vratiti odgovore unutar mikrosekundi kako bi omogućio iskustvo za istraživanje.

- Privatnost podataka: čuvanje povjerljivih podataka o korisnicima i zaštita identiteta korisnika u svakom trenutku.

Hadhrami [24] u svom radu prati broj učenika, ocjenu učenika i vrijeme koje je proveo učenik u čitanju materijala. Na temelju tih podataka zaključuje kako korištenje nadzorne ploče za analitiku učenja pruža informacije nastavnicima i učenicima s konačnim ciljem unaprjeđenja procesa učenja i poučavanja. Ipak, Tanes i sur. [25] upozoravaju kako nije sve idealno. Svjesni su kako je mnogo učinjeno na vizualizaciji rezultata analitike učenja u obliku nadzornih ploča, ali njihov dizajn i upotreba su daleko manje razumljivi. Također, dizajn nadzornih ploča može dovesti do provedbe slabe i možda štetne nastavne prakse kao rezultat promicanja neučinkovitih tipova i metoda povratnih informacija. Primjer za takvu štetnu djelatnost dali su Gašević i sur. [26] navodeći kako je često zastupljen pristup vizualizacije usporedbe učenika s prosjekom razreda.

A. Vrednovanje nadzornih ploča u obrazovanju

Corrin i Barba [27] ispituju utjecaj kako nadzorna ploča utječe na motivaciju sudionika. Većina sudionika izvijestila je o povećanju njihove motivacije nakon što je vidjela povratnu informaciju na nadzornoj ploči. Na primjer, ispitujući kako povratne informacije utječu na njihovu motivaciju, učenici su odgovarali: *"Definitivno ću pokušati više sljedeći put"* i *"Tjera me da želim učiniti više"* ili "*Poboljšava motivaciju, jer vidim gdje sam i znam kako idem do sada*". Međutim, mali dio učenika izvijestio je da povratne informacije o nadzornoj ploči nisu utjecale na njihovu motivaciju. Ti su učenici imali tendenciju da budu iznad prosjeka razreda ili su trenutno zadovoljili svoja očekivanja glede predmeta.

Santos i sur. [28] provode istraživanje u kojem se pitaju da li njihova nadzorna ploča udovoljava zahtjevima učenika. Učenici su izvijestili da je nadzorna ploča pomogla u procjeni njihova položaju u skupini, no nije pomogla u upravljanju vremenom ili usmjeravanju prema potrebnim resursima. Bitno je naglasiti kako učenici nisu uvjereni da korištenje njihove nadzorne ploče povećava motivaciju.

Reimers i Neovesky [29] su proveli anketno ispitivanje među učenicima i studentima. Rezultati ankete pokazuju da osnovni zahtjevi učenika u trenutnim platformama za učenje i nadzornim pločama nisu realizirani. Rezultati istraživanja pokazuju kako detaljna online statistika ocjena, grafički prikazujući napredak učenika predstavlja najveći motivacijski faktor za učenje, dok online usporedba sa svojim kolegama ili online rangiranje smatraju de-motivacijskim faktorima u većini slučajeva. Učenici se slažu kako bi svoje ocjene trebali vidjeti online, ali se ne slažu sa usporedbom svojih ocjena sa drugim učenicima.

De Laet i Broos [30] provode vrednovanje akademskog uspjeha koristeći nadzornu ploču i dolaze do saznanja kako je većina učenika koja je dala povratne informacije naznačila da je nadzorna ploča korisna i jasna, a više od polovice učenika ukazuje da je ploča s instrumentima promijenila njihovo zadovoljstvo akademskim uspjehom. Moramo biti oprezni i imati na umu kolika je sposobnost učenika da apsorbiraju podatke koji su im ponuđeni nadzornom pločom.

Zanimljiv komentar učenika u svom istraživanju citiraju Knight i sur. [31] *„Kada izrađujete nadzornu ploču želite li uputiti učenika ili obavijestiti učenika? Općenita stvar koja stoji iza toga, iz moje perspektive, jest da učenici žele informacije, ali na kraju dana žele sami donijeti odluku. Mislim da će ih frustrirati sustav koji je izgrađen i misli da je dovoljno pametan da bi mogao donijeti odluku.“* Ova rečenica nam sugerira kako moramo biti iznimno oprezni pri korištenju analitike učenja u obrazovne svrhe i ne zaboraviti kako je bit i svrha analitike u prvom redu unaprjeđenje učenja.

B. Etika korištenja nadzornih ploča

Ključna etička pitanja vezana uz korištenje velikih podataka i analiza učenja su privatnost, suglasnost i način korištenja, pohranjivanja i zaštićenosti podataka [32]. Slade i Prinsloo [33], Swenson [34] zaključuju kako se primjena analitike učenja događa bržim tempom od razmatranja etičkih pitanja koja se odnose na njihovu upotrebu. Kako bi se zadovoljile etičke smjernice i stvorilo ugledno okruženje za učenje, potrebno je uključiti učenike u proces odlučivanja, a učenici bi trebali imati aktivan glas u određivanju podataka prikupljenih o sebi, načinu korištenja i pohranjivanja, tko će imati pristup podacima i kako će biti zaštićen identitet učenika.

V. ZAKLJUČAK

Korištenje informacijsko komunikacijske tehnologije u obrazovnoj domeni stvara lavinu podataka koji se zasigurno mogu iskoristiti na razne načine. Svi ti podaci, bilo da su strukturirani, nestrukturirani ili polu-strukturirani, čine velike skupove podataka. Analiza podataka obrazovne kategorije implicira pojavu analitike u obrazovne svrhe, čiji cilj i svrha postaje što bolje razumijevanje procesa učenja i poučavanja, a pri tome se veliki naglasak stavlja na omogućavanje personaliziranog učenja. Iz perspektive učenika, od analitike učenja se očekuje da se poveća sposobnost učenja. Iz perspektive nastavnika, analitika učenja može odgovoriti na pitanja koja su dio svakodnevice u sferi obrazovanja poput angažmana učenika. Također, nastavnik je u mogućnosti prilagoditi svoje poučavanje prema potrebi. Obrazovne institucije mogu koristiti podatke analitike učenja za analizu izvedbe različitih programa, a osim toga može im pomoći definirati probleme i nedostatke koji se tiču cjeline i pojedinca. Način na koji se mogu prikazati obrađeni podaci je putem nadzorne ploče analitike učenja.

Pri izradi nadzorne ploče analitike učenja moramo biti posebno oprezni i držati se Dyckhoff-ovih zahtjeva. Na samom početku moramo definirati tko su korisnici kojima će podaci biti prezentirani. Korisnici mogu biti učenici, nastavnici, obrazovne institucije ili istraživači. Nakon toga bitno je donijeti odluku koje vrste podataka će se prikupiti, potom kako, a na kraju, način na koji će se prezentirati podaci. U radu su navedena dva primjera aktualnog korištenja nadzorne ploče analitike učenja, te je

pokazano kako nadzorna ploča ima pozitivan utjecaj na učenike kao korisnike sustava.

Uglavnom, rezultati su bili pozitivni, a ono najbitnije je da nadzorna ploča utječe na povećanje motivacije za učenje. Pri izradi nadzorne ploče jako je bitno na početku riješiti etičke dileme oko privatnosti, suglasnosti, načina pohranjivanja, korištenja i zaštićenosti podataka, a zgodno bi bilo „osluškivati“ što učenici očekuju od nadzornih ploča. Nesumnjivo je kako je analitika učenja jako važna za obrazovnu sferu ali ipak, ostaje dojam, kako je trenutno puno više zastupljena u oblasti visokog obrazovanja.

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Ekonomski modeli objavljivanja znanstvenih časopisa u svijetu te njihova važnost za cjelokupnu akademsku zajednicu u svijetu s osvrtom na RH

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Sažetak - Ovaj rad baviti će se znanstvenim časopisima te njihovoj važnosti za cjelokupnu akademsku zajednicu, a zatim će se preći konkretno na ekonomske modele objavljivanja znanstvenih časopisa u svijetu pošto je reprodukcija znanstvenih časopisa u RH relativno mala za proučavanje. Prvo će biti obrađen sam postupak objavljivanja znanstvenih časopisa te razlika između komercijalnih i nekomercijalnih izdavača. Razmotriti će se i ekonomski modeli izdavanja tiskanih časopisa te pet osnovnih aktivnosti pri objavljivanju tiskanih znanstvenih časopisa. Proučiti će se i kako povećanje broja objavljenih članaka u časopisu utječe na trošak izdavanja, a time i na cijenu pretplate te kako porast pretplata utječe na poslovanje knjižnica. U radu će biti proučeno i elektroničko nakladništvo te njegov utjecaj na samo nakladništvo i promjene koje je ono donijelo. Te kako je razvoj informacijske i komunikacijske tehnologije utjecao na znanstvene časopise. Analizirati će se i povećanje znanstvene produkcije, njen utjecaj na porast broja članaka i cijenu te dva moguća modela uređivanja jeftinijeg časopisa u elektroničkom obliku. U radu će biti spomenuto i planiranje troškova pri objavljivanju znanstvenih časopisa.

Ključne riječi: znanstveni časopisi, ekonomski modeli objavljivanja znanstvenih časopisa, poslovanje knjižnica, elektroničko nakladništvo, informacijska i komunikacijska tehnologija, znanstvena produkcija, planiranje troškova

I. UVOD

Ovaj rad bavi se znanstvenim časopisima te njihovoj važnosti za cijelu akademsku zajednicu u svijetu i Republici Hrvatskoj. U radu će se prvo dati osnovne definicije koje su važne za samo razumijevanje teme, a zatim će se krenuti u samu srž teme tijekom na ekonomske modele objavljivanja znanstvenih časopisa. Pod ovom temom biti će obrađeno: sam postupak objavljivanja znanstvenih časopisa, ekonomski modeli izdavanja tiskanih časopisa te pet osnovnih aktivnosti pri objavljivanju tiskanih znanstvenih časopisa, određivanje cijena pretplata i njen utjecaj, elektroničko nakladništvo te razvoj informacijsko komunikacijske tehnologije i njen utjecaj na znanstvene časopise, planiranje troškova pri objavljivanju znanstvenih časopisa te stanje znanstvenih časopisa u Republici Hrvatskoj.

II. ŠTO SU TO UOPĆE ZNANSTVENI ČASOPISI?

Na samom početku potrebno je razjasniti što je uopće znanstveni časopis? Moglo bi se jednostavno reći da su časopisi periodičke serijske publikacije. Gdje se pod pojmom publikacija misli na: „Tiskani ili drugom tehnikom umnoženi duhovni proizvod u jednom ili više nakladničkih svezaka, na jednom ili više slobodnih listova.“[1] A pod serijskom publikacijom misli se na jedinicu neomeđene građe, bez unaprijed utvrđenoga kraja izlaženja, objavljenu u uzastopnim zasebnim sveščićima ili dijelovima, obično s nekim brojčanim oznakama. [2] Periodička publikacija definira se kao vrsta serijske publikacije koja izlazi u redovitim razmacima kraćim od godine, a obično sadrži zasebne članke. [2] Dok je znanstveni časopis vrsta periodičke građe koja donosi nove rezultate istraživanja i razvoja, a članci u njemu sadrže sve podatke potrebne za procjenu valjanosti zaključka i za ponavljanje istraživanja. [3] Moglo bi se reći da su danas znanstveni časopisi općeprihvaćeni i uvriježeni oblik prenošenja znanstvenih informacija. [4] Zašto je tome tako? Vjerojatno zato što oni omogućavaju brzo, relativno jednostavno, ekonomično i efikasno prenošenje nekih znanstvenih informacija kao na primjer nekih rezultata istraživanja, velikih znanstvenih otkrića, nekih novih znanstvenih saznanja itd. koja se pomoću znanstvenih časopisa brzo šire među cjelokupnom znanstvenom zajednicom ali istovremeno joj i služe jer omogućavaju i drugim znanstvenicima da ponove neko istraživanje, dobiju uvid u korištenu literaturu itd. te na taj način cjelokupna znanstvena zajednica ide naprijed. „Sam oblik i struktura znanstvenih časopisa uglavnom su ujednačeni iako različita područja znanosti imaju neke svoje specifičnosti. A ujednačeni su i struktura i stil pisanja znanstvenih članaka te navođenje referenci.“ [5] Toj ujednačenosti među ostalim doprinose i takozvane upute autorima i upute recenzentima koje ako se poštuju dosta skraćuju vrijeme same recenzije i olakšavaju posao samim recenzentima.

III. POSTUPAK OBJAVLJIVANJA ZNANSTVENIH ČASOPISA

Kao prvo treba istaknuti da sam postupak objavljivanja nije besplatan. Tome je tako jer iako se neki suradnici (autori, urednici, lektori, korektori i drugi) mogu odreći honorara, ali nezamislivo je da se svi suradnici i svi izdavači časopisa odriču zarade, a osim toga postoje i razni drugi troškovi prilikom same objave znanstvenih časopisa. Pri tome treba reći da su znanstveni časopisi dugo temeljili svoj opstanak putem dobre volje suradnika i naknade dijela troškova pretplatom.[5] Komercijalni izdavači opravdavaju povećanje pretplata povećanjem troškova (više rukopisa dolazi na recenziju – više ih se prihvaća – više posla oko recenzije i uređivanja članaka).

Kod nekomercijalnih izdavača pretplate su bile razumne, nisu bile previsoke za institucije, a ponekad ni za pojedince. (Tako je bilo od prvih znanstvenih časopisa pa sve do komercijalizacije izdavaštva – nakon 2.svj. rata). Nekomercijalni izdavači smatraju da cijena objavljivanja ne može biti toliko visoka i da se troškovi mogu smanjiti dobrom organizacijom i korištenjem novih tehnologija. [5] Dakle to je i osnovna razlika između komercijalnih i nekomercijalnih izdavača jer komercijalnima je zarada veliki prioritet i nastoje što više zaraditi dok nekomercijalnima izdavačima sama zarada ne mora biti na prvome mjestu.

IV. EKONOMSKI MODELI IZDAVANJA TISKANIH ČASOPISA TE PET OSNOVNIH AKTIVNOSTI PRI OBJAVLJIVANJU TISKANIH ZNANSTVENIH ČASOPISA

Donald W. King i Carol Tenopir proučavali su ekonomske modele izdavanja tiskanih časopisa 1998-e godine. [6] Tada su cijene pretplata bile izuzetno visoke. Treba istaknuti da su tada već postojale tehnologije potrebne za elektroničko izdavaštvo, a postojali su i elektronički znanstveni časopisi. King i Tenopir izdvajaju pet osnovnih aktivnosti pri objavljivanju tiskanih znanstvenih časopisa:

1. Priprema kategoriziranih znanstvenih članaka – obuhvaća postupak zaprimanja rukopisa, odabira recenzenata, komunikaciju s recenzentima, trošak rada recenzenata, oblikovanje teksta, uređivanje priloga, izradu identifikacijskih i klasifikacijskih oznaka, prijevoda sažetaka i sl.

2. Priprema ostalih dijelova časopisa- spadaju omot, preliminarne stranice i nekategorizirani članci.

Cijena pripreme kategoriziranih članaka za objavljivanje ovisi o njihovu broju, duljini i prilozima koji se objavljuju uz članak (npr. fotografije ili grafički prikazi koje je potrebno urediti).

Trošak prvih dviju skupina aktivnosti isti je neovisno o mediju objavljivanja – bez obzira hoće li biti objavljeni u tiskanim ili elektroničkim časopisima, članci moraju proći pripremu. Taj trošak naziva se troškom prvog primjerka i obuhvaća sljedeće poslove: Zaprimanje članka, Recenziju članka, Komunikaciju s autorima i recenzentima, Pripremu za objavljivanje, Prijelom (grafičko oblikovanje),Objavljivanje tiskom i/ili u elektroničkom obliku. [5]

3. Umnožavanje časopisa- u tiskanoj sredini nakon pripreme prvog primjerka slijedi umnožavanje, tiskanje i uvez. Tiska se uvijek više primjeraka od broja pretplata kako prodaja ne bi bila ograničena samo na pretplatnike. Kod određivanja naknade u obzir treba uzeti i broj autora koji imaju pravo na autorske primjerke. Autori ponekad imaju pravo i na posebne otiske (separate) koji se tiskaju istovremeno s časopisom, pa u ukupne troškove ulaze i troškovi tiska i uvezivanja posebnih otisaka.

4. Raspačavanje - pakiranje; sortiranje; održavanje liste pretplatnika, njihovih adresa i načina plaćanja; slanje primjeraka pretplatnicima i autorima.

Navedene četiri grupe troškova izravni su troškovi vezani uz pripremu za objavljivanje pojedinih sveščića.

5. Neizravni troškovi- od kojih su najvažniji:

Marketing (oglašavanje, objavljivanje kataloga, izlaganje sveščića, troškovi osoblja i opreme za marketing...); Administracija (osoblje koje održava podatke i opremu, računovodstvo, održavanje prostora...); Upravljanje pravima (zaštita autorskih prava, registracija, licenciranje, pravni savjeti...); Istraživanje i razvoj, unapređenje opreme, porezi, osiguranja, itd.

TABLICA I. OSNOVNE KARAKTERISTIKE PROSJEČNOG ZNANSTVENOG ČASOPISA U SJEDINJENIM AMERIČKIM DRŽAVAMA 1975. I 1995. GODINE

Prosječno godišnje	Godina	
	1975.	1995.
Broj svezaka	6,5	8,3
Broj objavljenih članaka	85	123
Broj zaprimljenih rukopisa	90	205
Broj stranica s člancima	630	1434
Broj grafičkih prikaza	114	260
Ukupan broj stranica	820	1723
Broj pretplata	6100	5800

Iz tablice se može vidjeti da neizravni troškovi najčešće rastu proporcionalno s izravnim troškovima. Takva specifikacija troškova nastala je na temelju istraživanja znanstvenih časopisa u SAD-u. Tablica pokazuje karakteristike prosječnog časopisa u 75-oj i 95-oj godini. Na temelju provedenog istraživanja Ivana Hebrang Grgić zaključuje da je očit porast svih parametara osim broja pretplatnika koji se jedini smanjio. [5]

V. ODREĐIVANJE CIJENA PRETPLATA I NJEN UTJECAJ

Kada se odlučuje o cijeni pretplate važan je broj pretplata, tj očekivana prodaja primjeraka. Logično ako je više pretplata biti će manja cijena. A sam broj pretplata ovisi o nizu čimbenika, a neki od važnijih su kvaliteta časopisa i promidžba. King i Tenopir proučavali su i kako

povećanje broja objavljenih članaka u časopisu utječe na trošak izdavanja, a time i na cijenu pretplate. Te su zaključili da četiri puta veći broj članaka povećava cijenu 2.9 puta, a ne 4 puta. Upravo zbog toga izdavači radije povećavaju broj članaka u postojećim časopisima, nego da pokreću nove časopise. Porast pretplata utječe i na poslovanje knjižnica. To su proučavali i time su se bavili Joseph J. Branin i Mary Case 1996-e godine kada su proučavali utjecaj porasta cijena pretplata na nabavu u znanstvenim knjižnicama. Rezultati njihova istraživanja pokazali su da američke knjižnice moraju preusmjeriti troškove kako ne bi morale otkazivati sve veće pretplate na časopise ili kako bi broj otkazivanja smanjile. Tako je u razdoblju od 86-e do 96-e godine cijena časopisa porasla za 147%, izdatci za časopise porasli su za 124%, a nabava časopisa pala je za 7%. Cijena znanstvenih knjiga u istom je razdoblju porasla za 63%, izdaci za knjige povećali su se za 29%, a nabava knjiga pala je za 21%. [7] Što nam to govori? Da što se više povećavaju cijene to više pada nabava kako časopisa tako i knjiga. Očito podizanje cijena nije rješenje, već bi se trebali pronaći načini smanjenja troškova a da se pritom zadrži kvaliteta.

VI. ELEKTRONIČKO NAKLADNIŠTVO TE RAZVOJ INFORMACIJSKO KOMUNIKACIJSKE TEHNOLOGIJE I NJEN UTJECAJ NA ZNANSTVENE ČASOPISE

Zagovornici elektroničkog izdavaštva nadali su se da će nova tehnologija riješiti problem dostupnosti izazvan sve većim pretplatama na tiskane časopise. Pa tako S. Harnad pokreće jedan od prvih elektroničkih znanstvenih časopisa *Psycoloquy* nastojeći dokazati da je u elektroničkom izdavaštvu moguća ušteda do 75%. Harnad nagovara znanstvenike da što više svojih radova učine dostupnima na mreži kako bi izdavače potaknuli na razmišljanje o elektroničkom izdavaštvu.[8] Andrew Odlyzko analizira povećanje znanstvene produkcije te njegov utjecaj na porast broja članaka i cijenu. Te zaključuje da se produkcija udvostručuje svakih desetak godina, a cijene pretplata rastu za oko 7% godišnje.[9] Elektronički časopisi ne moraju nužno svi biti jeftini, ali nov način objavljivanja može znatno smanjiti troškove, a time i cijenu. Pa tako da se trošak po članku za elektronički časopis može kretati od 300-1000 $, za razliku od tiskanog koji ima trošak od 2000-4000$ po članku. Kako bi usporedio troškove objavljivanja u tiskanoj i elektroničkoj sredini, Odlyzko navodi dva moguća modela uređivanja jeftinijeg časopisa u elektroničkom obliku. [10] U prvom modelu glavni urednik časopisa koji objavljuje 200 članaka godišnje i donosi godišnju zaradu od milijun dolara želi pokrenuti elektronički časopis iste kvalitete čiji će godišnji troškovi biti oko 50 000 dolara. Za posao uređivanja uredniku bi trebao samo jedan asistent, a rukopise bi autori slali u obliku tehnički prihvatljivom za objavljivanje pa oko tehničke pripreme ne bi bilo dodatnih poslova ni troškova. Trošak po članku u takvom časopisu bio bi 250$.

U drugom modelu koji Odlyzko opisuje urednik manjeg časopisa ne misli da su pristigli rukopisi tehnički
2. Naplata po pristupu članku (pay-per-view) je model koji se temelji na naplaćivanju pristupa pojedinim člancima, a ne časopisu kao zbirci članaka.
adekvatno uređeni. Sam uređuje članke i prosječno mu po stranici treba 30-60 minuta. Želi li ubrzati posao, urednik može zaposliti asistenta čija bi plaća mogla biti oko 100 000$ godišnje, a to je do 1000$ po članku. Kako god u oba modela, troškovi su znatno manji od 4000$ po članku koliko može iznositi objavljivanje tiskanog članka.

Svi pokušaji rješavanja problema dostupnosti znanstvenih časopisa uglavnom se temelje na razvoju novih informacijsko- komunikacijskih tehnologija. Tome je tako zato što je elektronička sredina pružila nove mogućnosti, ali troškovi ipak postoje te ih treba pažljivo planirati koristeći postojeće i pokrećući nove poslovne modele.[5]Jedan od načina rješavanja problema dostupnosti znanstvenih časopisa svakako je elektronički način objavljivanja koji je pružio znanstvenicima i znanstvenim ustanovama mogućnost samostalnog objavljivanja članaka čineći ih tako vidljivim, pretraživim i besplatno dostupnim širokoj znanstvenoj zajednici. Takav oblik izdavaštva naziva se samoarhiviranjem, a odnosi se na polaganje elektroničkog dokumenta na javno dostupnu mrežnu stranicu. Polaganje dokumenta podrazumijeva stvaranje jednostavnog sučelja na koje autor/ustanova unosi metapodatke (datum, ime autora, naslov, naslov časopisa itd.) i uz njih veže cjelovit tekst dokumenta. Na taj način nastaju arhivi elektroničkih znanstvenih članaka, tj. zbirke digitalnih zapisa. [5]

VII. PLANIRANJE TROŠKOVA PRI OBJAVLJIVANJU ZNANSTVENIH ČASOPISA

Kada govorimo o planiranju troškova pri objavljivanju znanstvenih časopisa ono uključuje mnogo toga. No prvo je važno spomenuti da urednik časopisa s članovima uredništva mora redovito izrađivati planove poslovanja, odabrati odgovarajući model financiranja te stvoriti financijski održiv plan. To je između ostalog veoma važno za postizanje visoke kvalitete časopisa. Pri samoj izradi godišnjeg plana uredništvo treba predvidjeti: tehničke podatke o časopisu, podatke o tržištu, troškove pripreme i izvore financiranja.

Prije pojave komercijalnih izdavača bilo je nekoliko osnovnih izvora financiranja znanstvenih časopisa: naplatom pretplata, članarina i/ili preusmjeravanjem drugih sredstava. Veliki preokret dogodio se pojavom elektroničkog izdavaštva jer je razvoj novih tehnologija omogućio nov način objavljivanja koji je zahtijevao nove poslovne modele naplate troškova. Tako da su nastali sljedeći modeli naplate:

1. Vezanje pretplata je jedan od prvih modela naplate koji su počeli koristiti izdavači u e-okruženju gdje je pretplata na tiskani časopis uključivala i uporabu e-inačice ili obratno. Taj je model karakterističan za hibridnu okolinu (ona u kojoj postoje i tiskane i elektroničke inačice časopisa).

Te povezane pretplate su korisne znanstvenicima jer omogućuju pristup nedostupnim časopisima

2. Naplata po pristupu članku (pay-per-view) je model koji se temelji na naplaćivanju pristupa pojedinim člancima, a ne časopisu kao zbirci članaka.

3. Model naplaćivanja troškova autorima (APC) je model u kojem troškove objavljivanja znanstvenih časopisa je moguće prebaciti s korisnika na autora.

VIII. STANJE ZNANSTVENIH ČASOPISA U REPUBLICI HRVATSKOJ

Što se tiče stanja znanstvenih časopisa u Republici Hrvatskoj važno je prvo reći da je ona relativno mala zemlja koja s obzirom na ostale zemlje ima relativno malu akademske zajednicu ali bez obzira na to ima jedan jako kvalitetan portal znanstvenih časopisa *Hrčak* koji većinom nudi časopise u otvorenom pristupu iz raznih znanstvenih područja te koji je kao takav veoma koristan cjelokupnoj akademskoj zajednici u RH. Mnogo članaka nudi se na hrvatskom ali i na engleskom jeziku. A cijeli portal je veoma dobro strukturiran i organiziran te su kvalitetno iznijeti svi važni podaci svakog časopisa a i članci u njima se vrlo lako mogu pronaći.[1]

IX. ZAKLJUČAK

Kao što se moglo vidjeti u radu sam postupak objavljivanja znanstvenih časopisa košta. I ta cijena troška objavljivanja znanstvenih časopisa kao i cijena pretplata se mijenjala kroz godine. Kako su se povećale cijene pretplata tako je došlo do krize dostupnosti znanstvenih informacija. U tom problemu se nisu našli samo znanstvenici nego i knjižnice koje su zbog toga počele otkazivati ili smanjivati pretplate na neke znanstvene časopise.

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Zaista prvi koraci u programiranju - radionica unutar aktivnosti All Digital Week

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***Sažetak* – U radu se opisuje radionica u kojoj je učiteljicama iz tri riječke osnovne škole objašnjeno kako mogu svoje učenike uvesti u svijet programiranja. Obrađeni su pojmovi program, naredba, varijabla, konstanta, adresa i kompatibilnost.**

Ključne riječi - programiranje; prvi razred; program; varijabla

I. UVOD

Metoda Mema [1] postoji već više od trideset godina, ali se ne koristi onoliko koliko bi trebala. Jedan od mogućih razloga je nedostatak motivacije kod učitelja i učiteljica da metodu primjene u razredu. Godinama na razne načine autorice ovog rada nastoje utjecati na popularizaciji metode [2] koju su same razvile i koju su kroz godine nastojale usavršiti i proširiti [3].

A. *Metoda Mema*

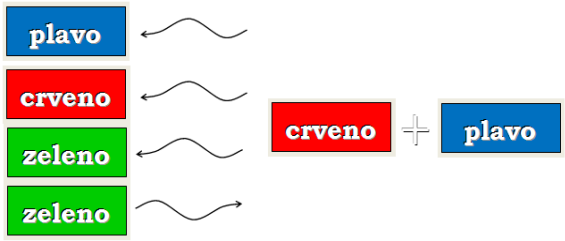
Metoda Mema iscrpno je opisana u [2], pa se ovdje daju samo osnovni podaci.

Koristi se igračka koja se zove Mema (po njoj je metoda dobila ime), koju djeca sama izrađuju od praznih kutijica šibica (slika 1.), a programi se zadaju crtežom (slika 2.)

Pretinci predstavljaju varijable radne memorije, oni su raznih boja, pa boje u toj fazi postaju adrese, pretinci se pune zrnima graha, pa broj zrna postaje sadržaj varijable.

Slika 1. Igračka Mema koju djeca sama izrađuju i po kojoj je metoda dobila ime

Grad Rijeka potpomaže Društvo kibernetičara i aktivnost društva u propagiranju metode Mema



Slika 2. Program za zbrajanje dva broja

Program na slici 2. ime četiri naredbe. Prva je da korisnik stavi koliko želi zrna u plavi pretinac, druga da stavi koliko želi u crveni, treća da u zeleni stavi zbroj koji dobije kad zbroji crveni i plavi, te četvrta da ispiše koji se broj zrna nalazi u zelenom pretincu.

II. RAZLOZI ZA KORIŠTENJE METODE

A. *Prethodni rezultati*

Metoda je prvi put korištena pred više od trideset godina u osnovnoj školi „Nikola Tesla“ u Rijeci u razredu učiteljice Maje Mulac. Nekoliko godina kasnije je nastavnik Damir Čović uočio da djeca iz jednog paralelnog razreda mnogo bolje uče programirati nego njihovi vršnjaci iz preostala tri razreda. U razgovoru s djecom došao je do saznanja da su oni o tome učili već u prvom razredu osnovne škole. Kontaktirao je njihovu učiteljicu, koja ga je povezala sa autoricom metode. Ta prilika je iskorištena da se napravi istraživanje u sva četiri razreda, pa su svi učenici isti dan pisali test iz programiranja na programskom jeziku Basic. Razred koji je imao ranije nastavu po metodi Mema imao je statistički značajan bolji rezultat iz programiranja [4].

B. *Plan budućeg istraživanja*

- Nastojat će se u što više škola u bar jednom razredu sustavno raditi sa djecom po metodi Mema. Poželjno je da nastavu odrade njihove učiteljice ili učitelji.
- Kada u višim razredima započne nastava programiranja koja će koristiti neki programski jezik, kompjutorske igre ili robote provjerit će se hoće li se učenici obučeni po Mema metodi bolje snaći u programiranju.

- Hipoteza budućeg istraživanja glasi: Učenici obučeni po Mema metodi značajno bolje usvajaju programiranje od učenika koji nisu bili obučeni po toj metodi.

C. Radionica Zaista prvi koraci u programiranju

Tri ravnateljice u tri riječke škole zainteresirale su se za radionicu i tako se na nju prijavilo 11 učiteljica.

Trajanje radionice je bilo ograničeno na dva školska sata. Slične radionice su i ranije bile održavane u nekim školama u Rijeci i okolici, ali nakon radionica nije bilo daljnjih aktivnosti. Učiteljice uglavnom nisu smatrale da bi trebale nastaviti s upoznavanjem metode ni njenom primjenom. Možda je pogreška bila i u našem pristupu, jer smo ih premalo motivirale. Ovaj put težište smo stavile ne na upoznavanje metode, nego na motivaciju učiteljica. Dakle one su trebale osjetiti da mogu savladati metodu i da bi ona mogla biti od velike koristi njihovih učenicima.

Tijekom radionice učiteljice su izradile igračku Memu, te bile upoznate samo sa jednom naredbu: Ulaz.

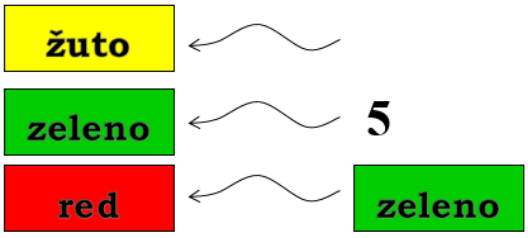
Međutim, tu su naredbu upoznale vrlo detaljno, a malo smo je i proširili jer smo osim čistog ulaza predstavili i punjenje varijable konstantom i punjenje sadržaja varijable varijablom.

Dok su izrađivale Memu proveli smo diskusiju o varijablama. Rečeno im je da će kasnije, u pravim programima varijable imati svoja imena, a boja se u prvom razredu koristi iz dva razloga:

- Prvi je da neka djeca još ne znaju čitati ili loše čitaju,
- Drugi je da se u prvom razredu ionako upoznaju sa raspoznavanjem i imenovanjem boja.

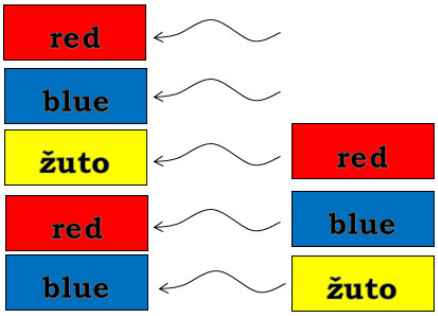
Zatim smo prodiskutirali zašto sve Meme moraju imati iste boje. Razlog je u tome da se boje koriste i u programima, pa da se neka boja spominje u programu, a ne postoji na Memi, taj se program ne bi mogao provjeravati na toj Memi (i odmah je slijedilo objašnjenje pojma kompatibilnosti i testiranja programa).

Na slici 3. je najprije primjer ulazne naredbe, druga naredba je punjenje pretinca konstantom, a treća punjenje pretinca sadržajem drugog pretinca.



Slika 3. Primjeri punjenja varijabli

Nakon toga su učiteljice dobile zadatak da samo sa naredbama koje su im objašnjene, dakle ulaz i proširene upute za punjenje pretinca, sastave program koji učitava dva broja u dva pretinca i zatim zamijeni sadržaje pretinaca. Taj zadatak je prikazan na slici 4.



Slika 4. Primjer programa „Zamjena sadržaja pretinaca“ koristeći samo naredbe ulaza

Postavilo se pitanje: Što ako naredba zahtjeva da se u neki pretinac stavi neki broj, a u njemu se već nešto nalazi? U ovom koraku učiteljice su dobile uputu da se prije punjenja pretinac uvijek prazni.

Od početka radionice učiteljice su bile aktivne i zainteresirane. Neke od učiteljica priznale su da se ne bi prijavile na radionicu da u naslovu uz prve korake u programiranju nije stajala i riječ „zaista“. Na kraju su popunile anketu.

D. Rezultati ankete

Na kraju radionice koja je održana u okviru aktivnosti „All Digital Week 2018“ provedena je anketa sa svrhom ispitivanja stavova učiteljica prema uvođenju programiranja pomoću metode koja koristi igračku Mema za djecu u ranom školskom uzrastu.

U istraživanju je sudjelovalo 11 ispitanica - učiteljica iz tri osnovne škole u gradu Rijeci, koje su sve bile ženskog spola te su imale između 25 i 60 godina starosti.

Istraživanje je provedeno u ožujku 2018. godine nakon održane radionice „Zaista prvi koraci u učenju programiranja za učiteljice i učitelje“ u okviru *All Digital Week 2018*. Učiteljice su zamoljene da popune anketni upitnik u papirnatom obliku koji je bio anoniman i zasnovan na dobrovoljnoj razini.

Prvi dio upitnika je sadržavao 8 pitanja vezanih uz demografska pitanja. Drugi dio upitnika je sadržavao 8 pitanja vezanih uz stavove o programiranju te uvođenju programiranja pomoću Meme za djecu ranog školskog uzrasta koji su bili korišteni u prethodnom istraživanju sa studentima - budućim učiteljima [5].

Učiteljice (N=11) su svoje odgovore na tvrdnje odabrane za ovo istraživanje mogle dati na Likertovoj skali od 1 do 5 na sljedeći način: 1=potpuno netočno, 2=uglavnom netočno, 3=niti netočno, ni točno; 4= uglavnom točno; 5=potpuno točno.

U tablici II. dan je usporedni prikaz postotaka odgovora sudionika na navedenoj skali te artimetičke sredine i standardna devijacija. Prema dobivenih aritmetičkim sredinama vidljivo je kako su učiteljice na tvrdnju „Općenito, smatram da je programiranje teško.“ u prosjeku bile neodlučne u davanju odgovora (M=3.18).

Zatim učiteljice u prosjeku uglavnom smatraju da je igračka Mema korisna kao pomoć u svladavanju brojeva

(M=4.0). Gotovo sve učiteljice (90.9%) se slažu da je igračka Mema korisna u svladavanju boja.

Također je iz dobivenih rezultata (tablica II.) vidljivo da učiteljice u prosjeku smatraju uglavnom točnom tvrdnje da je Mema korisna u svladavanju motorike (M=4.45) te da je korisna kao pomoć u razvoju znanja o algoritmima (M=4.55).

Gotovo su sve učiteljice, njih 90.9%, iskazale da bi rado učile više o korištenju metode Mema te isto toliko njih smatra ovu metodu zanimljivom i uvjerenja je da je igračku Memu lako koristiti.

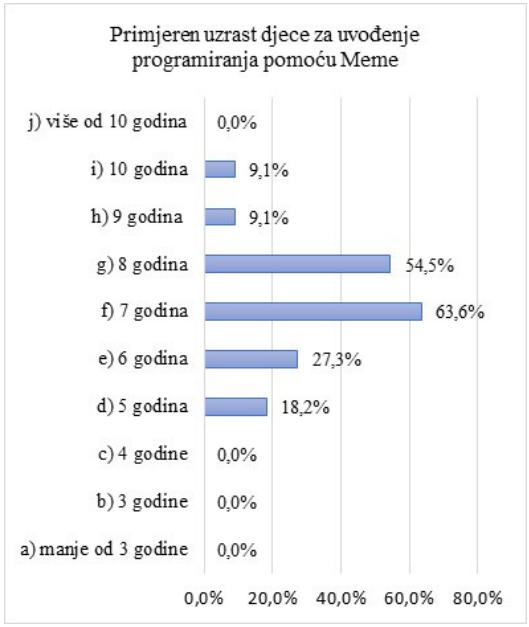
TABLICA I. STAVOVI **UČITELJICA** (N=11) PREMA UVOĐENJU RAČUNALNOG PROMIŠLJANJA I PROGRAMIRANJA POMOĆU METODE KOJA KORISTI IGRAČKU MEMA ZA DJECU RANOG ŠKOLSKOG UZRASTA (% ODGOVORA NA STUPNJEVIMA OD 1- POTPUNO NETOČNO DO 5 - POTPUNO TOČNO, M -ARITMETIČKE SREDINE I σ-STANDARDNE DEVIJACIJE)

Tvrdnje	**1**	**2**	**3**	**4**	**5**	**M (σ)**
Općenito, smatram da je programiranje teško.	1	1	5	3	1	**3.18 (1.08)**
Igračka Mema korisna je kao pomoć u savladavanju brojeva.	0	0	4	3	4	**4.00 (0.89)**
Igračka Mema korisna je kao pomoć u savladavanju boja.	0	0	1	1	9	**4.73 (0.65)**
Igračka Mema korisna je kao pomoć u savladavanju motorike.	0	0	2	2	7	**4.45 (0.82)**
Igračka Mema korisna je kao pomoć u usvajanju osnovnih znanja o algoritmima.	0	0	1	3	7	**4.55 (0.69)**
Kad bi mi se za to pružila prilika, rado bih o Memi te o njenoj primjeni naučila/naučio više.	0	0	1	3	7	**4.55 (0.69)**
Koristeći igračku Memu u čini mi se lako.	0	0	1	5	5	**4.36 (0.67)**
Koristeći igračku Memu čini mi se zanimljivo.	0	0	1	4	6	**4.45 (0.69)**

Rezultati istraživanja su pokazali da 63.6% učiteljica sudionica radionice nisu tijekom svojeg obrazovanja učile programirati u nekom od programskih jezika (npr. Logo, Qbasic, C++, Python i slično).

Na skali od 1=izvrsno do 5= vrlo slabo, učiteljice su svoje prethodno znanje i vještine iz programiranja u prosjeku ocijenile kao „slabo“ (M= 4.18, SD=0.98). Sve učiteljice su se izjasnile da do tada nisu koristile neku od metoda za rano učenje programiranja kod učenika nižih razreda osnovne škole.

Nadalje, 90.9% učiteljica je iskazalo interes za korištenje metode Mema u svojem budućem nastavnom radu sa učenicima ranog uzrasta ako bi za isto imale mogućnosti. Najveći udio učiteljica (63.6%) u prosjeku se slaže da je ova metoda najprimjerenija za djecu od 7 starosti, dok nešto malo više od polovice učiteljica (54.5%) smatra da je metoda Mema najprimjerenija za djecu od 8 godina starosti. Navedeno je vidljivo na slici 5.



Slika 5. Postotak učiteljica s obzirom na uvjerenje o primjerenom uzrastu djece za uvođenje programiranja pomoću metode Mema

III. ZAKLJUČAK

U ovom radu prikazani su rezultati radionice u kojoj su učiteljice bile poučavane o načinu korištenja metode Mema za rano učenje programiranja i razvoj logičkog razmišljanja kod djece nižeg školskog uzrasta.

Obzirom da su sudionice radionice bile učiteljice s višegodišnjim iskustvom u radu sa djecom nižeg osnovno školskog uzrasta, smatra se da su njihovi iskazani stavovi o primjeni metode Mema u nastavnom procesu poseban doprinos ovog rada.

Velika većina učiteljica smatra da spomenuta metoda omogućuje kod male djece usvajanje i razvoj informatičkih i općih sadržaja, zatim smatraju da je metoda zanimljiva, te da je laka za naučiti koristiti.

U usporedbi sa prethodnim istraživanjem [5] koje je provedeno sa studentima-budućim učiteljima, može se zaključiti da su obje grupe ispitanika zaključile da je ova metoda najprimjerenija uzrastu djece u rasponu od 5 do 8 godina kao što je predviđeno u izvornoj metodi Mema.

Važno je naglasiti da je velika većina učiteljica iskazala interes za daljnjom edukacijom vezanom uz primjenu metode Mema za rano učenje programiranja i razvoj logičkog razmišljanja. Učiteljice su jedine educirane za rad sa tako malom djecom, stoga se smatra da je upravo potrebno nadograditi njihove kompetencije za uvođenjem ranog učenja programiranja u nastavni proces. Ograničenje ovog rada se ogleda u malom broju ispitanica, međutim sve učiteljice su se dobrovoljno prijavile na radionicu što se smatra potvrdom njihove želje za uvođenje ranog učenja programiranja u svom nastavnom procesu. Rezultati ovoga rada mogu poslužiti svima koji žele uvoditi rano učenje programiranje kod djece malog uzrasta sa ili bez primjene računala.

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Platforma za online učenje WeCliqued

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***Sažetak* - Ovaj rad opisuje funkcionalnosti WeCliqued platforme za online učenje s naglaskom na njenu primjenu i olakšavanje savladavanja online tečajeva na ostalim platformama. Zainteresiranima za stjecanje novih znanja WeCliqued platforma omogućava organizirano grupno praćenje online tečajeva te kreiranje i organiziranje online tečajeva.**

Ključne riječi – e-učenje; edukacija; platforma za učenje

I. UVOD

Razvoj tehnologije i interneta omogućio je kombinirano učenje poznato pod pojmom *Blended Learning* koje je u klasičnu edukaciju unio digitalne medije čime se olakšalo i ubrzalo savladavanje materije, arhiviranje te razmjenjivanje materijala između učitelja i učenika. Nastavak na kombinirano učenje je E-učenje. Danas E-učenje više nije novost u svijetu edukacije, pogotovo kada je riječ o informatici. Postoje mnoge platforme koje polaznicima pružaju svu potrebnu literaturu, primjere i ostale materijale kako bi savladali gradivo koje sadrži neki online tečaj.

Najveća mana takvog sustava je nenaviknutost ljudi na takav oblik učenja kroz svoje školovanje. Veliki je nerazmjer u broju korisnika koji započnu online tečaj i broj onih korisnika koji ga završe. Ljudi su navikli raditi u kolektivu i jako im je teško naći motivaciju da sami prolaze i savladavaju novo gradivo i tehnologije.

Osnovna ideja digitalne agencije Drap bila je pomoći polaznicima online tečajeva da imaju mogućnost savladavanja gradiva u grupi ljudi koji također prate isti online tečaj kao i oni ili da organiziraju vlastito okupljanje u svrhu grupnog učenja kroz online tečaj.

Danas, kada je potražnja za znanjem iz područja programiranja, dubinskog učenja i marketinga iznimno velika, kao i količina online tečajeva iz navedenih polja, WeCliqued platforma za e-učenje na kojoj smo radili kao programeri klijentskog dijela aplikacije, nameće se kao optimalno rješenje za sve korisnike koji žele stjecati nova znanja s ostalim polaznicima online tečajeva.

II. OSNOVNA STRUKTURA APLIKACIJE

WeCliqued je klijent-poslužiteljska web aplikacija razvijena u Ruby on Rails radnom okruženju što omogućuje složenu funkcionalnost sustava, laku nadogradnju i brzinu rada na visokom nivou. Aplikacija je vezana na PostgreSQL bazu koja služi za pohranu podataka [1]. Poslužiteljski dio sustava temeljni je dio aplikacije jer je zadužen za pohranu podataka o tečajevima, za sustav prijave polaznika, prijavu organizatora tečajeva, vođenje računa o broju prijavljenih korisnika na određeni tečaj, listi čekanja, datumima održavanja tečajeva, njihovom trajanju itd. Cijeli razvoj sustava pokriven je jediničnim i integracijskim testovima radi lakšeg održavanja koda projekta.

III. KORIŠTENJE APLIKACIJE

A. *Registracija novog korisnika*

Registraciju je moguće obaviti na dva načina. Putem Google registracije ukoliko korisnik posjeduje Google račun ili ispunjavanjem obrasca za registraciju. Korisnik treba unijeti ime i prezime, svoju e-mail adresu, željenu lozinku te na kraju pročitati i potvrditi uvjete korištenja. Također može odabrati opciju primanja biltena ukoliko to želi. Klikom na gumb "Registriraj se" korisnik na svoju e-mail adresu prima aktivacijsku poveznicu. Klikom na aktivacijsku poveznicu korisniku se u pregledniku prikazuje početna stranica s njegovim imenom i prezimenom u gornjem desnom uglu stranice.

Korisnik može uređivati svoj profil. Ima mogućnost dodavanja profilne slike u jpg ili png formatu veličine do 500 KB, ima mogućnost promjene lozinke, dodavanja svoje web stranice te kratkog vlastitog opisa u tekstualnom okviru naziva "O meni".

B. *Prijava na tečaj*

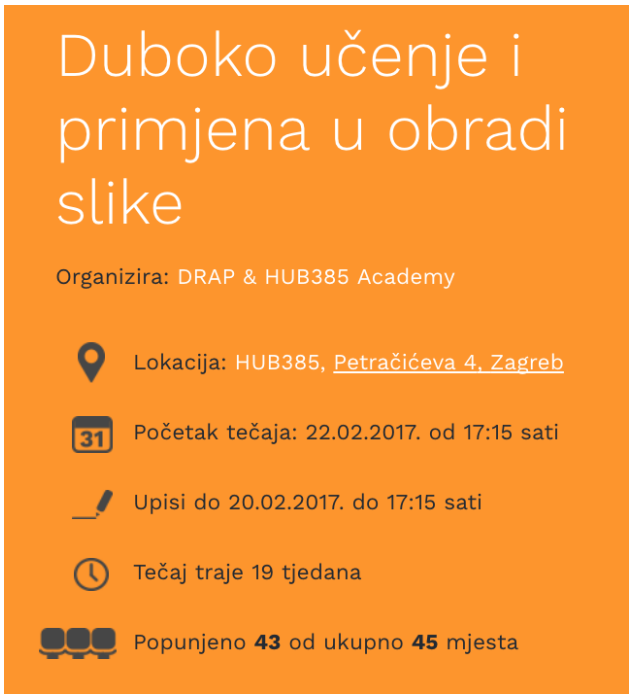
U navigacijskoj traci odabirom stavke "Pretraži tečajeve" korisniku se prikažu svi tečajevi te kratke informacije o svakome od ponuđenih (Sl. 1.).

Slika 1. Izgled kratkog opisa pojedinog tečaja

Korisniku je u sažetom opisu prikazan naziv, lokacija održavanja, datum početka i broj slobodnih mjesta u tečaju.

Odabirom opcije "Vidi više", korisnik dolazi na stranicu gdje mu se prikazuju detaljni podaci o tečaju. Podaci koji su prikazani korisniku su: adresa, početak (dan i sat), rok do kada se može prijaviti (dan i sat), trajanje te

popunjenost tečaja (Slika 2). Korisniku je također vidljiv detaljan opis tečaja i pripadajuće napomene, životopis mentora koji vodi tečaj te podaci o organizatoru. Vidljiv je i datum svih termina tečaja kao i vremensko trajanje svakog termina. Klikom na gumb "Upiši tečaj" korisnik se upisuje te prima potvrdu na elektroničku poštu. Na istu



Slika 2. Dio detaljnog prikaza informacija o tečaju

adresu elektroničke pošte dobivat će daljnje informacije o tečaju. Ukoliko je tečaj popunjen, korisnik ima mogućnost prijaviti se na listu čekanja, te ukoliko se mjesto otvori, automatski će biti prijavljen na tečaj te će dobiti elektroničku poštu s povratnom informacijom.

C. Organizacija tečaja

Svaki registrirani korisnik ima mogućnost organizacije tečaja. Klikom na "Organiziraj tečaj" u donjem dijelu stranice korisniku se prikaže stranica organizacije tečaja na kojoj je obrazac koji mora ispuniti. Prva stavka obrasca je web adresa online tečaja čije pohađanje korisnik želi organizirati. Druga stavka je naziv tečaja. Zatim slijedi stavka za postavljanje slike tečaja dozvoljenog formata jpg i png do 500KB veličine (Slika 3). Potom korisnik ispunjava opis tečaja i eventualno odabire opciju "Mogućnost certificiranja".

U idućem koraku određuje se minimalan i maksimalan broj sudionika. Zatim slijedi unos podataka o lokaciji održavanja tečajeva te izbor tvrtke organizatora u padajućem izborniku. Ukoliko tvrtka nije na popisu, korisnik ima mogućnost dodavanja nove tvrtke .

Klikom na gumb "Nova tvrtka" prikaže se skočni prozor na kojem je obrazac za ispunjavanje podataka o novoj tvrtci (Slika 4). U glavnom obrascu za organizaciju tečaja korisnik još treba odabrati mentora (mentor može biti bilo koji registrirani korisnik) i dodati napomene ako ih ima (npr. da je obavezno na tečaj ponijeti prijenosno računalo). Na kraju korisnik klikom na gumb "Pregledaj" dobiva na uvid kako će izgledati svi podaci o tečaju koje je unio. Klikom na gumb "Uredi", vraća se na glavni obrazac, a klikom na gumb "Prihvati" podaci se šalju na poslužitelj. Da bi tečaj bio vidljiv svim korisnicima, administrator ga mora odobriti kroz administracijsko sučelje.

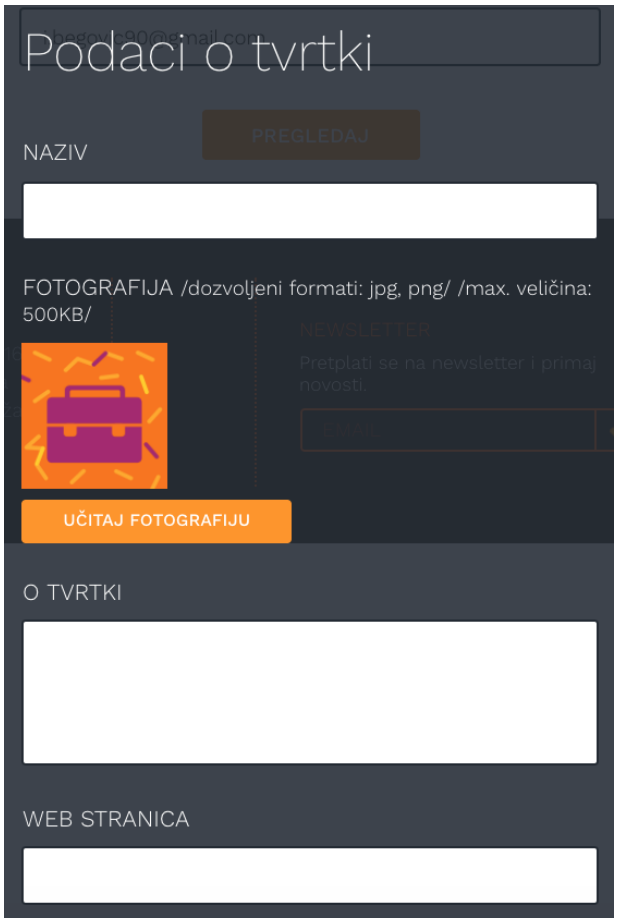
Slika 3. Početni dio forme organizacije tečaja

IV. ADMINISTRACIJA APLIKACIJE

Administracija aplikacije izvršava se putem Rails-admin dodatka koji je dio programske strukture web platforme. Rails-admin je administratorsko sučelje kroz koje se ulazi s posebnim imenom i zaporkom [2]. U njemu se mogu ručno dodavati tvrtke, administratori tvrtki, tečajevi, predavači, polaznici tečajeva i termini tečajeva. Također, kroz administratorsko sučelje vidljivi su svi tečajevi za koje je poslan zahtjev za održavanjem te se kroz sučelje tečajevi mogu odobriti, ali i odbiti.

Također vidljivi su svi održani tečajevi, svi tečajevi koji su u tijeku te svi otkazani tečajevi. U pregledu registriranih korisnika prijavljenih na određeni tečaj vidljivo je koji tečaj pohađaju, tj. za koji tečaj su prijavljeni te nalaze li se na listi čekanja ili su uspješno uspjeli rezervirati svoje mjesto.

Također je vidljiv popis svih korisnika kao i adrese njihove elektroničke pošte kako bi se u iznimnim situacijama registrirani korisnici mogli kontaktirati i prenijeti im potrebne informacije.



Slika 4. Izrada nove tvrtke

V. TEČAJEVI

A. *Prvi tečaj iz strojnog učenja*

Prvi održan tečaj bio je iz područja Strojnog učenja koji se temeljio na popularnom Courserinom online tečaju autora Andrewa Nga. Tečaj se održavao u HUB385 akademiji u Zagrebu. Predavač i mentor tečaja bio je Davor Runje, vlasnik digitalne agencije Drap, koji je tečaj nadopunio mnogim korisnim iskustvima iz praktične primjene modela koji su se koristili u tečaju. Tečaj se sastojao od 27 termina koji su bili raspoređeni unutar 3 mjeseca u trajanju od 2 sata i 45 minuta. 35 korisnika se moglo prijaviti na tečaj te je tečaj bio popunjen u roku 24 sata (Slika 5).

Slika 5. Praćenje online tečaja uz mentora [3]

Tečajevi su se održavali u pravilu dva puta tjedno. Prvi dan su se slušala i gledala predavanja samog Courserinog tečaja uz mentorova pojašnjenja kompleksnijih dijelova tečaja, a drugi dan su se rješavale vježbe koje su bile sastavni dio online tečaja. Dio se sastojao od teoretskih testova znanja s ponuđenim odgovorima na zaokruživanje, a dio testova bio je koncipiran na principu pisanja koda. Najviše se koristio programski jezik Python i alat Tensorflow.

Od 35 upisanih, desetero polaznika je uspješno završilo tečaj. Dakle, otprilike oko 30% prijavljenih korisnika je uspjelo odraditi cjelovit tečaj strojnog učenja, dok je Courserin prosjek 12.5%. U svakom slučaju radi se o brojci koja ide u prilog činjenice da ljudi kvalitetnije i predanije uče u kolektivu, nego potpuno samostalno.

B. *Ostali tečajevi*

Pred kraj prvog tečaja, uskoro je bio organiziran i drugi tečaj iz područja strojnog učenja, ali ovoga puta u Puli u Industrijsko-obrtničkoj školi pod mentorstvom Lovre Žmaka.

Za vrijeme prvog tečaja, bio je pokrenut još jedan tečaj u BIZkoshnici u Zagrebu pod nazivom Digitalna transformacija. Tečaj se temeljio na platformi Future Learn. Mentori ovog tečaja bile su izvršna direktorica Drapa Hajdi Ćenan i direktorica društvenih medija u Drapu Katarina Exlé. Tečaj se sastojao od četiri termina raspoređenih u četiri tjedna u trajanju od 3 sata. Temeljio se na uvođenju digitalne tehnologije u svakodnevno poslovanje tvrtki svake vrste. Popunjenost tečaja je bila potpuna, od 57 mogućih mjesta svih 57 je bilo popunjeno.

Zbog velikog interesa za tečaj strojnog učenja bio je pokrenut novi tečaj ponovo pod mentorstvom Davora Runje. Ovoga puta radilo se o tečaju dubinskog učenja kroz prilično na tečaj strojnog učenja. Naziv tečaja bio je Duboko učenje i primjena u obradi slike. Tečaj je trajao 19 tjedana. Tečaj se temeljio na kolegiju SC231n sa sveučilišta Stanford. Cilj tečaja bio je naučiti teoriju i praktičnu primjenu dubokih neuronskih mreža u obradi slike. Alati koji su se koristili bili su programski jezik Python i Tensorflow.

VI. PREDNOSTI WECLIQUED PLATFORME

A. *Dostupnost polaznicima i mentorima*

Ključna prednost WeCliqueda u odnosu na ostale platforme je njegova dostupnost. WeCliqued je teško uspoređivati s platformama poput Coursere ili Udemya jer postojeće platforme ne pružaju mogućnost praćenja tečajeva uživo. Mnoge obrazovne ustanove, poput visokog učilišta Algebra, pružaju kombinirani oblik nastave gdje studenti mogu predavanja pratiti online, ali mogu i prisustvovati uživo. WeCliqued je donekle sličan spomenutim modelima edukacije, ali je opet jedinstven na ovim prostorima. Ni jedna tehnologija iz područja online učenja nije tako uspješno rješavala problem nekonzistentnosti učenja putem online tečajeva kao WeCliqued.

Kada se uzme u obzir da je u potpunost besplatan i da tečaj može organizirati bilo tko i bilo gdje ukoliko administrator sustava to odobri, WeCliqued prednjači u

dostupnosti svima. Uz pomoć ove platforme veoma je lako proširiti mogućnost kvalitetne edukacija izvan većih gradova i olakšava napredak svakog pojedinca koji pohađa tečaj.

Gledajući iz perspektive korisnika, gotovo je nemoguće naći kvalitetniju edukaciju bez ikakvih potrebnih sredstava izuzev vlastitog prijenosnog računala ukoliko je potrebno za tečaj. Promatrajući platformu iz perspektive mentora ili tvrtke organizatora, jako je teško naći bolji način za stvaranje zajednice ljudi čiji su interesi fokusirani na istu tehnologiju.

S obzirom da se radi o sustavu koji nije vezan uz ni jednu obrazovnu ustanovu može bez problema pratiti sve tehničke inovacije i dinamično adaptirati ponudu tečajeva jer samu ponudu kreiraju registrirani korisnici. Upravo su za to tečajevi strojnog i dubokog učenja najbolji dokaz jer većina polaznika koja je položila prvi tečaj iz strojnog učenja, nastavila je pohađati i drugi tečaj iz dubokog učenja.

Nedostaci platforme su potreba za organizacijom svakog tečaja. Potrebno je pronaći adekvatnog predavača i rezervirati odgovarajući prostor koji zadovoljava uvjete za održavanje tečaja.

B. Budućnost WeCliqueda

Cilj razvoja WeCliqueda je pratiti nove tehnologije i shodno tome nuditi pomoć pri online edukaciji svim zainteresiranim korisnicima. Također, cilj je da i dalje ostane platforma ostane besplatna za pomoć u svladavanju online tečajeva jer se na takav način najbolje stvaraju zajednice ljudi sličnih tehnoloških interesa i preferencija. Uskoro je u planu pokrenuti novi niz tečajeva, a prvi u planu će biti nastavak strojnog i dubokog učenja, kako za one koji tek ulaze u to područje, tako i za naprednije poznavatelje ove brzorastuće tehnologije.

Dugoročan plan je proširiti korištenje platforme izvan granica Hrvatske. Doradu koju će sustav zahtijevati je svakako implementacija višejezičnosti kako bi platforma bila dostupna širem govornom području.

C. Iskustva u izradi platforme WeCliqued

S programerske strane WeCliqued je predstavljao izazov jer se radi o vrlo kompleksnom sustavu koji ima više mogućnosti registracije i gdje su korisničke ovlasti dosta velike te ih većinu treba kontrolirati kroz prilično složeno administracijsko sučelje. Poslužiteljska strana se sastoji od mnogo međusobno ovisnih funkcija poput praćenja slobodnih mjesta na tečajevima i broja prijavljenih korisnika koji su na popisu čekanja.

Baza podataka koja se nalazi u pozadini takvog sustava je također veoma složena jer korisnik na stranici može biti samo korisnik, ali i polaznik, mentor ili organizator tečaja.

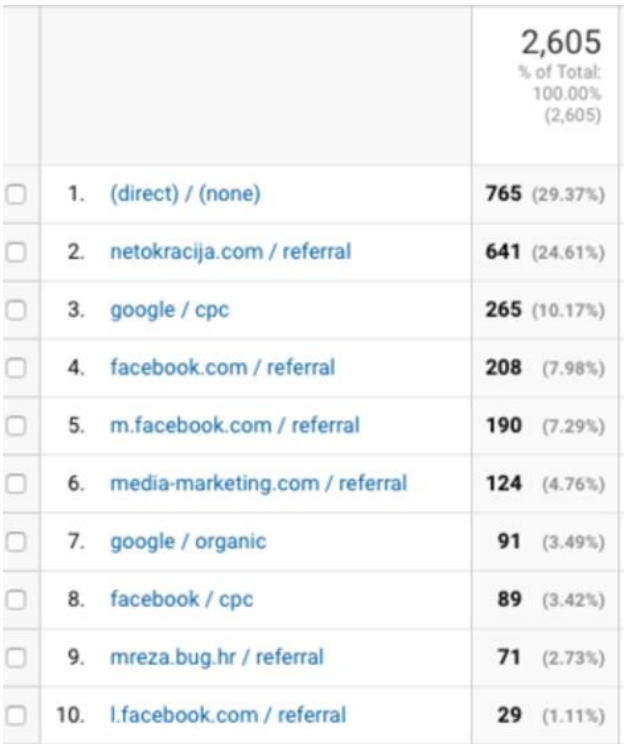
Bilo je važno cjelokupni kod takvog velikog sustava pokriti testovima kako bi ga bilo što lakše održavati (oko 90% koda je pokriveno testovima prema statističkim podacima dostupnim na CodeClimateu[4]). Za poslužiteljsku stranu web stranice korišteni su RSpec testovi[5], a za klijentsku stranu web stranice korišteni su Cucumber[6] testovi.

Klijentska strana koda je ponešto jednostavnija. Bazirana je na sljedećim tehnologijama: HTML-u (prilagođenim za Ruby on Rails radnu okolinu), za stiliziranje stranice korišten je SASS, a za dinamičke funkcionalnost korištena je JavaScript biblioteka jQuery. Svi tekstovi na stranici koji se ne uređuju kroz administratorsko sučelje u Rails-adminu na web stranicu su dodani u yaml [5] formatu kako bi ih bilo što lakše izmjenjivati.

D. Održavanje stranice i oglašavanje

Stranica se većinski održava kroz spomenuto administratorsko sučelje u Rails-adminu. Kroz administratorsko sučelje se redovito provjerava stanje zahtjeva za organizacijom novih tečajeva, broju novih korisnika te novokreiranih tvrtki. Također, s registriranim korisnicima se komunicira i putem redovnih e-mail obavijesti u kojima ih se obavještava o svim novim tečajevima i ostalim novostima vezanim uz platformu.

Oglašavanje se u pravilu radi s objavom novog tečaja, tj. s otvaranjem mogućnosti upisa na tečaj. Najviše putem Facebooka putem Facebook stranice WeCliqued-a i Drap-a. Usprkos oglašavanju, najviše korisnika stranicu u prosjeku posjećuje preko objava na drugim medijima poput Netokracije, ali i izravnim dolaskom na stranicu (Slika 6).



		2,605 % of Total: 100.00% (2,605)
1.	(direct) / (none)	765 (29.37%)
2.	netokracija.com / referral	641 (24.61%)
3.	google / cpc	265 (10.17%)
4.	facebook.com / referral	208 (7.98%)
5.	m.facebook.com / referral	190 (7.29%)
6.	media-marketing.com / referral	124 (4.76%)
7.	google / organic	91 (3.49%)
8.	facebook / cpc	89 (3.42%)
9.	mreza.bug.hr / referral	71 (2.73%)
10.	l.facebook.com / referral	29 (1.11%)

Slika 6. Dolasci na stranicu u rasponu od 10 dana

VII. ZAKLJUČAK

WeCliqued predstavlja način kako online učenje i klasičan način učenja u skupinama mogu ići zajedno i na taj način doprinijeti razvitku znanja i vještina svakog pojedinca. Njegova dostupnost ga čini drugačijim od većine ostalih platformi za online učenje. WeCliqued

platforma je dokaz kako online učenje vjerojatno nikad neće u potpunosti zamijeniti klasičan način učenja, nego da iz oba pristupa treba uzeti najbolje dijelove i prakse i objediniti ih u jedan način učenja.

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Organizacija nastave iz kolegija Oblikovanje web stranica uz povezivanje s mikro tvrtkama

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***Sažetak* - Osnovne tri web tehnologije za izradu modernih web stranica su HyperText Markup Language (HTML), Cascading Style Sheets (CSS) i JavaScript. Kolegij Oblikovanje web stranica koji se predaje na studiju Informacijske tehnologije na Sveučilišnom odjelu za stručne studije u Splitu, obuhvaća gradivo CSS-a, teoriju modernog dizajna te obradu slika korištenjem programa za obradu slika Gimp, smatrajući da studenti već raspolažu znanjem HTML-a i JavaScripta. Nastavni program polazi od same početne faze procesa oblikovanja dizajna, do konačnog cilja, oblikovane moderne web stranice, odnosno modernog web mjesta (skup više web stranica) koje uspješno predstavlja određenu tvrtku, proizvod, uslugu, aktivnost i slično. U akademskim godinama 2015./2016.g. i 2016./2017.g. uvedena je suradnja Sveučilišnog odjela sa Županijskom komorom Split kako bi studenti mogli izrađivati seminarske radove, odnosno moderna web mjesta za stvarne mikro tvrtke, pritom omogućujući studentima povezivanje sa realnim sektorom i upoznavanje sa stvarnim situacijama koje ih očekuju nakon završetka fakulteta. Iako je ovaj način izrađivanja seminarskog rada bio jako zahtjevan za studente, suradnja se pokazala jako uspješna, kao i sami rezultati, odnosno izrađena web mjesta, koja su na suvremeni način prezentirala tvrtke i pripadno poslovanje.**

Ključne riječi - obrazovanje, web, dizajn, CSS, Gimp, WebStart, tvrtke

I. UVOD

Sveučilišno nastavno okruženje nalaže praćenje kurikuluma, sveučilišnih ciljeva i odgovarajućih nastavnih metoda, pri postizanju osnovnog cilja, odnosno učenja ili akcijskog znanja [1][2]. Za svaki kolegij je bitno odrediti najbolju odgovarajuću strategiju učenja koja će pridonijeti da studenti savladaju i razumiju gradivo, kako bi to isto poslije mogli primijeniti na razne situacije. Zbog specifičnosti različitog nastavnog gradiva, ista strategija se ne može primjenjivati kod svakog kolegija [3]. Za kolegij Oblikovanje web stranica koji se predaje na studiju Informacijske tehnologije na Sveučilišnom odjelu za stručne studije u Splitu, uz primjenu raznih metoda učenja i poučavanja, studenti se povezuju sa realnim sektorom i prema pripadnim zahtjevima izrađuju projekte, odnosno web mjesta za svaku pojedinačnu mikro tvrtku. Gradivo kolegija obuhvaća teoriju modernog dizajna, stilski jezik CSS te obradu slika korištenjem besplatnog programa za obradu slika Gimp. Studenti slušaju kolegij na zadnjoj godini studija. Cilj kolegija je osposobiti studenta da samostalno izradi web stranicu i/ili mjesto modernog izgleda prema zahtjevima klijenta. Sami kolegij zahtijeva određenu kreativnost pri primjeni gradiva te je preporučljivo koristiti metode poučavanja s kojima će studentova kreativnost izaći na vidjelo. Uz nezaobilaznu teoriju dizajna, prikazuju se i praktični primjeri, kako bi studenti mogli jednostavnije povezati teoriju i praksu te oblikovati zadane zadatke na svoj kreativni način. Ne nalaže se primjena određenih predložaka, već se želi potaknuti studenta na razmišljanje izvan uobičajenih okvira te na taj način probuditi studentovu kreativnost.

II. NASTAVNI PROGRAM I PROGRAMSKE TEHNOLOGIJE

Gradivo kolegija Oblikovanje web stranica obuhvaća teoriju i značajne tehnologije za oblikovanje web mjesta modernog dizajna, a koncept nastavnog programa polazi od samog početnog procesa oblikovanja dizajna [4]. Razvoj web mjesta je teško zamisliti bez korištenja CSS-a, odnosno jezika za oblikovanje modernog dizajna. CSS predstavlja temeljnu tehnologiju samog dizajna, iako se u praksi realnog sektora uglavnom primjenjuju već provjereni stilski predlošci, pritom ne razmišljajući kako u suštini to funkcionira [5]. Razumijevanje načina funkcioniranja određenog programskog jezika ili tehnologije je jako bitno, budući da se na taj način onda može i koristiti na pravilan način. CSS nije klasičan programski jezik, već opisni stilski jezik, koji sadrži skup pravila koji oblikuju web stranicu i pripadna pojedina područja stranice.

Studenti bi trebali već poznavati HTML, deklarativni jezik za izradu web stranica, kako bi mogli povezati pripadni HTML dokument, odnosno web stranicu sa pripadnim CSS predloškom. Uz oblikovanje stilskog predloška, nezaobilazan zadatak je i obrada i stvaranje vlastitih slika i uzoraka koji se potom mogu koristiti unutar web stranica, odnosno mogu se ukomponirati kao dio stilskog predloška. U tu svrhu koristi se program za obradu slika Gimp, unutar kojeg studenti rješavaju razne zadatke i to od izrade vlastitih slika do obrade fotografija. HTML i CSS kod se piše korištenjem programa Notepad++ ili Brackets.

III. NASTAVNI PROCES

Predavanja su oblikovana u dvije cjeline, od kojih prva cjelina obuhvaća teoriju modernog dizajna, a druga, učenje stilskog jezika CSS-a te se svaka cjelina testira kolokvijem. Laboratorijske vježbe su podijeljene u dvije cjeline, odnosno prva cjelina čini učenje i korištenje programa za obradu slika Gimp, a druga cjelina objedinjuje korištenje CSS jezika i pravila teorije

modernog dizajna, kako bi studenti oblikovali početne web stranice, sukladno odrađenom gradivu na predavanju, budući da je gradivo kolegija koncipirano tako da vježbe iz CSS-a moraju pratiti pripadna predavanja.

A. Organizacija predavanja

Prva cjelina obuhvaća nastavno gradivo: uvod u web dizajn, karakteristike i smjernice današnjeg modernog dizajna, razvojne faze izrade web stranica, sheme i strukture web stranica, principi dizajniranja, tipografija, boje, grafika, redizajn web mjesta (koncipiran kao pregled raznih primjera „izgled web mjesta prije i poslije redizajna"), optimizacija web mjesta za tražilice i web pristupačnost. Svi potrebni materijali za učenje se otvaraju na sustavu Moodle neposredno poslije poučavanja gradiva putem tradicionalne nastave.

CSS nije standardni programski jezik već opisni stilski jezik, gdje je za oblikovanje prosječnog web mjesta potrebno poznavati velik broj CSS svojstava i pripadnih vrijednosti. Prema tome, prvi dio CSS predavanja se uglavnom fokusira na prezentiranje svojstava iz raznih područja za oblikovanje web stranice, kao što su oblikovanje teksta, grafike, sheme i strukture web stranice, uz pripadne jednostavne primjere. Posebno se naznačuju i noviteti iz najnovije CSS specifikacije, CSS3, koja donosi jako velik broj novih mogućnosti oblikovanja koja se mogu izvesti na puno jednostavniji način u odnosu na CSS2 specifikaciju. Najzanimljiviji novitet je oblikovanje raznih vrsta transformacija, promjena i animacija, gdje u drugi plan padaju dosad aktualne i nepraktične Flash animacije. Posebno zanimljivi segment CSS sintakse, je prikazivanje načina oblikovanja web mjesta kojem bi pripadni sadržaj bio prilagodljiv svim uređajima, odnosno stvaranje responzivnog web dizajna [6]. Drugi dio CSS predavanja prikazuje razne primjere oblikovanja web mjesta budući da poznavanje samih CSS pravila nije dovoljno za isto, već je potrebno uvidjeti način njihovih kombiniranja kako bi se dobio željeni izgled stranice, budući da CSS ima posebna pravila specifičnosti, prednosti i nasljeđivanja, o kojima treba voditi računa pri pisanju CSS-a.

B. Organizacija laboratorijskih vježbi

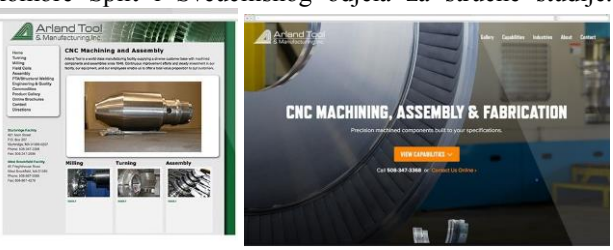
Prvi dio laboratorijskih vježbi obuhvaća vježbe iz Gimpa koje su koncipirane kao tutorijali koji studente podučavaju korak po korak, razne primjere stvaranja i obrade slika. Sukladno objašnjenju primjera, studenti trebaju primijeniti iste postupke pri stvaranju i obradu svojih slika. Prethodnih godina je uočeno da opisani koncept savladavanja Gimpa predstavlja najbolji način učenja, budući da kod prezentacije istog korak po korak preko projektora za vrijeme laboratorijskih vježbi, odnosno prezentiranje u stvarnom vremenu, ipak nije toliko učinkovito, budući da studenti brzo zaborave postupak i potrebno je stalno iznova ponavljati isto, što je nepotrebno kod postojanja tutorijala ovog tipa, kojeg naravno mogu i kod kuće samostalno savladati. Također, moguće su situacije gdje studenti kasne ili iz određenih razloga nisu prisutni pa onda moraju samostalno savladavati isto gradivo bez ikakvog tutorijala, lutajući web prostranstvima ili čekati nadoknade i pritom gubeći određeno vrijeme. Gimp vježbe obuhvaćaju slijedeća područja: upoznavanje s programom za obradu slika, korištenje raznih alata za obradu postojeće i stvaranje vlastite slike, stvaranje određenih dizajn elemenata, rad sa slojevima, rad sa maskama, rad s filter efektima, stvaranje raznih efekata na slikama. Primjer jednog od Gimp zadataka glasi: korištenjem slika po želji, ostvarite efekt preklapanja slika sa slojevnim maskama kao u primjerima kojima su opisane slojevne maske.

Drugi dio laboratorijskih vježbi obuhvaća CSS vježbe koje su koncipirane na drugačiji način, odnosno kada se obradi određeni dio gradiva na predavanju tada se taj dio odradi na vježbama, s tim da se obično unutar vježbe implementira i dio iz teorije modernog dizajna, odnosno iz prvog dijela gradiva kolegija, kako bi se isto još bolje savladalo primjenjujući izravno na vlastitom radu. Kod ovog dijela nema potrebe za tutorijalima budući da se sva svojstva i primjeri detaljno obrađuju za vrijeme predavanja. Primjer jedne od navedenih vježbi glasi: nadogradite web stranicu iz prethodne vježbe tako da oblikujete smislenu shemu web stranice prema želji te oblikujte navigaciju korištenjem nenumerirane liste; web stranicu je potrebno oblikovati prema određenoj shemi boja i potom je naznačiti. Drugi dio vježbi obuhvaća i opisnu vježbu vezanu za sami koncept dizajna, odnosno redizajn web stranica. Za navedenu vježbu svaki student dobiva različitu web stranicu te njen početni i redizajnirani izgled, a potrebno je prema teoriji web dizajna/redizajna uočiti izvršene preinake i popisati ih prema elementima web dizajna, a za svaku preinaku obrazložiti što nije bilo u redu i na koji način je to promijenjeno (Slika 1). Na kraju je potrebno dodati još barem jedan prijedlog kojim bi student poboljšao izgled web stranice.

Laboratorijske vježbe se u pravilu započinju unutar tradicionalne nastave u laboratoriju, a mogu se završiti od kuće, budući da vježbe navedenog tipa nije ipak moguće završiti unutar dva predviđena školska sata, već za pravilno savladavanje vježbi potrebno je dodatno vrijeme i to kod kuće, ili za vrijeme slijedećih vježbi, uz eventualno korištenje uobičajenih konzultacija ili online konzultacija.

C. Seminarski rad i mikro tvrtke

Studenti unutar kolegija također trebaju izraditi i seminarski rad, odnosno oblikovati moderno web mjesto. Izuzev posljednje dvije akademske godine, studenti su timski izrađivali web mjesta po želji i oblikovali prema teoriji modernog dizajna koristeći jednostavni CSS bez korištenja raznih stilskih predložaka. No, u posljednje dvije akademske godine (2015./2016.g. i 2016./2017.g.) kolegij Oblikovanje web stranica je bio dio projekta WebStart, koji se izvodio u organizaciji Županijske komore Split i Sveučilišnog odjela za stručne studije.



Slika 1. Početni i redizajnirani izgled jedne od web stranica odabranih za laboratorijske vježbe

Tema seminarskog rada je bila izrada modernog web mjesta za stvarnu mikro tvrtku (do 3 zaposlenika), a studenti bi odabirali tvrtku prema želji, s tim da bi web mjesto jedne tvrtke oblikovalo zajedno dva studenta. Projekt omogućuje studentima susretanje sa realnim sektorom i stvarnim situacijama koje ih uskoro očekuju nakon završetka fakulteta. Studenti trebaju odgovoriti na zahtjeve klijenata, suočiti se sa stvarnim problemima te pokušati ostvariti uspješnu suradnju pri oblikovanju odgovarajućeg web mjesta na obostrano zadovoljstvo. Projekt se pokazao jako uspješan, iako dosta zahtjevan za studente. No, studenti su bili toliko motivirani i to ne samo upoznavanjem sa realnim sektorom i mogućom daljnjom suradnjom sa određenim tvrtkama, već i simboličnim i novčanim nagradama koje dobivaju najbolja tri rada. Na web stranici https://www.hgk.hr/zk-split-i-sveucilisni-odjel-za-strucne-studije-urucili-nagrade-najboljima-u-projektima-webstart-i-planstart-najava može se pročitati obavijest o proglašenju najboljih radova i o uručenju nagrada. Uspješnost se očitovala i u tome, što su studenti prešli granice samog kolegija i prikazali i primijenili dodatno znanje unutar određenog seminarskog rada, odnosno unutar pripadnog web mjesta koji na suvremeni način prikazuje samu tvrtku i pripadno poslovanje.

D. Metode ispitivanja

Ocjena kolegija obuhvaća teorijski dio koji se ispituje uz pomoć dva kolokvija, laboratorijske vježbe, seminarski rad i nazočnost na tradicionalnom dijelu nastave.

Svako navedeno područje ima svoj težinski faktor i to bodovi prvog kolokvija imaju faktor 0.30, bodovi drugog kolokvija 0.26, laboratorijske vježbe 0.18, nazočnost 0.1 te seminarski rad 0.16. Maksimalna vrijednost bodova iz svakog područja je 100, a konačna ocjena se utvrđuje prema bodovnom rasponu i to ocjena dovoljan za interval bodova 50-61, ocjena dobar za interval 62-74, ocjena vrlo dobar za interval 75-87 i ocjena izvrstan za interval 88-100. Provođenjem projekta WebStart, utvrđeno je kako studenti puno više vremena provode stvarajući i oblikujući svoj seminarski rad pa su sukladno tome promijenjeni i sami težinski faktori i to slijedno tome prethodnim redoslijedom: 0.28, 0.26, 0.16, 0.08 i 0.22.

Gradivo 2. kolokvija ima manji težinski faktor u odnosu na 1. kolokvij, budući da je to gradivo više orijentirano na praktične primjere, koje se u biti ispituju kroz seminarski rad i laboratorijske vježbe, tako da ocjenjivanje same CSS sintakse i eventualno manjih primjera, ne može imati veći značaj u odnosu na teoriju web dizajna. Testovi kolokvija imaju do deset pitanja, kojima se utvrđuje znanje i razumijevanje određenog dijela gradiva.

Studenti za svaku laboratorijsku vježbu ostvaruju određene bodove prema odrađenim zadacima, dodatno uzimajući u obzir način oblikovanja stranice prema stilskim pravilima (posebice kod druge cjeline laboratorijskih vježbi).

Kriteriji za ocjenjivanje seminarskog rada, odnosno uspješnost web mjesta se očituje kroz slijedeće stavke: jasno definirana i prezentirana funkcionalnost web mjesta, dizajn web mjesta, vizualna prepoznatljivost web mjesta, lakoća i jasnoća kretanja po web mjestu, čitljivost informacija i tipografija, konzistentnost web mjesta, uravnoteženost grafičkih i tekstualnih informacija, originalnost i kreativnost pri izradi stranica i grafičkih elemenata.

TABLICA I. BODOVI STUDENATA IZ PODRUČJA SEMINARSKOG RADA, KOLOKVIJA I UKUPNE OCJENE

Organizacija kolegija	**Bodovi studenata**		
	Seminarski rad	***Kolokviji***	***Ukupna ocjena***
Bez projekta WebStart	83.8	69.0	76.0
Uz projekt WebStart	85.4	76.0	79.3

Ispitivanje i ocjenjivanje svih područja se provodi korištenjem sustava Moodle, od testova do predaje zadaća, gdje studenti na jednom mjestu imaju uvid u ocjene iz svih segmenata kolegija.

E. Rezultati

U Tablici I su prikazane ocjene studenata iz akademske godine u kojoj nije bio uveden projekt WebStart i ocjene iz akademske godine u kojoj se provodio projekt WebStart. Tablica prikazuje prosječne vrijednosti bodova iz seminarskog rada, teoretskog dijela (kolokviji) i ukupne ocjene. Može se uočiti da se dobiveni rezultati ne razlikuju puno, no bitno je naglasiti da je uvođenjem projekta WebStart, studentima dosta otežan proces učenja. U takvim okolnostima, očekivao bi se pad ocjena/bodova studenata, no prikazani rezultati pokazuju da se dogodila upravo obratna situacija, odnosno postignuti bodovi su se blago povećali te je sveukupno razumijevanje gradiva kolegija poboljšano.

IV. ZAKLJUČAK

Cilj samog kolegija je savladavanje potrebnih temeljnih znanja iz oblikovanja web stranica/mjesta zbog boljeg razumijevanja koncepata web dizajna.

Uvođenje kolegija u projekt WebStart, studente je dodatna motivacija navela na savladavanje dodatnog gradiva, što je dovelo do bolje oblikovanih web mjesta za mikro tvrtke prema najnovijim smjernicama dizajna.

Daljnji cilj kolegija je dodatno unapređivanje u smislu boljeg povezivanja teorije i prakse i u konačnici boljeg savladavanja samog dizajna kao takvog.

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Korištenje elektroničkih izvora podataka u izradi studentskih radova

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***Sažetak* - Za hrvatski sustav visokoškolskog obrazovanja digitalizacija znanstvenih publikacija od iznimnog je značaja. Kvalitetan studentski rad uključuje objavljene relevantne rezultate istraživanja na globalnoj znanstvenoj razini. Ministarstvo znanosti i obrazovanja Republike Hrvatske i Nacionalna i sveučilišna knjižnica u Zagrebu omogućuju studentima pristup takvim bazama podataka. Provedenim se istraživanjem analiziralo koliko studenti Sveučilišta Sjever koriste elektroničke izvore podataka u pisanju radova. Rezultati istraživanja pokazali su da studenti ne koriste baze podataka Nacionalne i sveučilišne knjižnice. Oni preferiraju hrvatske znanstvene portale koji objavljuju domaće radove, najviše portal Hrcak.hr. Ne postoje značajnija odstupanja na razini preddiplomskih i diplomskih studija Sveučilišta Sjever u Sveučilišnom centru Koprivnica.**

Ključne riječi - studenti, elektronički izvori informacija, baze podataka, Nacionalna i sveučilišna knjižnica Zagreb, Hrcak.hr

I. UVOD

Razvojem informacijsko-komunikacijske tehnologije obrazovanje dobiva novu dimenziju. Uz udžbenike i predavanja, koji su do sada imali najveću ulogu u prenošenju znanja, danas postoji niz lako dostupnih podataka i objavljenih radova na tzv. „mreži svih mreža“, popularno nazvanoj internet. Internet je postavio temelj razvoja informacijsko-komunikacijske tehnologije, danas prisutne u svim područjima ljudskog života i djelovanja. Mnoštvo je prednosti interneta, od kojih su najvažnije jednostavnost i dostupnost informacija, ali i problema. Jedan od najvećih problema interneta je vjerodostojnost ponuđenih informacija. Učenici i studenti koriste internet kao temeljni izvor svih podataka, stoga se pojavljuje pitanje točnosti naučenih činjenica i vjerodostojnosti tih izvora podataka u procesu određivanja osobnog profila u temeljnim područjima znanja.

Internet, kao najvažniji medij 21. stoljeća, zahtijeva od studenata visoku razinu medijske pismenosti, koju je ključno uvrstiti u osnovne razine obrazovnog sustava. S obzirom na sveprisutnost interneta, koji omogućuje odgovor na svako pitanje, nužna je i uloga profesora. Njihov je zadatak naučiti, odnosno prakticirati teorijski usvojena znanja studenata u području kako učiti. Na visokoj razini obrazovanja, kompetencije i vještine informacijske i medijske pismenosti mogu se lako prepoznati kroz pisane studentske radove. Seminarski, završni ili diplomski radovi moraju pokazivati određenu razinu ozbiljnosti i kvalitete, temelj kojih je raspoznavanje validnih podataka.

II. INFORMACIJSKA, MEDIJSKA I DIGITALNA PISMENOST

Informacijska pismenost obuhvaća učinkovito pronalaženje, korištenje i vrednovanje informacija. S razvojem informatičkog društva, pojam informacijske pismenosti se mijenja te obuhvaća niz općih vještina koje se koriste u različitim okruženjima; ukoliko se primjenjuju u digitalnom okruženju, informacijska pismenost postaje digitalna ili ako se koriste u medijskom okruženju, ona postaje medijska pismenost. Informacijska pismenost uključuje sposobnosti pronalaska informacija, odabir odgovarajućih informacija i njihovo vrednovanje te efikasno prenošenje informacija drugima. Razvojem informacijsko – komunikacijske tehnologije, broj dostupnih informacija značajno je porastao te se sukladno tome, kao temeljna sposobnost unutar konteksta informacijske pismenosti, navodi sposobnost odabira pouzdanih i vjerodostojnih informacija. Informacijska pismenost predstavlja temelj za razvoj digitalne i medijske pismenosti, jer obuhvaća sve informacije, digitalne i tiskane.

Medijskoj pismenosti ne treba pristupati samo kao osobnom svojstvu pojedinca. Ona predstavlja sposobnost kritičkog razmatranja medijskog sadržaja, uz razvoj novih vještina i znanja, koje obuhvaćaju identifikaciju netočnih navoda i postavljanje kvalitetnih pitanja koja će pomoći u iskorjenjivanju netočnih informacija. Uz navedeno, područje medijske pismenosti ne odnosi se nužno samo na tekstualne podatke, već na sve multimedijske podatke, primjerice fotografije, videozapise, zvuk i sl. Žitinski naglašava kako je važna komponenta medijske pismenosti *„naučiti razlikovati stvarnost od njezine refleksije, zato što, iako smo uvjetovani medijske teme gledati kao pojedinačne „proizvode“, valja uzeti u obzir i to da se sve takve teme ideološki konzistentno konstruiraju i tako raznose kumulativni društveni vrijednosni sustav.“* [1] Sve informacije koje mediji prenose, predstavljaju se publici odnosno konzumentima zbog prenošenja određenih vrijednosti društva. Cilj medijske pismenosti jest kritički pristupiti danom sadržaju te ocijeniti svrhu i istinitost prikazanog. Zbog velikog utjecaja novih medija, medijska pismenost, u

kontekstu pismenosti opstanka, smatra se ključnim preduvjetom uspješnog individualnog razvoja i obrazovanja u 21. stoljeću.

Uz medijsku pismenost veže se digitalna pismenost, koja nastaje pojavom digitalnih medija i ima najveći utjecaj na suvremeno obrazovanje. Ova vrsta pismenost temelji se na poznavanju rada na računalu, odnosno poznavanju informacijsko-komunikacijske tehnologije. Ono što je specifičnost digitalne pismenosti jesu stalne promjene, zbog čega je nužno neprestano proširivati i usavršavati postojeće znanje. Informacijsko–komunikacijska tehnologija je u neprestanom razvoju pa se svakim danom otkrivaju nove mogućnosti. S obzirom na navedeno može se zaključiti kako je u konceptu cjeloživotnog učenja sposobnost prilagodbe iznimno važna. Koncept cjeloživotnog učenja nastaje kao posljedica brzog razvoja tehnologije i dostupnosti svjetskog znanja korištenjem interneta. Digitalna pismenost, slijedom kontinuiranih i brzih promjena u području informacijsko-komunikacijske tehnologije, omogućuje stjecanje jedne od najvažnijih kompetencija današnjice, digitalne kompetencije. *„Digitalna kompetencija odnosi se na osposobljenost za sigurnu i kritičku upotrebu informacijsko-komunikacijske tehnologije za rad, u osobnomu i društvenomu životu te u komunikaciji. Njezini su ključni elementi osnovne informacijsko-komunikacijske vještine i sposobnosti: upotreba računala za pronalaženje, procjenu, pohranjivanje, stvaranje, prikazivanje i razmjenu informacija te razvijanje suradničkih mreža putem interneta."* [2]

Razvijanje digitalne kompetencije i vještina studentima će omogućiti višu razinu kvalitete obrazovanja na teorijskoj i praktičnoj razini jer usvojene navedene kompetencije predstavljaju temelj za kreiranje kvalitetnih znanstvenih radova i individualni napredak. *„Širenjem digitalnih medija u profesionalnom i privatnom životu pojačan je zahtjev za korištenjem tih tehnologija i u obrazovanju. Obrazloženje toga zahtjeva zasniva se na općoj društvenoj važnosti, na budućoj profesionalnoj relevantnosti digitalnih medija, na pedagoškim učincima u poboljšanju učenja i rezultata učenja te na potencijalu promjena koje bi mogle nastupiti u institucijama kao što su škole."* [3]

Digitalni mediji imaju široku primjenu i njihova važnost nije samo u individualnom napretku i poboljšanju. Korištenje ovih najsuvremenijih medija poboljšava rezultate učenja, što u konačnici vodi do poboljšanja cjelokupnog obrazovnog sustava i društvenog sustava općenito.

III. DIGITALIZACIJA ZNANSTVENIH PUBLIKACIJA

Informacijsko-komunikacijska tehnologija utjecala je na porast količine građe u digitalnom obliku. Tiskane publikacije danas se većinom mogu pronaći u digitalnom obliku poput e-knjiga i digitalnih zbirki. Internet ima mnoštvo baza podataka u kojima se mogu pronaći znanstvene publikacije, međutim pristup tim publikacijama svim zainteresiranim korisnicima često nije omogućen.

Digitalizacija kao proces nužna je zbog sve većeg utjecaja informacijsko–komunikacijske tehnologije. Kroz digitalizaciju znanstvenih publikacija nastoji se poboljšati pristup određenoj publikaciji, zaštiti autore i omogućiti stvaranje novih radova. Korištenje digitalnih publikacija omogućuje studentima jednostavan i brz pristup stručnim i znanstvenim informacijama, koje su temelj nastanka novih vrsta radova.

Aktivno se radi na otvaranju pristupa svim vrstama znanstvene literature. Najčešće se, za pristup određenoj vrsti podataka, zahtijevalo članstvo i prijava, što se negativno odražavalo na veći broj korisnika jer nisu mogli udovoljiti navedenim materijalnim uvjetima. Otvaranjem pristupa znanstvenim informacijama, svi bi korisnici brzo i jednostavno mogli doći do željene literature.

A. Otvoreni pristup znanstvenoj literaturi

Otvoreni pristup znanstvenoj literaturi podrazumijeva digitalan i besplatan sadržaj dostupan svim korisnicima interneta. U digitalnu znanstvenu literaturu najčešće se ubrajaju znanstveni časopisi koji su digitalizirani i u tom obliku postali dostupni svim korisnicima.

Prednost otvorenog pristupa znanstvenoj literaturi svakako je lakše pronalaženje željenih izvora informacija, što podrazumijeva i učestaliju upotrebu određene znanstvene literature. Ukoliko korisnici interneta češće pretražuju određeni materijal, internetski pretraživači će upravo taj materijal postaviti na početne stranice jer izvor smatraju važnijim zbog broja pregleda. Eksponiranost specifične znanstvene literature stavlja fokus na autora i instituciju, što pridonosi većem interesu za određenu instituciju, primjerice sveučilište, ili za pojedinog autora i njegove radove. Otvoren pristup znanstvenoj literaturi naglasak stavlja na znanje, neovisno o mjestu prebivanja ili drugim čimbenicima. Jednake informacije dostupne su svakom pojedincu, gdje god se on nalazio.

U Republici Hrvatskoj za otvoreni pristup informacijama koristi se portal Hrcak.srce.hr. Prema službenoj stranici, Hrčak je definiran kao *„centralni portal koji na jednom mjestu okuplja hrvatske znanstvene i stručne časopise koji nude otvoreni pristup svojim radovima. Korisnicima omogućuje lagano pronalaženje časopisa i radova putem prebiranja (prema abecedi ili prema području znanosti) ili pretraživanja prema raznim poljima. (...) portal je izrađen uz potporu tadašnjeg Ministarstva znanosti, obrazovanja i športa (današnjeg Ministarstva znanosti i obrazovanja), realiziran je u Srcu, a osnovna ideja potekla je iz Hrvatskog informacijskog i dokumentacijskog društva."* [4]

B. Razlike između zlatnog i zelenog otvorenog pristupa

Šember naglašava postojanje dvaju oblika publiciranja radova, a to su „zlatni" i „zeleni" put. [5] Temeljna razlika između navedena dva pristupa očituje se kroz vrijeme dostupnosti, financiranje pristupa, korisnička prava itd.

Petrak objašnjava kako se zlatnim putem izvorne znanstvene informacije prenose znanstvenim časopisima. Ti časopisi mogu biti u potpunosti otvorenog pristupa ili se otvoreni pristup odnosi na pojedine članke, što tada nazivamo hibridnim časopisima. U zlatnom pristupu, članci su odmah po objavljivanju otvoreno dostupni, a plaćanje troškova objavljivanja obveza je autora. U slučaju da troškove snosi izdavač ili se oni alimentiraju iz državnog proračuna, tada to nazivamo dijamantni ili platinasti otvoreni pristup. Za razliku od zlatnog pristupa, u zelenom pristupu znanstvene informacije postaju slobodno dostupne arhiviranjem prije, usporedno ili nakon objavljivanja. U slučaju zelenog pristupa, moguće je pristupiti autorskoj verziji rada prije recenzije ili nakon recenzije, ovisno o zahtjevima izdavača. Pristup radovima u zelenom pristupu može biti spriječen na određeno vrijeme, o čemu odluku također donosi izdavač. [6]

Primjer zelenog otvorenog pristupa u Republici Hrvatskoj su Digitalni akademski arhivi i repozitoriji (u daljnjem tekstu Dabar). *„Dabar omogućava jednostavnu uspostavu i održavanje većeg broja pouzdanih i interoperabilnih institucijskih i tematskih digitalnih repozitorija i arhiva bez troškova za ustanove - korisnike Dabra.“* [7]

IV. ISTRAŽIVANJE O KORIŠTENJU ELEKTRONIČKIH IZVORA PODATAKA NA SVEUČILIŠTU SJEVER

Korištenje elektroničkih izvora podataka u izradi studentskih radova istraživalo se na primjeru studenata Sveučilišta Sjever (u daljnjem tekstu SS) i to anketnim upitnikom poslanim na adrese elektroničke pošte studenata koje osigurava samo SS.

Cilj i svrha istraživanja bila je uvidjeti u kojoj se mjeri studenti SS koriste elektroničkim izvorima podataka u izradi studentskih radova, posebice bazama podataka Nacionalne i sveučilišne knjižnice u Zagrebu (u daljnjem tekstu NSK), kao i kojim se izvorima najviše koriste. Pristup bazama NSK omogućen je za cijelu akademsku zajednicu suradnjom Ministarstva znanosti i obrazovanja Republike Hrvatske i NSK. Pravo pristupa nije jednako za svako sveučilište u Hrvatskoj, to ovisi o samom sveučilištu. Studenti im pristupaju putem svog AAI identiteta i to mogu učiniti s bilo kojeg mjesta putem računala. U prostorijama SS sva su računala automatski spojena s odobrenim bazama NSK i nije potreban unos AAI identiteta studenta. Bazama NSK studenti mogu pristupiti i bez AAI identiteta, ali u tom slučaju imaju ograničen pristup, onaj koji je osiguran za sve građane izvan kruga akademske zajednice. Najveća vrijednost takvih baza ogleda se u činjenici što one sadrže znanstvene i stručne radove objavljene na razini cjelokupne svjetske znanstvene zajednice. U ovaj okvir ulaze i hrvatski znanstveni radovi pa nije potrebno posebno pretraživanje domaćih baza podataka. Tako hrvatska akademska zajednica ima pristup najnovijim relevantnim svjetskim istraživanjima. Prijeko je to potrebno u izradi kvalitetnih znanstvenih i studentskih stručnih radova.

Istraživanje je polazilo od dvije hipoteze: 1. studenti se u izradi svih vrsta radova u pravilu ne koriste bazama podataka, posebice ne bazama podataka NSK, 2. nema značajnije razlike u korištenju baza podataka kod studenata preddiplomske i diplomske razine studija.

Istraživanje se vršilo anketnim upitnikom koji je sadržavao 12 pitanja od kojih je 8 pitanja zatvorenog tipa, što znači da su studenti mogli birati samo između ponuđenih odgovora. Kroz 4 pitanja otvorenog tipa studenti su, uz ponuđene odgovore, mogli dodati i osobna promišljanja. Istraživanje se jednim dijelom odnosilo isključivo na korištenje baza NSK pa su taj dio anketnog upitnika rješavali samo studenti koji su se u prethodnim odgovorima izjasnili da ih koriste.

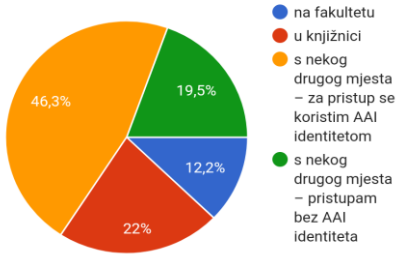
Odgovori na anketni upitnik prikupljali su se odvojeno, u dvije skupine studenata - preddiplomska i diplomska razina studija. Riječ je o ukupno 504 studenta preddiplomske razine i 124 studenta diplomske razine studija SS. Treba naglasiti kako se radi o novoootvorenim studijskim programima diplomskih studija SS koji su s radom krenuli u tekućoj akademskoj godini 2017/2018. Najveći dio studenata upisanih na diplomsku razinu studija SS čine upravo studenti koji su završili preddiplomsku razinu studija na SS. Anketni odgovori prikupljali su se tri tjedna, u periodu od 12. prosinca 2017. godine do 2. siječnja 2018. godine. Na razini preddiplomskih studija anketnom ispitivanju pristupila su 132 studenta, odnosno 26,19% od ukupnog broja studenata, a na razini diplomskih studija 46 studenta, točnije 37,1% od ukupnog broja studenata.

A. Korištenje elektroničkih izvora podataka - studenti preddiplomskih studija

U ispitivanju su sudjelovala 132 studenta preddiplomskih studija Novinarstva, Medijskog dizajna i Poslovanja i menadžmenta u medijima SS. Tek trećina je osoba muškog spola, odnosno 31,1%, dok je 68,9% osoba ženskog spola. Očekivano, najbrojnija je dobna skupina od 18 do 24 godine, 74,2%; u dobi od 25 do 30 godina 14,4% je ispitanika; u dobi od 31 do 35 godina njih 3,8% i 7,6% u dobi od 36 godina ili stariji. Ispitivanje je pokazalo da svi studenti u izradi studentskih radova koriste elektroničke izvore podataka, njih 10,6% koristi isključivo takve izvore, dok se 89,4% studenata koristi još i tiskanim izvorima podataka. Najveći broj ispitanika koristi se pretraživanjem Googlea (njih 85,4%), dok se Google Znalcem koristi samo 17,7% ispitanika. Baze podataka pretražuje 41,5% ispitanika, dok je jedan ispitanik naveo da koristi „sve što dođe pod ruku, cilj opravdava sredstvo“.

Tek četvrtina ispitanika prilikom pretraživanja koristi baze NSK. Pitanja vezana isključivo uz korištenje baza NSK u daljnjem dijelu anketnog upitnika ispunjavali su samo ti studenti. Namjera istraživanja, između ostalog, bila je uvidjeti način na koji su se studenti upoznali s bazama podataka NSK. Najmanji broj ispitanika, njih 14,3%, upoznao se s bazama NSK putem samostalnog pretraživanja weba; 21,4% ispitanika saznalo je za njih od kolega s fakulteta; 28,6% studenata upoznati su s njima još od vremena prije studija, a najveći broj ispitanika, njih 35,7%, s bazama je upoznalo nastavno osoblje fakulteta.

Studenti im, kako je već rečeno, mogu pristupiti s ili bez AAI identiteta i to s bilo kojeg mjesta putem računala. Tek 12,2% ispitanika bazama pristupa u informatičkim učionicama fakulteta; njih 22% bazama pristupa u jednoj od knjižnica, a 46,3% s nekog drugog mjesta. Riječ je o pristupima putem AAI identiteta. Za pristup bazama podataka 19,5% studenata ne koristi AAI identitet i redovito to čine s nekog mjesta izvan prostorija fakulteta. (Slika 1.)



Slika 1. Način pristupa bazama podataka – preddiplomski studiji

Od baza NSK kojima SS osigurava pristup studenti najviše pretražuju bazu Web of science i to u 54,1% slučajeva; bazu EBSCOhost pretražuje 29,7% ispitanika, a JSTOR njih 10,8%. Baze SciVerse i Springer Link koriste se u istom postotku od 8,1%, a najmanje se koristi baza MathSciNet, 5,4%.

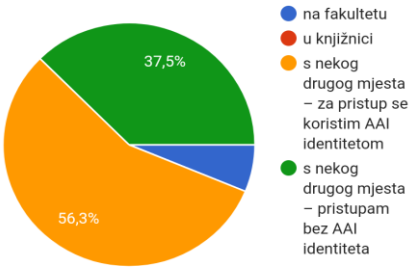
Istraživanjem se obuhvatio i stupanj zadovoljstva korisnika bazama NSK. Čak 35,9% studenata smatra ih vrlo korisnima jer uvijek pronalaze što trebaju, a 59% njih smatra ih korisnima jer uglavnom pronalaze što su tražili, unatoč tome što teško vrše selekciju radova. Isti postotak studenata, 2,6%, smatra ih beskorisnima, kao i nedovoljno korisnima jer teško vrše selekciju radova i uglavnom ne pronalaze što su tražili. Na pitanje: *Koje baze podataka koristite?*, najveći broj ispitanika, njih 62,1%, odgovorili su da koriste isključivo portal znanstvenih časopisa Republike Hrvatske Hrcak.hr; paralelno baze NSK i portal Hrcak.hr koristi 31,8% ispitanika, a 2,3% njih koristi samo baze NSK. Takvi podaci u nesuglasju su s podacima iz ranijeg pitanja: *Ukoliko pretražujete baze podataka, pretražujete li baze Nacionalne i sveučilišne knjižnice u Zagrebu?* Na to pitanje tek je četvrtina ispitanika pozitivno odgovorila.

Istraživanje je pokazalo da tek trećina ispitanika provjerava točnost podataka kojima se koriste u izradi svojih radova, a njih 59,1% pazi tek ponekad, ovisno o tome koliko im je rad bitan. Ujedno, 7,6% ispitanika nikada ne provjerava točnost podataka kojima se služe.

B. Korištenje elektroničkih izvora podataka - studenti diplomskih studija

U ispitivanju je sudjelovalo 46 studenata diplomskih studija Novinarstva, Medijskog dizajna, Ambalaže i Održive mobilnosti i logistike SS. Gotovo isto kao i u slučaju preddiplomske razine, više od 2/3 studenata, njih 67,4% su osobe ženskog spola, osoba muškog spola je 32,6%. Polovicu studenata čine studenti u dobi od 18 do 24 godine; 26,1% u dobi je od 25 do 30 godina; 13% u dobi je od 31 do 35 godina, a 10,9% u dobi 36 godina ili više. U izradi studentskih radova svi ispitanici koriste elektroničke izvore podataka; 21,7% njih koristi samo takve izvore, a 78,3% koristi još i tiskane izvore podataka. Bazama podataka koristi se tek nešto više od polovice ispitanika, njih 56,5%. Gotovo svi ispitanici, njih 93,5%, koriste se prikupljanjem podataka pretraživanjem Googlea, a Google Znalac koristi samo 26,1% ispitanika.

Preko 2/3 ispitanika koji se koriste bazama podataka, njih 69,6%, ujedno ne koristi baze NSK. Tek 30,4% ispitanika koristi baze NSK, a najveći broj njih (u istom postotku od 22,2%) s njima se upoznao putem samostalnog pretraživanja weba ili od nastavnog osoblja na fakultetu. Od vremena prije studija ili preko kolega na fakultetu s bazama je upoznat isti postotak studenata, njih 16,7%. Jedan ispitanik navodi da se tek ispunjavanjem anketnog upitnika upoznao s postojanjem baza NSK. Njima ispitanici najviše pristupaju s AAI identitetom, 6,3% njih na fakultetu, a 56,3% izvan prostorija fakulteta; dok ih 37,5% za pristup ne koristi AAI identitet. (Slika 2.)



Slika 2. Način pristupa bazama podataka – diplomski studiji

Ispitanici u istom postotku, 36,4%, pristupaju bazama EBSCOhost i Web od Science; u nešto manjem postotku od 27,3% koriste se bazom SciVerse, a tek 9,1% njih koristi Springer Link. Druge baze NSK ne koriste.

Što se tiče stupnja zadovoljstva bazama NSK, svi ispitanici smatraju ih korisnima, 1/4 uvijek nađe što traži, a 3/4 teško vrši selekciju radova, ali uglavnom pronalaze što traže.

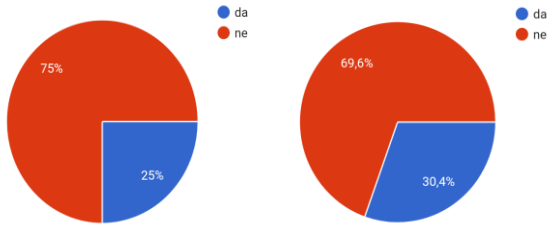
Na pitanje: *Koje baze podataka koristite?*, najveći broj ispitanika, njih 45,7% odgovorio je da koriste isključivo portal znanstvenih časopisa Republike Hrvatske Hrcak.hr; 37% ispitanika koristi paralelno i baze NSK i Hrcak.hr, a 4,3% koristi samo baze NSK. Takvi podaci u nesuglasju su s podacima dobivenima u sklopu ranijeg pitanja: *Ukoliko pretražujete baze podataka, pretražujete li baze Nacionalne i sveučilišne knjižnice u Zagrebu?* Na to pitanje tek je nešto manje od trećine ispitanika pozitivno odgovorilo.

Manje od petine ispitanika, njih 19,6% odgovorilo je da uvijek pazi na točnost podataka kojima se koriste u pisanju radova i redovito ih provjeravaju, a tek nešto manji broj, njih 15,2%, nikada ne provjerava podatke. Najveći broj ispitanika, njih 65,2%, pazi tek selektivno na točnost podataka, ovisno koliko im je rad bitan.

C. *Usporedba korištenja elektroničkih izvora podataka kod studenata preddiplomskih i diplomskih studija*

Spolna struktura svih studenata slična je – gotovo je 2/3 osoba ženskog spola. Studenti su uglavnom starosti od 18 do 24 godine, s tim da je populacija studenata preddiplomskih studija nešto mlađe dobne strukture, njih je četvrtinu više u navedenom dobnom rasponu. Studenti u izradi svih vrsta radova koriste uglavnom i tiskane i elektroničke izvore podataka. U nešto većoj mjeri studenti diplomskih studija koriste isključivo elektroničke izvore podataka, ali ne u značajnijem postotku. Oni imaju tek neznatno stariju dobnu strukturu pa se ne može zaključiti kako bi ona utjecala na povećano korištenje isključivo elektroničkih izvora podataka.

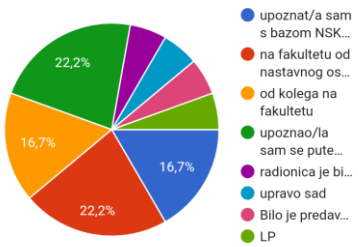
Gotovo svi studenti obje skupine koriste se pretraživanjem Googlea kao izvorom podataka, tek oko polovica njih bazama podataka, a najmanji broj Google Znalcem. Porazni su podaci kod obje skupine studenata – ako se i koriste bazama podataka, ne koriste baze NSK, tek 25%, odnosno 30,4% studenata ih koristi. (Slika 3.)



Slika 3. Korištenje baza NSK – preddiplomski i diplomski studiji

Neznatan broj studenata upoznao se s bazama NSK u vremenu prije studiranja, nešto više studenata preddiplomske razine studija. Studenti su uglavnom za njih saznali ili putem samostalnog pretraživanja weba, i to veći broj studenata diplomskih studija, ili od kolega i nastavnog osoblja na fakultetu, nešto veći postotak studenata preddiplomskih studija. (Slika 4. i Slika 5.)

Slika 4. Način upoznavanja s bazama NSK – preddiplomski studiji



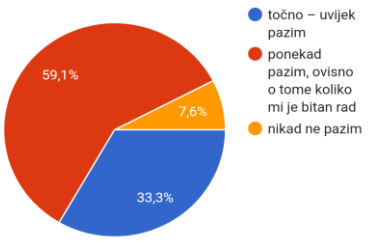
Slika 5. Način upoznavanja s bazama NSK – diplomski studiji

Značajnija razlika vidljiva je u načinu pristupa bazama NSK. Studenti diplomskih studija češće im pristupaju bez korištenja AAI identiteta. Kako je već rečeno, takav pristup ne omogućuje povlašten pristup bazama osiguran za pripadnike akademske zajednice, nego pristup kakav ima svaki drugi građanin, ograničenog broja objavljenih radova. Razlika se ogleda i u mjestu pristupa bazama, studenti diplomskih studija nikada im ne pristupaju u knjižnicama. EBSCOhost i Web of Science najkorištenije su baze NSK u obje skupine studenata. Studenti preddiplomskih studija više koriste bazu JSTOR i MathSciNet, a studenti diplomskih studija tri puta više koriste bazu SciVerse.

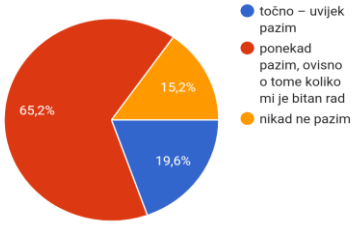
Razlika u skupinama, neznatnog značaja, vidljiva je u zadovoljstvu studenata korištenjem baza NSK. Svi studenti diplomskih studija smatraju ih ili korisnima ili vrlo korisnima, dok ih oko 5% studenata preddiplomskih studija smatra nedovoljno korisnima ili čak beskorisnima. S obzirom da im studenti diplomskih studija češće pristupaju bez AAI identiteta, možda je to razlog većeg zadovoljstva. Sužen izbor radova omogućuje im veću preglednost i lakši odabir. Ipak, sužavanjem izbora, sužava se i kvaliteta izbora, što u konačnici djeluje i na kvalitetu nastalih radova.

Kada koriste baze podataka, studenti se uglavnom oslanjaju isključivo na Hrcak.hr kao portal koji objavljuje domaće znanstvene radove i to studenti preddiplomskih studija gotovo 17% više u odnosu na studente diplomskih studija. Oko trećine studenata koristi i Hrcak.hr i baze NSK, a vrlo malen broj studenata koristi samo baze NSK. Time su većinom onemogućeni u pristupu radovima koji su objavljeni na razini svjetske znanstvene zajednice i ograničeni samo na radove domaćih znanstvenika.

Duplo veći broj studenata diplomskih studija u odnosu na preddiplomske studije uopće ne provjerava podatke kojima se služi u pisanju radova. Ujedno, 13% njih manje uvijek provjerava istinitost podataka. Sličan broj studenata obje skupine pazi selektivno, ovisno o tome koliko im je rad bitan. (Slika 6. i Slika 7.)



Slika 6. Provjera korištenih podataka – preddiplomski studiji



Slika 7. Provjera korištenih podataka – diplomski studiji

Posebno je potrebno naglasiti kako nema sustavnog rada na povećanju medijske, digitalne i informacijske pismenosti studenata na SS. U sklopu pojedinih kolegija njih se spominje, ali tek na teorijskoj razini. Međutim, ne postoji poseban kolegij koji bi se bavio opismenjivanjem studenata u tom smislu, posebice ne na praktičnoj razini.

D. Zaključno o istraživanju

Studenti u izradi svih vrsta obveznih radova koriste elektroničke izvore podataka, uglavnom zajedno s tiskanim izvorima podataka. Međutim, činjenica je da se gotovo svi koriste Googleom kao pretraživačem pomoću kojeg dolaze do podataka i vrše njihovu selekciju, a tek oko polovica studenata koristi baze podataka. Izuzetno je nizak broj studenata koji se koriste bazama NSK kao bazama koje omogućuju pristup najnovijim relevantnim znanstvenim i stručnim radovima i publikacijama na svjetskoj razini - tek četvrtina, odnosno niti trećina studenata, ovisno o studijskoj razini. Portal Hrcak.hr, koji objavljuje domaće znanstvene i stručne radove, glavna je baza podataka kojom se studenti služe.

Veliki problem jest činjenica što studenti uopće nisu upoznali baze NSK i njihove mogućnosti korištenja. Nešto veći broj njih na preddiplomskoj razini studija upoznao se s njima u vremenu prije studiranja, ali nema značajnije razlike u načinu upoznavanja s bazama NSK na preddiplomskoj i diplomskoj razini studija. Ujedno, tek je neznatno veća njihova korištenost na diplomskoj razini u odnosu na preddiplomsku. Nužno je da se studenti s ovim bazama i njihovim vrijednostima i mogućnostima upoznaju već na preddiplomskoj razini studija odnosno tijekom prvog semestra prve godine studiranja.

V. ZAKLJUČAK

Na SS tijekom 2017. godine održana je edukacija koju su vodili zaposlenici NSK u sklopu projekta pod nazivom *Povećanje pristupa elektroničkim izvorima znanstvenih i stručnih informacija*, sufinanciranog iz Europskog socijalnog fonda s ciljem boljeg upoznavanja studenata s bazama NSK. Predavanje je održano samo za studente diplomske razine studija i nastavno osoblje SS, a nije bilo obveznog karaktera. Samo su se dva studenta u anketi izjasnila kako su se upoznali s bazama NSK na navedenoj edukaciji. Gledajući rezultate u smislu vrednovanja, radi se, dakle, o neuspješnoj edukaciji.

Na Sveučilištu Sjever vidljivo je da postoje određeni pomaci i nastojanja u podizanju kvalitete kompetencija i vještina informacijske opismenjenosti studenata, najviše u sklopu pojedinačnih edukacija, ali ne i za sve studente SS. Nužno je slične edukacije provoditi i na preddiplomskoj razini studija. Ujedno, one moraju biti obveznog karaktera jer bi se na taj način osigurala velika uključenost studenata.

Navedeni pokazatelji istraživanja upućuju na zaključak da se ipak ne radi na sustavnom medijskom, digitalnom i informacijskom opismenjivanju studenata, a to je nužan preduvjet i uvjet za kvalitetno usvajanje novih znanja. Poseban kolegij na prvoj godini studija na teorijskoj i praktičnoj razini i kontinuirano implementiranje usvojenih kompetencija i vještina tijekom daljnjeg akademskog obrazovanja, osobito na praktičnoj razini, omogućili bi i kvalitetno višestruko opismenjivanje studenata, koje je važno nakon završetka studija i ulaska u svijet rada i procese cjeloživotnog učenja.

U kontekstu navedenog i na kraju zaključnih misli treba podsjetiti na Plan razvoja sustava odgoja i obrazovanja 2005.-2010. (Ministarstvo znanosti, obrazovanja i športa, 2005.) čiji je cilj bio usmjeravanje cjelokupne politike na unaprjeđivanje odgoja i obrazovanja kao sustava koji povezuje zakonske, kadrovske, materijalne, znanstvene i stručne pretpostavke s ključnim polazištima: *utvrđivanje sadržaja djelatnosti koji trebaju pridonijeti razvoju kvalitetnijeg, dostupnijeg, prilagodljivijeg i učinkovitijeg sustava obrazovanja radi stvaranja intelektualnoga i radnog ljudskog kapitala kao ključnog bogatstva hrvatske države*. [8]

Navedene sastavnice ovog Plana aktualne su i danas jer se govori o novim naraštajima koji (prije ulaska u svijet rada) kroz svoje obrazovanje promijene više tehnologija. Osnovni preduvjeti su osigurani suvremeni prostorni uvjeti prema standardima, suvremena oprema i suvremeni nastavni planovi i programi u kontinuiranom revidiranju sukladno sve bržim promjenama u području informacijsko-komunikacijske tehnologije. U takvim je, suvremenim nastavnim programima, nužno povezati informacijsku i medijsku pismenost. Sveučilište Sjever usmjereno je prema razvoju knjižnice, koja će studentima predstavljati istraživački centar te boravak u kojem će se studenti moći educirati te obavljati praktično- seminarski dio nastave u manjim grupama.

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Bluetooth kao poveznica Android i Arduino platformi

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***Sažetak* – Uređaji upravljani Android operativnim sustavom, inherentno prema prirodi svoje pristupačnosti i otvorenosti, omogućuju lako povezivanje s drugim platformama. Stoga, ovaj se rad bavi mogućnošću povezivanja s Arduino platformom, popularnom u jednakoj mjeri kod učenika i profesora, hobista, ali i profesionalaca, zbog lakoće razvoja interaktivne upravljačke elektronike. Povezivanje je platformi ostvareno Bluetooth tehnologijom, međutim, ono predstavlja samo jednu od mogućnosti stvaranja moćne sinergije ovih dviju platformi otvorenog kôda.**

Ključne riječi - Android; Arduino; povezivanje; Bluetooth; sinergija; otvoreni kôd

I. UVOD

Ideja vodilja ovog rada jest stvoriti privlačan primjer za učenike i studente u svrhu buđenja interesa za elektroniku i programiranje. Iz navedena razloga, tehnologije koje su korištene vrlo su popularne i dovoljno prepoznatljive čak i manje upućenoj publici. Rad opisuje povezivanje Android uređaja s Arduinom, Bluetooth tehnologijom. Svaka od spomenutih tehnologija zahtijeva podrobnije objašnjenje pa prije samog povezivanja slijede detaljni osvrti. Zapravo, aplikacija na Android platformi prikuplja podatke o svojoj orijentaciji korištenjem akcelerometra, koje potom šalje Arduino uređaju koristeći Bluetooth. Arduino na temelju dobivenih podataka upravlja motorima na autiću i time ga pokreće u željenom smjeru.

II. ANDROID

Android je najzastupljeniji mobilni operacijski sustav pa je opravdano korištena komponenta rada u svrhu buđenje interesa navedene publike.

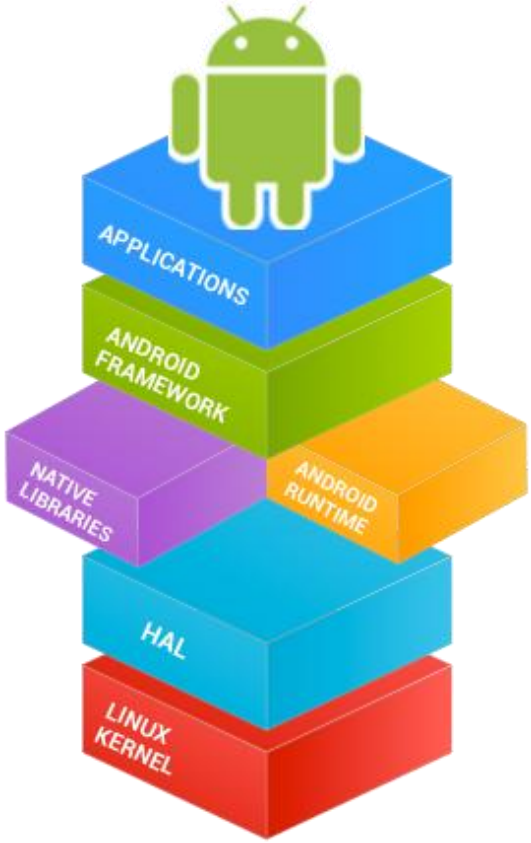
A. Platforma i operacijski sustav

Android je operacijski sustav koji je stekao veliku popularnost zbog svoje otvorenosti, slobode korištenja i kontinuirano rastuće kvalitete. Moguće ga je instalirati na velikom broju uređaja različitih hardverskih specifikacija. Android platforma pod okriljem je konzorcija Open Handset Allience, od kojih je Google.inc najutjecajniji član, a pritom i izvornik. Android aplikacije prodaju se putem mrežne trgovine Google Play Store. S obzirom na to da je platforma zaštićena licencama slobodnog softvera, proizvođači hardvera slobodno koriste Android kao operacijski sustav svojih uređaja. Spomenuta otvorenost i sloboda naziru se i na aplikativnoj razini. Premda operacijski sustav dolazi s predinstaliranim aplikacijama za telefoniranje i SMS, mogu se zamijeniti vlastitim implementacijama. Iz navedena razloga razvoj aplikacije za povezivanje s Arduinom korištenjem Bluetooth tehnologije ne stvara probleme.

B. Arhitektura

Android je arhitektura podijeljena u slojeve koji predstavljaju apstrakcije i time pojednostavljuju izvršavanje operacijskog sustava i aplikacija. Slijedi pregled slojeva, prikazanih slikom (Slika 1.):

- Linux jezgra (engl. *Linux kernel*) – operacijski sustav Android razvijen je u programskom jeziku Java. Međutim, na najnižem sloju sklopovlja, prema slici je evidentno kako je riječ o Linux jezgri, razvijenoj u C programskom jeziku. Ovaj sloj omogućuje rad osnovnim uređajima, poput tipkovnice i kamere, te implementira razne mrežne protokole od kojih je važno izdvojiti Bluetooth, korišten u ovom radu i naknadno objašnjen.
- Apstrakcija prema sklopovlju (engl. *Hardware Abstraction Layer*) – ima važnu ulogu jer komprimira mnoštvo biblioteka koje pružaju standardno sučelje prema sklopovlju. Programski kôd u Javi koristi ovaj sloj kada komunicira koristeći Bluetooth tehnologiju
- Android okruženje za izvršavanje (engl. *Android runtime*) – sloj zadužen za optimizirano pokretanje aplikacija, svake u vlastitu procesu.
- Nativne biblioteke (engl. *Native libraries*) – predstavljaju implementaciju kôda sistemskih komponenata, napisanih u C i C++ programskim jezicima.
- Android okvir (engl. *Android framework*) – okruženje za razvoj aplikacija. Predstavlja dio operacijskog sustava napisanog u programskom jeziku Java i korišten je prilikom izrade aplikacije ovog rada.
- Aplikacije (engl. *Applications*) – sloj aplikacija zadužen je za upravljanje aplikacijama instaliranim na uređaj s Android operacijskim sustavom.

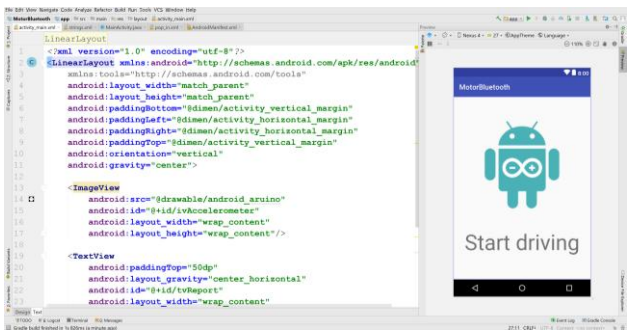


Slika 1. Android arhitektura [3]

C. *Programski jezici i okruženje za razvoj*

Android aplikacija je razvijena u programskom jeziku Java. Nasuprot tomu, Android omogućava programiranje i u programskom jeziku Kotlin koji je 2017. godine postao službenim jezikom Android platforme. Kotlin je srodan Javi zato što se izvorni kôd prevođenjem pretvara u međukôd istovjetan Javi.

Okruženje za razvoj službeni je razvojni alat (engl. *Integrated Development Environment*) Android Studio koji je korišten i za izradu ovog rada (Slika 2.). Moguće je koristiti se i drugim razvojnim alatima poput Microsoft Visual Studija, Eclipsea i drugih. Za razliku od navedenih surogata, Android Studio specijaliziran je za razvoj Android aplikacija. K tomu je i besplatan pa nije potrebno tražiti alternative.



Slika 2. Razvojni alat Android Studio

```
#include "dbele_motor.h"
#include <SoftwareSerial.h>
SoftwareSerial BTserial(12, 13); // RX | TX
const char FORWARD = 'F';
const char BACKWARD = 'B';
const char LEFT = 'L';
const char RIGHT = 'R';
const char NEUTRAL = 'N';

DB_Motor m(enA, in1, in2, enB, in3, in4);

void setup() {
  Serial.begin(9600);
  BTserial.begin(9600);
}
void handle_bluetooth() {
    if (BTserial.available()) {
      int data = BTserial.read();
```

Slika 3. Razvojni alat Arduino

III. ARDUINO

Arduino svoju veliku popularnost može zahvaliti lakoći kojom se koristi, uči i podučava, kao i kompatibilnosti s ostalom elektronikom, velikoj stabilnosti i, napokon, činjenici da je iznimno jeftin.

A. *Platforma*

Arduino platforma stvorena je u edukacijskoj okolini i vrlo je popularan edukacijski alat. Iznimno je popularan među laicima koji žele koristiti elektroniku, bez zahtjeva da su inženjeri (Banzi, 2014). Ali, istovremeno, izuzetno je zanimljiv i samim inženjerima, profesorima i studentima. Filozofija otvorenog kôda manifestira se snažnim povezivanjem u zajednicu kroz koju pojedinci dijele iskustva i projekte te se potpomažu u razvoju.

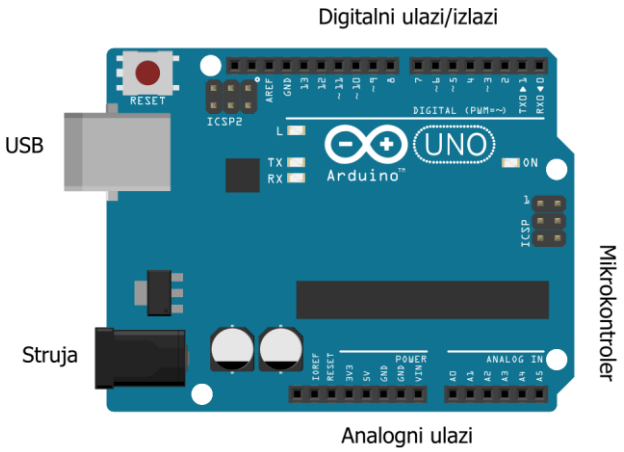
B. *Programski jezici i okruženje za razvoj*

Aplikacije za Arduino razvijaju se u dijalektu programskog jezika C++, posebno prilagođenom radi ograničene količine memorije. Biblioteke potpore napisane su u programskom jeziku C, s kojom je C++ jezik u potpunosti kompatibilan. Izvorni kôd prevodi se prvo u C programski jezik, potom avr-gcc prevoditeljem u objektni kôd i napokon povezuje u .hex datoteku koja se serijski prenosi na Arduino uređaj, bez potrebe za vanjskim programatorom. Spomenuto je moguće zbog činjenice da je mikrokontroler pretprogramiran pokretačem radnog sustava (engl. *bootloader*) koji prenosi program u memoriju.

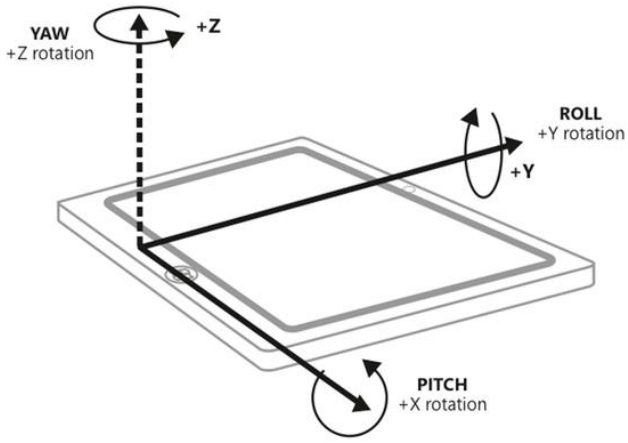
Okruženje za razvoj izrađeno je u programskom jeziku Java i besplatno je za instalaciju (Slika 3.).

C. *Arduino hardver*

Arduino pločica je integrirani krug koji sadrži procesor, memoriju, ulaze i izlaze, što ga čini malim računalom. Postoji mnogo različitih vrsta i većina je bazirana na 8-bitnom AVR mikrokontroleru (ATmega8, ATmega168, ATmega328, ATmega1280, ATmega2560) koji su našli svoje implementacije u komercijalnim verzijama (Uno, Diecimila, Duemilanove, Leonardo, Mega, Nano i druge). Verzije se međusobno razlikuju u broju analognih i digitalnih ulaza i izlaza, količini memorije i specifičnim mogućnostima. Ovaj je rad izrađen korištenjem Arduino Uno pločice, objašnjene u nastavku.



Slika 4. Arduino Uno



Slika 5. Akcelerometar u mobilnom uređaju [4]

D. *Arduino Uno*

Arduino Uno sastoji se od sljedećih važnijih dijelova, naglašenih na slici (Slika 4.):

- Digitalni ulazi/izlazi – predstavljaju osnovni način komunikacije s okolinom. Koriste se kao ulazi i izlazi digitalnim putem. Imaju mogućnost moduliranja širine impulsa pa se mogu koristiti kao analogni izlaz.
- Analogni ulazi – koriste se za analogno očitavanje napona raznih senzora.
- USB – omogućuje povezivanje s računalom i služi za serijsku komunikaciju kojom se prenosi .hex datoteka za izvršavanje. Koristi se i kao izvor napajanja ako nije osiguran.
- Struja – predstavlja napajanje.
- Mikrokontroler – ATMEGA328P-PU je osnovna komponenta i srce je pločice.

IV. BLUETOOTH

Bluetooth tehnologija omogućava prijenos podataka na kratkim udaljenostima (do desetak metara), koristeći UHF radiovalove frekvencije ~2.5 GHz. Osmišljen je kao bežična alternativa RS-232 serijskoj komunikaciji i koristi se za povezivanje bežičnih uređaja, poput tipkovnica, miševa, slušalica i slično.

Bluetooth uređaji imaju mogućnost automatskog prepoznavanja i povezivanja s maksimalno 8 uređaja. S obzirom na to da upareni uređaji koriste jednu od 79 mogućih frekvencija, ne dolazi do miješanja signala. Prilikom povezivanja uređaja tvore tzv. piconet mrežu u kojoj jedan od uređaja predstavlja vlasnika (engl. *master*), koji kontrolira mrežu, dok ostali uređaji dobivaju ulogu slugu (engl. *slave*) i slušaju zapovijedi.

Izuzetno je popularan i prepoznatljiv način povezivanja pa je pronašao svoje opravdanje i za korištenje u ovom radu.

V. AKCELEROMETAR

Akcelerometar je uređaj koji služi za mjerenje ubrzanja, odnosno promjene u brzini sila koje mogu biti posljedica pomicanja ili vibriranja. Ubrzanje ima svoj iznos i smjer, što ga čini vektorskom veličinom. Mjerenjem ubrzanja moguće je otkriti kut naginjanja uređaja u odnosu na zemljinu os.

Akcelerometar ima mogućnost detekcije pokreta, odnosno rotacije (Slika 5.):

- oko horizontalne (X) osi (engl. *pitch*)
- oko vertikalne (Y) osi (engl. *roll*)
- oko okomite (Z) osi (engl. *yaw*)

Posebno je zanimljiv za korištenje u ovome radu jer je prisutan u većini mobilnih uređaja s Android operacijskim sustavom. Detektirana orijentacija koristi se za usmjeravanje Arduino autića.

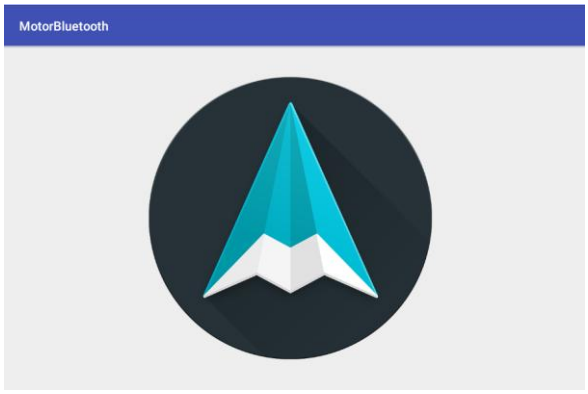
VI. DETALJI REALIZACIJE

Ovaj dio bavi se različitim dijelovima projekta koji se koriste prethodno spomenutim tehnologijama. S obzirom na to da je riječ o dvjema platformama, softverska implementacija sastoji se od Android aplikacije i Arduino aplikacije. U osnovi, Android aplikacija prikuplja podatke od akcelerometra i šalje ih Bluetoothom na Arduino. Arduino aplikacija analizira dobivene podatke i potom ih koristi za usmjeravanje autića u željenom smjeru, pokretanjem motora. Hardverska implementacija projekta sastoji se samo od Arduino dijela.

A. *Implementacija Android aplikacije*

Aplikativni dio Android dijela projekta ostvaren je implementacijom zanimljivih funkcionalnosti, navedenih u nastavku:

- Povezivanje Android uređaja s Arduinom – nakon uključivanja HC-05 Bluetooth modula na autiću, modul je vidljiv od strane Android uređaja. Stoga, fizičko je povezivanje uređaja omogućeno na standardni Bleutooth način. Softversko povezivanje unutar aplikacije ostvareno je korištenjem ugrađene *android.bluetooth* biblioteke.



Slika 6. Android aplikacija u radu

- Prikupljanje podataka od akcelerometra o željenoj korisničkoj orijentaciji – korištenjem *android.hardware* biblioteke, Android aplikacija prikuplja podatke od akcelerometra u razmacima od 600 milisekundi. Izmjenom vremenskog razmaka moguće je direktno utjecati na osjetljivost i odgovaranje sustava na promjene.
- Prikaz odabrane orijentacije na ekranu u obliku strelice – na temelju podataka dobivenih od akcelerometra, aplikacija iscrtava sliku strelice koja smjerom predstavlja željeni smjer gibanja autića (Slika 6.).
- Formatiranje podataka za slanje – podaci su jednostavnog formata, u obliku dva decimalna broja razdvojena dvotočkom, odnosno prema sljedećem obliku: *lijevo_desno:gore_dolje*.
- Slanje podataka Arduinu putem Bluetootha – Android aplikacija šalje formatirane podatke autiću korištenjem *android.bluetooth* biblioteke.

Navedeni koraci prikazani su kôdom u nastavku:

```
private void setupBluetooth() {
   mBluetoothAdapter =
           BluetoothAdapter.getDefaultAdapter();
   BluetoothDevice device =
           mBluetoothAdapter.getBondedDevices()
                        .iterator().next();
   UUID uuid = device.getUuids()[0].getUuid();
   btSocket = device
     .createRfcommSocketToServiceRecord(uuid);
   btSocket.connect();
}
@Override
public void onSensorChanged(SensorEvent event) {
   long now = System.currentTimeMillis();
   long timePassed = now - lastReading;
   float newX = -event.values[0];
   float newY = -event.values[1];
   StringBuffer report = new StringBuffer();
   report.append(newX+":"+newY+"\n\r");
   sendData(report.toString());
   handlePicture(newX, newY);
}
private void sendData(String data) {
   outStream = btSocket.getOutputStream();
   outStream.write(data.getBytes());
}
```

Kôd 1. Poslovna logika android aplikacije

B. Implementacija Arduino aplikacije

Nakon što su podaci odaslani od strane Android aplikacije, Arduino aplikacija ima sljedeće zadatke:

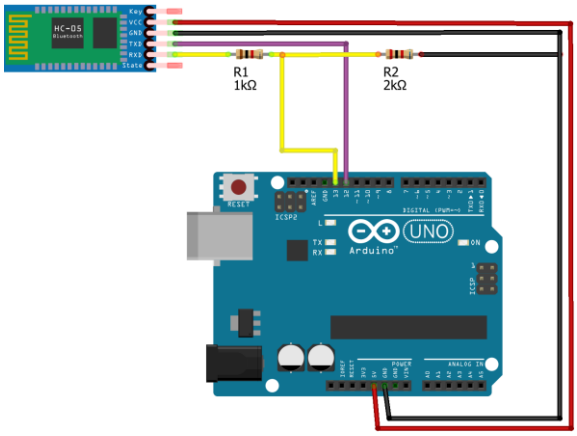
- Prikupljanje podataka pomoću Bluetooth modula – formatirani podaci prikupljaju se korištenjem *SoftwareSerial.h* biblioteke koja se koristi za serijsku komunikaciju Bluetooth tehnologijom.
- Određivanje smjera kretanja autića interpretacijom podataka formata *lijevo_desno:gore_dolje* – ako je decimalan broj *lijevo_desno* pozitivan, autić se usmjerava u lijevu stranu. Ako je broj *lijevo_desno* negativan, autić se usmjerava u desnu stranu. Analogno tomu, autić se usmjerava gore ako je broj *gore_dolje* pozitivan, odnosno dolje, ako je broj *gore_dolje* negativan. Intenzitet gibanja predstavlja vrijednost decimalnog broja s maksimumom vrijednosti 3.
- Pokretanje autića u željenom smjeru korisnika – autić se pokreće implementacijom DB_Motor zaglavlja koje upravlja H-Bridge modulom.

Prethodni koraci implementirani su na način prikazan u nastavku:

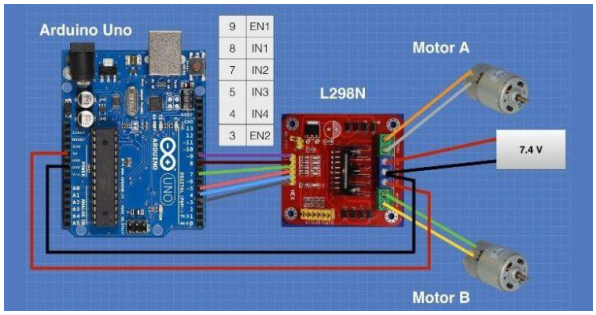
```
void handle_bluetooth() {
  if (BTserial.available()) {
    int data = BTserial.read();
    if ((char)data == '\n') {
      char dir = determine_direction(report);
      switch(dir){
       case FORWARD:
         m.drive_forward(255);
         break;
       case BACKWARD:
         m.drive_backward(255);
         break;
       case RIGHT:
         m.turn_right(192);
         break;
       case LEFT:
         m.turn_left(192);
         break;
       case NEUTRAL:
         m.stop();
         break;
      }
    }
  }
}
class DB_Motor {
public:
       void drive_forward(int val);
       void drive_backward(int val);
       void stop();
       void turn_right(int val);
       void turn_left(int val);
};
```

Kôd 2. Poslovna logika Arduino aplikacije

Kôd prikazuje kako je apstrakcija prema H-Brigde modulu za upravljanje motorima ostvarena zaglavljem DB_Motor, čiju implementaciju koristi Arduino aplikacija.



Slika 7. Povezivanje Bluetooh modula



Slika 8. Povezivanje H-Bridge modula [6]

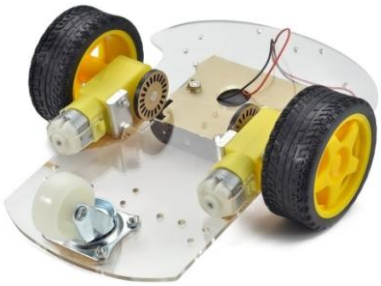
C. *Implementacija Arduino hardvera*

Hardverska komponenta implementirana je korištenjem sljedećih modula:

- Povezivanje Android i Arduino platformi ostvareno je HC-05 Bluetooth modulom, čije je spajanje s Arduinom prikazano slikom (Slika 7.). Zanimljivo je da je operativni napon modula HC-05 5V, međutim, RX i TX pinovi modula rade s naponom od 3,3 V. HC-05 modul s Arduinom je povezan na sljedeći način:
  - 5V Arduino pin spojen je na VCC pin HC-05 radi potreba operativnog napona
  - GND Arduino pin je spojen na GND pin HC-05 radi potrebe uzemljenja
  - Arduino pin 12 spojen je na TX HC-05 pin za slanje podataka od strane HC-05 modula prema Arduinu. Važno je napomenuti da Arduino nema problema s prihvaćanjem signala vrijednosti 3.3 V
  - Arduino pin 13 spojen je na RX HC-05 pin za prihvat podataka HC-05 modula od Arduina. Arduino koristi 5 V za signal koji mora biti prilagođen pomoću dijelitelja napona prema sljedećoj formuli (Slika 7.):

```
2kΩ/(2kΩ +1kΩ) * 5.0V = 3.3V
```

- Upravljanje motorima ostvareno je korištenjem L298N H-Bridge modula (Slika 8.), prema predlošku navedenom u izvoru [6].



Slika 9. Arduino autić

- Autić prikazan na slici (Slika 9.) s kućištem čija su dva kotača povezana s motorima istosmjerne struje, pomoćnim kotačem i kućištem za baterije.

VII. MOGUĆNOSTI IZRAĐENOG PROTOTIPA

Prikazani rad svjedoči o moćnoj sinergiji Android i Arduino platformi. Posebno je zanimljiva činjenica da je obrađena samo jedna od mogućnosti povezivanja i njezina korištenja. Naime, ovaj bi se prototip vrlo lako mogao preraditi u kontekstu korištenja drugih tehnologija. Primjerice, Android aplikaciju mogla bi zamijeniti Java ili Windows stolna aplikacija. Nadalje, povezivanje s Arduinom moguće je ostvariti korištenjem radiofrekventnog modula ili pak korištenjem lokalne računalne mreže. Na kraju, Arduino platforma mogla bi se zamijeniti Raspberry PI platformom. Dakle, korištene tehnologije u dovoljnoj su mjeri popularne i prepoznatljive da bi izazvale interes šire publike, ali ne predstavljaju nikakvo ograničenje.

VIII. ZAKLJUČAK

Težište ovog rada predstavlja opravdanje pretpostavke da udruživanje Android i Arduino tehnologija može poslužiti u svrhu buđenja interesa za elektronikom i programiranjem. Ciljana skupina su istovremeno učenici i studenti, ali i učitelji i profesori koji ovaj prototip, zbog modularnosti pristupa, mogu iskoristiti na različite načine. Proizlazi kako tehnologije usmjerene prema otvorenosti omogućavaju nepregledan broj međusobnih povezivanja kojima za maštovitu iskoristivost kamen spoticanja predstavlja tek ograničena misao. Otvorenost ovih platformi stvara mogućnost da studenti i učenici prevladaju predrasude o tome kako je bavljenje elektronikom i programiranjem pretjerano složeno i nepristupačno laicima, ali i spoznaju da je ta mogućnost u jednakoj mjeri otvorena svima koji su zainteresirani za tehnologiju.

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Analiza pripreme Google Rapid Response (GRR) sustava za potrebe nastave digitalne forenzike i kibernetičke sigurnosti

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***Sažetak* - Tijekom razvoja novog specijalističkog diplomskog stručnog studijskog programa "Informacijska sigurnosti i digitalna forenzika" za Tehničko veleučilište u Zagrebu postavio se niz izazova na koje je trebalo odgovoriti. Ključni izazovi koje je trebalo riješiti bili su: definiranje nastavnog plana i programa, te definiranje i izgradnja računalne infrastrukture za izvođenje laboratorijskih vježbi. Za praktične potrebe nastave kibernetičke sigurnosti i specifično digitalne forenzike, bilo je potrebno odabrati alate za izvođenje složenih vježbi forenzike živih sustava u skladu s pretpostavkama stručnog studija. Analiza moguće primjene jednog od pogodnih alata, Google Rapid Response (GRR), opisana je u ovom radu, s prednostima i nedostacima uočenim tijekom priprema i testiranja. Google Rapid Response (GRR) je složeni alat otvorenog koda koji teoretski ima sva potrebna svojstva za kvalitetnu primjenu u nastavi: mogućnost virtualizacije, lako proširenje sustava, otvoreni kod, dostupnu dokumentaciju i programski kod, podržan veliki broj operacijskih sustava, ali i tipične nedostatke zbog neformalne podrške održavanju i razvoju programskog koda.**

Ključne riječi* - *Informacijska sigurnost, digitalna forenzika, nastava digitalne forenzike

I. UVOD

Praktičan rad i vježbe studenata predstavljaju izuzetno važan dio procesa visokoškolske edukacije, posebno na veleučilištima koja su po definiciji usmjerena ka stjecanju praktičnih znanja i vještina. Stvaranje okruženja u kojem će se takve vještine praktično stjecati je složeni zadatak, koji se mora kontinuirano odvijati.

Tijekom razvoja novog specijalističkog diplomskog stručnog studijskog programa "Informacijska sigurnosti i digitalna forenzika" za Tehničko veleučilište u Zagrebu, ključni izazovi koje je trebalo riješiti bili su: definiranje nastavnog plana i programa, te definiranje i izgradnja računalne infrastrukture za izvođenje laboratorijskih vježbi. U skladu ranijem dogovorenim mehanizmima priprema i testiranja alata, kroz vođene radove provjeravani su i pripremani alati pogodni za praktičan rad. Primjena je rađena u skladu s opisanim načinom uvođenja novih sadržaja u nastavu digitalne forenzike i kibernetičke sigurnosti upotrebom studentskih radova [3].

TABLICA I. KORACI CIKLUSA UVOĐENJA NOVIH SADRŽAJA U NASTAVU I GRR ALAT

	Opis koraka	Uloga i korištenje GRR alata
1	Ideja za novi sadržaj ili proširenje postojećeg • Dolazi kao studentski prijedlog • Dolazi kao predavačka ideja ili zadatak	GRR okruženje dolazi kao predavačka ideja za proširenje mrežne forenzike i reakcije na incidente.
2	Ideja se testira i implementira kroz studentski rad • Studentski rad pod nadzorom ili mentorstvom nastavnika • Praktični rad na nivou demonstracije koncepta • Seminarski rad ili stručni članak • Završni rad ili diplomski rad	Izrada diplomskog rada s ciljem provjere GRR alata. Cilj je testiranje okoline GRR za instalaciju, održavanje, te izvođenje forenzičkih zadataka. Testiranje okoline nije dalo zadovoljavajuće rezultate za punu implementaciju alata, ali omogućuje demonstraciju automatiziranih alata za mrežnu forenziku.
3	Rezultati studentskog rada se prevode u cjeline za izradu nastavnih materijala • Teoretski opis ideje, testiranjem izvedivosti i primjenjivosti • Praktični radni primjeri, alati, sustavi, dokumentacija, digitalni dokazi , mediji za pohranu digitalnih dokaza, sustavi za generiranje digitalnih dokaza, simulacije i simulatorske konfiguracije, alati i konfiguracije alata	GRR omogućuje samo prikaz osnovnih koncepata alata za mrežnu forenziku, ali ne i radnu implementaciju za vježbe.
4	Izrada nastavnih materijala i uvođenje u nastavu • Nova poglavlja za predavanja • Novi zadaci i materijali za auditorne vježbe i samostalni rad • Novi praktični zadaci i materijali za laboratorijske vježbe	GRR konfiguracija za demonstraciju na predavanjima mrežne forenzike.

Tablica I je preuzeta iz rada [3], prema njoj je provedena analiza moguće primjene GRR alata.

U ovom članku je opisana analiza moguće primjene jednog od pogodnih alata, Google Rapid Response GRR, s prednostima i nedostacima uočenim tijekom priprema i testiranja. Google Rapid Response GRR je složeni alat otvorenog koda koji teoretski ima sva potrebna svojstva za kvalitetnu primjenu u nastavi: mogućnost virtualizacije, lako proširenje sustava, otvoreni kod, dostupnu dokumentaciju i programski kod, podržan veliki broj operacijskih sustava, ali i tipične nedostatke zbog neformalne podrške održavanju i razvoju programskog koda.

Polazne pretpostavke su da za praktične potrebe nastave kibernetičke sigurnosti i specifično digitalne forenzike i reakcije na incidente, GRR alat predstavlja pogodnu platformu za izvođenje složenih vježbi forenzike živih sustava i mrežne forenzike, u skladu s pretpostavkama stručnog studija. Da bi se provjerila upotrebljivost definiran je i obranjen diplomski rad „Implementacija i konfiguracija Google Rapid Response forenzičkog alata u svrhu udaljenog otkrivanja, nadzora i uklanjanja štetnog programskog koda“, Aleksandar Komparić, Algebra 2017 [1]. Iskustva iz tog diplomskog rada su opisana u ovom članku, uz prikaz plana povezivanja GRR alata u sustav za upravljanje forenzičkim laboratorijem [2].

II. OPIS GOOGLE RAPID RESPONSE ALATA

Google Rapid Response (GRR) je alat za udaljenu digitalnu forenzičku analizu, po građi to je alat otvorenog koda pisan u jeziku Python, a koristi SleuthKit [4] i Rekall [6] alate za analizu i prikupljanje forenzičkih podataka od interesa. Prikupljenih podaci s klijenata su pohranjeni u sql bazi podataka. Instalirana i korištena verzija GRR alata je 3.1.0.2, zadnja dostupna stabilna verzija u vrijeme pisanja rada i izrade testne okoline [1]. Opis GRR alata je dan u osnovnim crtama, da bi se mogao pratiti tekst i zaključak članka.

GRR alat se dijeli na poslužiteljsku i klijentsku komponentu. Klijenti ne moraju stalno biti u komunikaciji s poslužiteljem, ali mogu ga po potrebi kontaktirati. Višestruki klijenti kontaktiraju poslužitelj kojemu prijavljuju svoj status i osnovne informacije o sustavu na koji su instalirani, te isporučuju rezultate u forenzičkim pouzdanim formatima.

Slika 1: GRR konzola - Pregled klijenata

Osnovna organizacija GRR alata, njegova glavna konzola prikazana je na slici 1. Informacije koje klijenti automatski sakupljaju i prijavljuju su: status (da li je klijent aktivan i trenutno dostupan za komunikaciju s poslužiteljem), Subject (interna jedinstvena oznaka klijenta u GRR okolini), ime sustava na koji je klijent instaliran, verzija operacijskog sustava, fizička adresa, odnosno adrese sustava, korisnička imena koja imaju pravo prijave na sustav, vrijeme kada se klijent prvi puta javio poslužitelju, te opcionalne oznake za lakše upravljanje većim brojem sustava. Poslužiteljska komponenta službeno podržava instalaciju samo na 64 bitni Ubuntu Xenial poslužiteljski operacijski sustav. Zbog jednostavnosti u radu je korištena osnovna platforma iako se poslužiteljska komponenta može instalirati i na druge Linux platforme. Za klijente, tj. agente, podržani su Linux i Windows sustavi. Klijenti se automatski generiraju tijekom instaliranja GRR poslužitelja. Jednom kad se prijave poslužitelju, klijenti su spremni za izvođenje poslova koje im zada poslužitelj. Komunikacija među njima može biti kriptirana i kontrolirana po potrošnji propusnosti [5].

Jednom instalirani na odredišne sustave klijenti rade u pozadini, uz periodično slanje statusa poslužitelju. Pored glavnog klijentskog procesa, na sustavu je također aktivan i zasebni proces „dadilja“ (nanny) čija je uloga nadziranje rada klijentskog procesa, te njegovo terminiranje ako isti probije definirane granice trajanja izvođenja procesa ili zauzeća procesora, odnosno radne memorije [5]. Instalacija klijenata na veće sustave može biti problem, no mogu se koristiti postojeći mehanizmi automatizirane instalacije programske podrške.

Osnovna forenzička analiza klijenta podrazumijeva poduzimanje određenog broja akcija koje se moraju izvršiti slijedno kako bi postigle tražene rezultate [5]. GRR koristi koncept tokova (flows) i lova (hunt). Na poslužitelju se pokreće tok (proces), zadaju se akcije klijentu, potom se obustavlja izvođenje tog procesa sve dok klijent ne javi da je tražena akcija izvedena te preda rezultate. Tokovi su efikasni u okruženjima, gdje je veliki broj klijenata koji stalno izvršava određene akcije. Također tokovi omogućavaju da poslužitelj uvijek ima slobodne resurse na raspolaganju, što rezultira brzim izdavanjem novih naredbi i neprekinutim primanjem podataka s klijenata. Postoje jednostavni i složeni tokovi. Jednostavni tokovi, su oni kojima je cijela logika akcije na poslužiteljskoj strani i nemaju dodatna stanja na klijentu, mogu perzistirati i kroz ponovno pokretanje klijentskog stroja. Složeni tokovi su oni koji imaju dodatna klijentska stanja i obrade. Svaki tok ima svoj jedinstveni sesijski identifikator (session ID). Jedini tokovi koji ne koriste taj jedinstveni identifikator su takozvani predefinirani ili „dobro znani tokovi“ (well-known flows). Predefinirani tokovi koji imaju poznati identifikator ne zahtijevaju inicijalnu komunikaciju s poslužiteljem pa se koriste za akcije koje klijent mora inicirati kao što je na primjer prvo javljanje poslužitelju nakon instalacije klijenta ili pokretanje drugih tokova. Lov je serija tokova koji se izvršavaju na većem broju klijenata u isto vrijeme [5]. Namjena lova je traženje artefakata malicioznih programa ili analiza uzroka neuobičajenog ponašanja računala. Lovovi omogućavaju da se u kratko vrijeme dobije tražena informacija sa svih aktivnih strojeva u okolini, minimizirajući potrebno vrijeme za provjeru. U GRR alatu lov je glavni mehanizam za forenzičke aktivnosti, a se može pokrenuti kroz web sučelje ili kroz konzolu. Web

sučelje se obično koristi za pokretanje predefiniranih lovova. Rezultati se spremaju u forenzičke slike sustava ili dijelova sustava u AFF4 formatu [1],[5] što garantira nepromjenjivost podataka i rezultata, te daje kompatibilnost s drugim forenzičkim alatima.

III. OKOLINA ZA TESTIRANJE GRR ALATA

Zbog praktičnih razloga, u sklopu testiranja korištena je virtualizacija kako bi se prikazao i isprobao rad GRR alata na više različitih operacijskih sustava u paralelnom radu na ograničenim resursima. Kao virtualizacijski sustav iskorišten je VMware Workstation 12.5. Korišteni alati su instalirani bez dodatnih izmjena, zbog prirode testiranja je na svim virtualnim strojevima definirana IP adresa i ime poslužitelja. U teoriji se tako koncipiran sustav može prenijeti na Hyper-V ili neku drugu virtualizacijsku platformu bez većih problema. Konfiguracije sustava su zadržane na minimumu, izuzev inicijalnog ažuriranja sustava prije instalacije GRR klijenta, nikakva druga ažuriranja sustava nisu napravljena.

Korišteni virtualni strojevi:

UbuntuXenial: poslužitelj
- OS: Ubuntu Xenial 16.04, 64 bit
- 2 virtualna procesora
- 6 GB RAM-a
- 120 GB alocirano za disk

Windows Server 2012: klijent
- OS: Windows Server 2012 r2, 64 bit
- 1 virtualni procesor
- 2 GB RAM-a
- 40 GB alocirano za disk

UbuntuClient: klijent
- OS: Ubuntu LTS 16.04.3
- 1 virtualni procesor
- 2 GB RAM-a
- 20 GB alocirano za disk

Ukupno potrebni resursi :
- 4 virtualna procesora
- 10 GB RAM-a
- 180 GB prostora na diskovima

Ovakva konfiguracija jednostavno se prenosi na vanjskom mediju, te se lako instalira i pokreće za potrebe predavanja ili vježbi. Ovisno o raspoloživoj infrastrukturi konfiguracija se može proširivati dodatnim klijentskim računalima, moguće je i spajanje na mrežne simulatore poput IMUNES sustava za kompleksne mrežne konfiguracije i simulacije.

U najjednostavnijoj konfiguraciji student može koristiti okolinu na samo jednom računalu nezavisno od fakultetske infrastrukture, a upravo na takvoj okolini je obavljeno testiranje.

Cilj ovakve konfiguracije je jednostavnost i skalabilnost, te mali utrošak resursa, da bi se podržala limitirana infrastruktura i mogući izvanmrežni rad studenata, što je poželjno s obzirom na resurse kojima se raspolaže [3].

TABLICA II. REDOSLIJED KORAKA POSTUPANJA U DIGITALNOJ FORENZICI I ULOGA GRR ALATA

Korak	Opis postupanja i rada u nastavi	Opis postupanja i rada u nastavi
1	Priprema i razumijevanje medija s digitalnim dokazima	Umreženi sustav računala s instaliranim GRR klijentima je prostor s kojeg se prikupljaju digitalni dokazi . Na klijentska računala treba instalirati GRR klijente i povezati ih s GRR poslužiteljem koji se dodaje u sustav.
2	Izrada forenzičke slike medija s digitalnim dokazima	GRR klijent putem Sleuth kit alata, Rekall alata u AFF4 formatu generira forenzičku sliku udaljenog računala koristeći koncept lova
3	Analiza forenzičke slike	GRR se koristi za osnovnu analizu AFF4 forenzičkih slika klijenata, po potrebi se koriste i drugi forenzički alati za analizu.

IV. OČEKIVANA PRIMJENA GRR ALATA U NASTAVI

U nastavi bi GRR alat trebao omogućiti dva osnovna cilja, praktičan rad studenta samostalno ili u grupi na vježbama, te teoretski uvod u mrežnu forenziku kao primjer za opis alata i postupaka mrežne forenzike. GRR alat je vrlo koristan za teoretski opis postupaka mrežne forenzike. Pošto se radi o alatu otvorenog koda i nezavisnom o platformi, terminologiju i način rada GRR alata možemo koristiti kao referentni opis. Navedeni koncepti lova, mehanizam instalacije i distribucije klijenata, povezivanja klijenta i poslužitelja omogućuju da studenti stvore sliku o načinu rada forenzičkog alata u umreženom sustavu, te razlikama u odnosu na tradicionalnu digitalnu forenziku i potrebi korištenja više forenzičkih alata. Osnovna instalacija, opisana u poglavlju 3 ovog članka, omogućuje da se na predavanjima demonstriraju osnovni koncepti mrežne forenzike i reakcije na incidente.

Za samostalni studentski rad potrebno je zamisliti vježbe koje student može izvesti sam ili kao dio tima. Rad u mrežnoj forenzici i reakciji na incidente je vrlo često timski i zahtjeva suradnju stručnjaka raznih profila i raznih forenzičkih alata pa je timski rad poželjan i u nastavi. Samostalni rad studenata direktno ovisi o pouzdanosti alata koji koriste. Nepouzdani alat ne može biti korišten za samostalni rad, čak ni ako su zadaci definirani vrlo usko i zahtijevaju minimalnu interakciju s okolinom.

Osnovni koraci forenzičkog postupka organizirani su prema [4] i njihov odnos prema GRR alatu definiran je u tablici II preuzetoj iz [4]. Kao okolina za kontrolu izvođenja vježbi odabran je Foreman alat [2] za vođenje forenzičkog laboratorija. Rad u Foreman alatu je baziran na forenzičkom slučaju, sastavljenom od grupe forenzičkih zadataka s pridruženim digitalnim dokazima i forenzičkim alatima za analizu digitalnih dokaza. U tom obliku će se samostalni rad studenata zasnivati na

zadacima koji se izvode u GRR alatu. Foreman slučaj koji se rješava treba imati najmanje jedan Foreman zadatak koji se rješava u GRR alatu, prema tablici II, a može ih biti i više.

Vježbe sa GRR alatom su planirane tako da na postojećoj GRR okolini studenti pokreću GRR lovove i interpretiraju rezultate u okviru GRR zadatka iz Foreman slučaja u Foreman alatu, kao što je prikazano u tablici III.

TABLICA III. ODNOS FOREMAN ALATA I GRR ALATA U LABORATORIJSKOM PRAKTIČNOM RADU

Foreman elementi opisa forenzičkog zadatka	Primjer vrijednosti u Foreman alatu	Opis odnosa Foreman i GRR alata
Slučaj	20180129001	Broj slučaja u Foreman alatu, forenzički posao koji se mora obaviti
Zadatak u slučaju	20180129001_002	Broj zadatka u Foreman alatu, pod specifičnim slučajem, rješava se kroz GRR alat
Opis zadatka	Na konzoli GRR sustava pokrenuti predefinirani lov „Netstat“, prikupiti i interpretirati rezultate, te izvještaj i opis rada poslati prvom QA kontroloru na odobrenje. U slučaju da QA nije prošao slijediti upute QA. GRR konzola se nalazi na URL: XXX, dokumentacija i upute za korištenje se nalaze na YYY.	Opis zadatka s definiranim alatom, dokumentacijom, postupkom kontrole i drugim parametrima. QA je kontrola kvalitete u procesu Foreman alata. Na osnovi podataka iz zadatka GRR može pokrenuti procese i dobiti rezultate, koji se unose u Foreman zadatak.
Tip zadatka	„Machine Analysis“	Predefinirani tip zadatka u Foremanu, upućuje na alate koje treba koristiti
Uloga: Istražitelj	Pero Peric	Student koji rješava zadatak, definiran kao korisnik Foreman alata, s ovlastima uloge istražitelj u Foreman alatu.

V. REZULTATI TESTIRANJA I UOČENI PROBLEMI

U toku testiranja primijećeni su brojni problemi vezani uz lovove. Lovovi su najkompleksnija zadaća koju GRR izvršava, upravo se kod njih događa najveći broj grešaka, pa su tu rađena i intenzivna testiranja. Tijekom izvođenja lov se može nalaziti u više stanja:

•Pauziran – Lov čeka na izvođenje. Jednom pokrenut, lov se može jedino prekinuti, ne i privremeno zaustaviti.

•U tijeku – Lov je pokrenut i čeka na rezultate, odnosno na povratnu poruku da je lov gotov.

•Zaustavljen – Lov je zaustavljen prije nego je sam završio izvođenje. Lov se iz tog stanja može ponovno pokrenuti jer njegov unos ostaje u upravitelju lovova, ali će uvijek krenuti iz početka na svim klijentima, neovisno je li na nekima uspješno završen.

•Gotov – Lov je uspješno završio na svim klijentima.

•Greška – Lov je završio s greškom na svim klijentima. Teoretski bi trebala biti moguća samo s loše definiranim lovom ili postavljanjem prekratkog vremena izvođenja.

Najčešći problemi se javljaju sa statusom „u tijeku“, koji ostaje aktivan u upravitelju lova premda je sam lov prešao u neko drugo stanje i tako ne daje pravu sliku stanja.

Dublja analiza provedena u [1] tijekom testiranja pokazuje da alat nije dovoljno pouzdan te da je jedan od uzroka grešaka koje se javljaju virtualizacija, tj. nedovoljna podrška virtualizaciji sustava.

Kao primjer može se uzeti jednostavan lov koji je samo prikuplja rezultate netstat naredbe na klijentima. Lov ima status „Zaustavljen“ nakon što je ručno zaustavljen iz konzole. Pregledom detalja lova s greškom, vidi se da se na oba klijenta naredba uredno izvršila te da su rezultati poslani i zapisani u AFF4 strukturu. Greške lova (Hunt Errors) ne prikazuju nikakve greške sa samim lovom. Pregled zapisa sustava direktno ne pokazuje nikakve očite greške s izvođenjem lova. Izgleda kao da lov čeka na neko neodređeno sljedeće stanje i da je ostao u suspendiranom stanju aktivan na sustavu. Pregledom samog programskog koda i analizom izvođenja toka nije otkrivena nikakva greška. Kako se radi o toku koji je definiran od strane razvojnih inženjera aplikacije koji nema nikakvih dodatnih parametara koji bi mogli utjecati na rezultat, krajnje je čudno zašto taj lov ostane u statusu „U tijeku“, što upućuje na probleme s operacijskim sustavom ili virtualizacijskom okolinom. Čak i tokovi koji su vezani na vanjske programe, kao tok za prikupljanje memorije, također završe s greškom, sa sličnim nedefiniranim uzrokom uz poruke da je klijent terminiran, što opet upućuje na probleme s virtualizacijom ili operacijskim sustavom.

Zaključno, ta nekonzistentnost u radu alata je glavni problem. Uspješni tokovi često prestaju raditi, a neki tokovi koji isprva nisu radili uspješno bi imali nekoliko uspješnih izvođenja, bez da se mogao ustanoviti uzrok takvog ponašanja.

Tijekom testiranja je zamijenjen Linux CentOS sustav, koji je davao više grešaka od Windows sustava korištenog u okolini, s Ubuntu sustavom na istoj fizičkoj konfiguraciji stroja. CentOS operacijski sustav kao osnovu koristi RedHat Enterprise Linux, jedan od popularnijih sustava za poslovno korištenje, ali je s inačicom 7 i prelaskom na systemd koncept dosta starih alata postalo nekompatibilno što je također mogao biti uzrok problema. Nažalost ni Ubuntu operacijski sustav se nije pokazao pouzdanijim, greške se nisu smanjile, niti se sustav konzistentnije ponašao.

Google sam priznaje da interno koristi znatno modificiranu verziju GRR alata, premda se tu primarno misli na pohranu AFF4 struktura i korištenje druge baze za pohranu. Ipak nije isključeno da modifikacija s tim razlikama za sobom povlači i dodatne izmjene koje utječu na cjelokupan rad sustava.

GRR alat se nastavlja razvijati, a najavljene promjene također ukazuju na nedostatak zrelosti. Kao jedna od mogućih promjena spominje i prepisivanje cjelokupnog u programski jezik Go [8], što bi moglo povećati stabilnost GRR alata.

VI. ZAKLJUČAK

Za praktične potrebe nastave kibernetičke sigurnosti i specifično digitalne forenzike, potrebno je odabrati alate za izvođenje složenih vježbi forenzike živih sustava u skladu s pretpostavkama stručnog studija. U ovom članku je analizirana moguća primjena Google Rapid Response (GRR) alata. Prikazano je stanje dostupnih alata, kao i mogućnosti i doseg testiranja alata kroz studentski rad, te se prikazuje mogućnost ugradnje forenzičkog alata u sustav vježbi i predavanja. Može se zaključiti da iako svi ciljevi nisu postignuti [1], naučeno i postignuto je dovoljno za korištenje GRR alata u nastavi, te za daljnji rad na razvoju forenzičkog laboratorija.

Forenzički alat GRR je u stalnom razvoju, a za efikasno korištenje zahtjeva znanje i iskustvo koje većina studenta čak ni onih s dugom praksom u sistemskoj administraciji nema. To je razlog djelomičnog neuspjeha razvoja okoline za samostalni rad [1]. Mogući uzrok grešaka koje su dovele do nepouzdanosti je korištenje virtualizacijske tehnologije. Nažalost, nedostatak tehničkih materijala drastično ograničava mogućnost nalaženja gotovih rješenja, pa je potrebno odraditi daleko obimnija testiranja s većim rasponom testnih okolina. Takva testiranja zahtijevaju veće resurse i pripreme pa ih nije moguće izvršiti u sklopu jednog studentskog rada. Ponovljeno testiranje će se drugačije organizirati i provesti, a iskustva iz ovog testiranja će se ugraditi u poboljšanje testiranja i analiza drugih forenzičkih alata koji će se koristiti u nastavi. Za složene distribuirane sustave kakav je GRR, organizirat će se daleko šira testiranja, u više nezavisnih koraka koji se mogu odraditi kao samostalni zadaci.

Usprkos svemu GRR je alat čije su mogućnosti obećavajuće i njegov razvoj bi trebalo pratiti i koristiti. U trenutnom stanju nije pogodan za uporabu u sklopu laboratorijskih vježbi za samostalni rad studenata. Kao platforma za demonstraciju osnovnih koncepata mrežne forenzike u sklopu predavanja GRR alat zadovoljava i kao takav će biti uključen u predavanja uz neke komercijalne alate kao što „Fidelis Cybersecuirty“ ili „EnCase Enterprise“.

Plan korištenja Foreman alata i GRR alata također se može primijeniti na bilo koji drugi alat sa sličnom sposobnošću, uz prilagođavanje teksta zadataka za određeni forenzički alat. U tom smislu GRR je bio prvi alat svoje klase pripremljen za Foreman sustav što omogućava puno jednostavnije pripremanje drugih sličnih komercijalnih ili nekomercijalnih alata.

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PAPERS

Comparison of Computer Forensics Investigation Models for Cloud Environment

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Abstract - ***Computer forensics investigation process evolved from analysis of offline data copies to the process of finding whole spectrum of non-volatile traces in local and remote user environments. Many computer forensic investigations models proposed by researchers and incident respondents were widely accepted for static and live analysis of the systems. With cloud environment surrounding almost every aspect of information technology, researchers find it difficult to apply those models to investigation involved. In this paper, state-of-the-art forensic investigation models for cloud environment have been presented.***

Keywords **– digital** ***forensics; cloud computing; digital investigation; digital evidence;***

I. INTRODUCTION

In last 20 years digital forensic investigators and scientists have developed and proposed many forensic investigation models that were mostly applied to specific investigation sets. In 2001, Palmer at al. defined model that aimed to determine common phases of digital forensic investigation along with definition of key concepts and order of phases. The proposed investigative process is linear and consists of seven phases: *Identification, Preservation, Collection, Examination, Analysis, Presentation* and *Decision* [1]. Palmer at al. addressed open key questions regarding digital forensic science and its future development.

Many researches and forensic investigators proposed process models that extend existing and introduce new phases. New process models tend to be better suited for investigations that authors performed. This results in many different investigation models. Widely accepted models are mentioned in this paper.

On the other side, continuous development of IT related Internet services have evolved to whole new spectrum of services established in cloud environment. This makes it hard for forensic investigators to perform earlier established procedures, in environment that relies on remote resources. These resources may often be available in limited time for analysis due to possible subscription expiration of services, account suspension etc.

The rest of this paper is organized in following mater. Chapter II gives short description of traditional forensic investigation models and their phases. Main restrictions of those models applied to digital forensic investigation determined by researchers is also noted. In Chapter III state-of-the-art models and challenges in cloud environment are discussed. Chapter IV consists of conclusions and future research path considerations.

II. MATURATION OF FORENSIC INVESTIGATION PROCESS MODELS

Recent publications [2], [3], [4], [5] and [6] give brief overview regarding maturation of digital forensics investigation models. All comparisons of models start by giving detailed explanation of models proposed by M. Reith, C. Carr and G. Gunsch [7] along with model proposed by B. Carier and E. Spafford in 2003 [8].

In [2] authors give the short review of models developed prior to models proposed in [7] and [8]. First model described is *Computer Forensic Investigation Process* established in 1984 by FBI, and described by FBI agent M. Pollitt in [9]. This model consists of four phases: *Acquisition, Identification, Evaluation and Admission.* The second model described is one proposed by Palmer et al. [1].

The Abstract Digital Forensic Model proposed by M. Reith, C. Carr and G. Gunsch [7] consists of nine phases: *Identification phase, Preparation phase, Approach strategy selection phase, Preservation phase, Collection phase, Examination phase, Analysis phase, Presentation* phase and *Returning evidence phase*. Main disadvantages of this model are [3]:

- high-level approach to categorisation,
- there is no obvious method to test the model and
- more granularity of categories increases complexity.

The *Integrated Digital Investigative Process*, proposed and developed by Carrier and Spafford [8], involves *Digital Crime Scene Investigation* into *Physical Crime Investigation Phase*. The model consists of seventeen phases divided into five groups: *Readiness Phases, Deployment Phases, Physical Crime Scene Investigation Phases, Digital Crime Scene Investigation Phases* and *Review Phase* [4] [8]. Following this model, investigators should consider digital crime scene as "the virtual environment created by hardware and software where digital evidence of crime or incident exists" [3]. According to [3] the model has been applied to some case studies, but no evidence exists that it has been referenced while creating standards for forensic investigation models. This model is improved by *Enhanced Digital Investigation Process Model* [10] that instead of linear application of phases, represents phases as iterative.

According to authors, its iterative nature helps to trace the computer that has been used as tool to commit offense [10]. In order to prevent ambiguities, this model supports reconstruction only after all of the investigations have been completed.

Extended Model of Cybercrime Investigation, proposed by S. Ciarduhain, [11] is comprehensive model. The information flow between investigation phases is addressed in this model. The investigation activities are conducted in sequences. Iteration of some investigation parts is possible [5].

A Hierarchical, Objectives-Based Framework for the Digital Investigations Process [12] proposed by Beebe and Clark focuses on low-level activities of digital investigation. This is opposite to abstract concepts defined in previous models. Two contributions of this model [3] are „multi-tier" approach and introduction of *Principles* defined as high level procedures applied to multiple investigation phases.

Computer Forensics Field Triage Model [13] proposed by M.K. Rogers, J. Goldman, R. Mislan, T. Wedge and S. Debrota is model that aims to cover time-sensitive investigations. This model proposes onsite analysis of evidences, which is opposed to traditional models of seizing all evidences and analysis in laboratory environment.

A common Process Model for Incident Response and Computer Forensics [14] introduced in 2007 by Freiling and Schwittay explicitly introduces *Live Response* element in process model. *Live response* assumes collecting and analysis of evidences from digital sources that are still running. Authors of the model distinct incident response from computer forensics.

Common phases of existing models can be identified as [4]: *Incident detection, Planning, Preparation, Evidence Identification, Evidence Collection, Evidence Transportation, Evidence Analysis, Presentation* and *Conclusion*. Authors in [4] consider that reference principles of *Preserving Evidence*, *Preserving Chain of Evidence* and *Documentation* along with common phases are good basis that should be involved in creating future investigation models.

Recent studies [3] and [4] noted that for proper evaluation of digital investigation model process, interpretation should be considered in frame of Dauberts test. By using this test judges can determine reliability of the digital evidence presented. Five requirements should be followed:

- Whether the theories and techniques employed by scientific expert have been tested;
- Whether the theories and techniques have been under peer review and publication;
- Whether these techniques and theories have a known error rate;
- Whether the existence of relevant standards has been applied to its operation;
- Whether these theories and techniques have been accepted by relevant researchers and community.

According to [3], *Computer Forensics Field Triage Model*, satisfies four out of five requirements. The only requirement considered not satisfied is fifth. Author claims that no evidence exists of its wide acceptance in community.

III. OVERVIEW OF STATE-OF-THE ART CLOUD RELATED FORENSIC INVESTIGATION MODELS AND CHALLENGES

A. Cloud forensic definition

Recent research papers [15]-[21] give brief overview of challenges and establish taxonomy of cloud forensics. In [15] authors give definition of *cloud forensics* as a cross-discipline of *cloud computing* and *digital forensics*. Since *cloud computing* service is based on remote network access, author claim *cloud forensics* as a subset of *network forensics*. NIST in [16] defines it as the application of scientific principles, technological practices and derived and proven methods to reconstruct past cloud computing events through identification, collection, preservation, examination, interpretation and reporting of digital evidence.

B. Cloud forensic three-dimensional model

In [19] authors define three-dimensional nature of *cloud forensics*: *Technical, Organizational* and *Legal.*

Technical dimension tends to address technical related issues such as: data collection, live forensics, evidence segregation, virtualized environments and proactive measures. It addresses the problem of segregation of evidences in multiple-tenant nature of cloud environment.

Organizational dimension addresses the issue of determining the participants that are part of investigation. Authors claim that at least two participants are included: cloud service provider and cloud customer. According to authors it becomes difficult to identify participants in case when cloud service providers outsource services to the third parties. This dimension proposes five different roles that are required to establish cloud forensic capability: *Investigators*, *IT Professionals*, *Incident Handlers, Legal Advisors* and *External Advisors*.

Legal dimension addresses issues related to obeying law regulations in different international law zones. It proposes that service level agreements, between customers and cloud service providers, are made in manner that can allow investigators to comply with applicable laws, privacy and security.

C. Cloud forensic challenges

In [18], [19], [20] and [21] authors address technical challenges for *cloud forensic investigation*. Regarding forensic data collection authors find it easier to obtain data of forensic interest for *Infrastructure as a Service* cloud consumers, while on the other side *Software as a Service* cloud services give a little or no access to data. Anyways, forensic investigators working of data copies from *Infrastructure as a Service* cloud services, are not guaranteed to deal with recent copies of disks

and data. Cloud storage providers have encryption enabled on customers data. When encryption is enabled only persons that have encryption keys can deliver unencrypted media. Cloud providers do not offer physical access to storage devices, and customer access to virtual disk devices. Physical access to storage devices can be granted to legal authorities, but that opens the problem of data segregation in multiple-tenant environment. It is hard to secure privacy for tenants not included in investigation.

D. *Cloud forensic investigation state-of-the-art models*

An integrated conceptual digital forensic framework for cloud computing proposed by B. Martini and K. R. Choo [22] consists of four phases:

- Evidence source identification and preservation
- Collection
- Examination and Analysis
- Reporting and presentation

Evidence source identification phase - addresses the issue of cloud service and providers relevant to subject of investigation and proper preservation of acquired data. *Collection phase* - addresses the methods for adequate data capture. It also addresses *chain of custody*. *Examination and Analysis phase* – addresses using well established forensic tools and procedures after all of the data in previous two phases are identified and collected. *Reporting and presentation phase* – addresses well established reporting procedures and presentation of evidences in court of law. The model is proposed as iterative since *Examination and Analysis phase* can lead to identification of new evidence sources.

Digital Forensic Model for a Cloud Environment proposed by M. Sihiya gives *Forensic as a Service* model description. *Cloud Forensic Process Model* as a part of *Forensic as a Service Model* consists of following processes: *Incident Detection, First Response, Planning Process, Preparation, Potential Evidence Identification, Evidence Acquisition, Evidence Transportation, Evidence Storage, Evidence Examination and Analysis, Reporting, Presentation* and *Investigation Closure.* According to noted processes, this model extends [23] by adding nine additional phases. Author gives detailed recommendations regarding to evidence collection, selecting appropriate forensic tools, incident classification, interpretation and industry standards compliance if applicable.

IV. CONCLUSION AND FUTURE WORK

Development of digital forensics procedures and models for cloud forensics application has been established in the past years. Different authors propose models that tend to be more generic and able to apply in wider spectrum of digital investigation processes. Future development of cloud forensics includes not only technical obstacles but rather legal. Cloud providers have data centers on global locations and depending on data center locations, different jurisdictions may apply.

Development of well documented and general digital forensic investigation process model is a challenge that has not been resolved jet. Researchers should focus on continuous cooperation and development of previously established model. Even though if some of the models are widely used, there is no feedback from researchers and forensic investigators. Focusing on feedback papers could help in better understanding of different model applications.

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Performance Impact of DVFS for Molecular Dynamics Simulations on Tesla K40 GPU

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Abstract – **Nowadays the most crucial challenge in High-Performance Computing (HPC) is to optimize the power consumption of resources and to couple the performance with energy efficiency. The graphics processing units (GPUs) have been used intensively due to their computational performance, which are significantly accelerate the execution of many HPC applications. A series of studies have been carried out based on GROMACS (GROningen MAchine for Chemical Simulations) package to reveal the nature of NVIDIA Tesla K40 graphical card with different frequencies and to estimate the energy efficiency from frequency viewpoint. The analyzes show that the performance of the Tesla K40 is equivalent to the performance of the 1024 cores of IBM BlueGene/P supercomputer or the 64 CPUs of HP CP4000BL nodes. In the meantime, the usage of low frequencies leads to the energy conservation up to 20-30%. It is stated that the optimal power efficiency is achieved with the low-frequency GPU.**

Keywords – GROMACS; GPU benchmarking; energy-efficient computing; dynamic frequency scaling; HPC.

I. INTRODUCTION

Power and energy consumption can be identified as the most recognized concern in exascale systems such as HPC or supercomputers. Hence decreasing the power consumption of large-scale HPC systems is becoming a crucial challenge in the context of increasing the performance and consuming as less energy as possible [1-2]. Accordingly, finding ways in energy efficiency improvements in HPC applications is a challenge [3]. In recent years, the potential for accelerating computational processes has grown significantly using multicore CPUs and general-purpose computing (GPGPUs). GPU-accelerated computing offers unprecedented application performance by offloading compute-intensive portions of the application to the GPU to handle GPGPUs, while the remainder of the code still runs on the CPU [4]. It is obvious that GPU consumes much more power than a CPU. However, the total amount of watt consumed per unit gigahertz is much lower compared to the CPU [5]. The CPU/GPU hybrid calculations lead to improvement of both the performance and the energy efficiency. The Dynamic voltage and frequency scaling (DVFS) is a power-management technique where the processor frequency is manipulated to study the supply voltage (terms known as overvolting/undervolting) [6]. The abovementioned technique makes it possible to improve the performance by switching/adapting the frequency to better suit load characteristics [7].

The article aims to study the impact of DVFS on molecular dynamics simulations of complex systems regarding performance and energy efficiency for GPU computing and compare them with the experiments carried out on HPC CPU resources. The simulation performance with and without GPU acceleration by changing processor clock from 666MHz to boosting 875MHz have been determined using a set of testing systems by paying attention to the power consumption challenges. All benchmarking experiments have been carried out using the HP server consists of 12 dual-core Xeon E5-2620 processors and Nvidia Tesla K40 Kepler GPU graphical card plugged into a PCI-e slot.

The remaining content of the paper is organized as follows. Related work is presented in section 2, the experimental methodology in details can be found in Section 3 and the experimental results are given in Section 4. Finally, the conclusion and directives for future research are drawn in Section 5.

II. RELATED WORK

The HPC and GPGPU resources are usually used for molecular dynamics (MD) simulations and there is a series of free-available software codes in this field, like NAMD [8], GROMACS [9] or AMBER [10]. It should also be noted that there is also a MD code entirely implemented namely on GPUs [11]. The GROMACS, known as "fastest MD" code is one of the most popular parallelized software packages. The speed of calculation, the scalability, dealing with a huge number of atoms, many useful modules and optimal code – these are the main priority things to which GROMACS developers pay much attention. The scaling of GROMACS package has been intensively carried out on different platforms, where the parallel scalabilities were discussed [12-16].

MD simulations play a vital role in understanding many phenomena in complex systems and such effects, as a rule, occur on nano- or micro-time scales. Therefore, the usage of supercomputers is aimed to study such kind of systems, like biological model membranes [17] or surfactant/polymer complexes [18-20]. Indeed, the usage of HPC resources allows performing the long-term simulations on different levels including atomistic scale and even CPU-time-consumable coarse-grained level [21].

However, the usage of CPU architecture only is not rather an effective solution in case of performance-per-watt ratio. Recently, the GPU computations have become more and more attractive in the field of parallel computing, although the implementation of new strategies to improve the performance is in rather a primordial stage. The impact of DVFS on application performance and energy efficiency for GPU computing has been discussed by Rong and coworkers, where the detailed experimental data has been represented using Nvidia Tesla K20 [22]. Regarding the essential criteria's, such as the performance-to-price and energy consumption, a series of benchmarking runs have been executed by Kutzner and co-workers to reveal GROMACS efficiency on a variety of platforms, from workstations to HPC clusters [23]. Analyzing various GPUs (GTX 6xx/7xx/9xx, GTX TITAN and Tesla K20/K40) in term of performance, there is an assumption that instead of installing and using expensive clusters, it is better to buy cheap GPUs, which provide much more efficiency and productivity. The effectiveness of CPU and CPU/GPU hybrid systems has been discussed in [24], where the authors, using Nvidia GTX 780/TI and ATI R9 290/X graphics cards, report the performance data by changing the hardware configurations and software parameters (changing precision - single/double). Another work performed by Enos and co-workers demonstrates that the results on Tesla C1060 indicating that although GPUs significantly increase power consumption, the provided acceleration results in a reduction of the overall energy consumption [25].

III. Environment Setup

The experiments have been carried out using GROMACS software package (version 5.0.4) based on Linux OS (Ubuntu 14.04) with standard compilation and optimization options. To analyze the performance a series of benchmarks (more than 500 runs) have been performed typically for 10000-time steps, depending on the number of processor cores (1, 4, 8, 16 and 24 cores) and GPU. The following resource of the Armenian National Grid infrastructure is used for the experiments [26-27]:

- 12 Xeon E5-2620 processors with 6 cores, Nvidia Tesla K40 Kepler GPU graphical card plugged into a PCI-e slot and 65GB system memory.
- The DVFS has four frequency modes, accordingly 666, 745, 815 and 845 MHz.

Note that K40 GPU implements the Nvidia GK110B Kepler architecture having total 2880 CUDA cores. Besides, the experiments have been carried out also for the newest one – the fastest application booster Nvidia Tesla K80. The NVIDIA System Management Interface (nvidia-smi) has been used for changing the GPU frequency, and also to obtain the average power consumption in watt.

We emphasize only on the power consumption of GPU, without taking into account some other hardware constraints. The systems extracted from GROMACS official webpage with 5K, 24K, 134K atoms, as well as the system consists of about ~2.5M atoms. The simulations have been carried out with the following parameters: 2fs time step, the PME electrostatics, van der Waals forces truncated at 0.9nm with the corresponding temperature control (v-rescale algorithm). The benchmark runs were typically for 10000 steps without any writing outputs. Mdrun -pin flag was on, which set affinities for cores, i. e. the threads remain locked to cores and do not jump around. The studied complex systems include showcase systems [28] and a huge system is available at Bioinformatics website [29]. The latter largest system consists of 128 sodium pentadecyl sulfonate molecules in the 35x35x20nm^3 water box.

IV. Results and Discussions

The Villin system, consists of 5K and 25K atoms, has been studied and each plot has been obtained with 20 simulations for each point and that standard deviation was small. The benchmarking results for a small system with 5K atoms (Villin headpiece) are represented in figure 1.

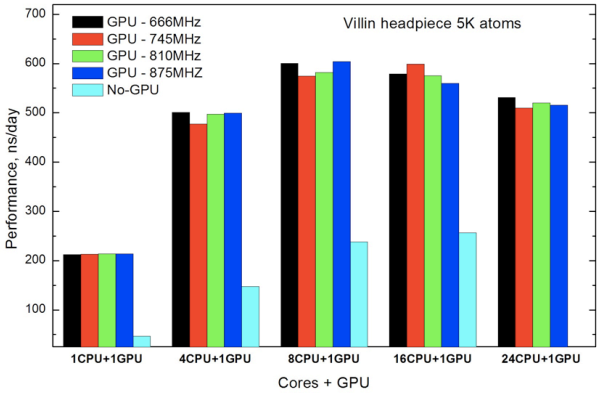

Figure 1. The performance of a smaller system with 5K atoms depending on a number of cores and GPU

For instance in case of 666MHz the performance of the system (ns/day) is the following: 1CPU+1GPU = 212, 4CPU+1GPU = 501, 8CPU+1GPU =600, 16CPU+1GPU = 578, 24CPU+1GPU = 531.

Usually, in MD simulations, the parameter which describes the speed of calculation or performance is expanding nanoseconds per day and therefore, in further plots, the mentioned parameter has been examined (computational throughput in nanoseconds /ns/ per day versus the number of cores). As mentioned before, several experiments have been performed depending on the number of CPU cores (1, 4, 8, 16 and 24 cores) and GPU. The GROMACS mdrun module was run using following flags: -pin on -nb cpu -nt number-of-cores (for only CPU runs) and -pin on -nt number-of-cores (for CPU/GPU runs). As an .mdp file we get pme_verlet_vsites.mdp, i.e. with full PME electrostatic; in a rhombic dodecahedron box; 10000 steps and timestep of 5fs.

As shown in figure 1, the GPU significantly accelerates the simulation (from 2.2 up to 4.6 times). In case of usage of CPU power and increase the number of cores, we track gradually increase in performance up to 256ns/day. As GROMACS does not create domains of a certain minimum size, the performance on 24 cores is not pos the system scales linearly up to 16 cores. The speedup coefficient, which measures the efficiency of using

multiple processes with respect to single one, according to Amdahl's law can be represented as:

$$\sigma = \frac{1}{j_p / N_p + j_s + C(N_p)} \quad (1)$$

where N_p - number of cores, j_p and j_s is the amount of jobs, which can be done in parallel and in serial ($j_p + j_s = 1$) and the $C(N_p)$ describes the network depending on the network bandwidth and the latency time. The ideal parallelization claims - $j_p = 1$ ($j_s = 0$ and $C(N_p) = 0$), which means N_p times faster operations and vice versa, no gain observed when $j_s = 1$. The mentioned parameter - the speedup relative to one processor was calculated by simply dividing executing time on a single-processor T_1 to the executing time on N cores - T_N . $\sigma = \frac{T_1}{T_N}$. The following speedup values were obtained: 3.18 (4 cores); 5.14 (8 cores) and 5.53 (16 cores).

When GPU is active, we track the acceleration up to 4.6 times compared to CPU results. Figure 1 also presents the results of GPU acceleration with different frequency values. The best speedup for a small system is achieved when the frequency is 666MHz with 8CPU/1GPU set. As a system size is small, therefore further increase of a number of cores does not lead to a significant increase in performance even in the presence of GPU. Moreover, the maximal number of cores (24 CPUs) shows worst results, i.e. we observe a slowdown in scaling efficiency for all frequency cases. Note that when GPU is active, the most compute-intensive part – nonbonded interactions are computed on graphics processing units, i.e. heavy nonbonded force calculations lie on GPU accelerator, meanwhile, the CPU performs the operations on bonded force and lattice summation (PME).

It is noteworthy to mention that GPU Tesla K40 processor clock varies from 666MHz up to 875 MHz with 745MHz being the default value, so in order to boost performance the 810MHz and 874MHz clock frequencies are used. Although GPUs have more cores than CPUs, however, the latter runs significantly faster than GPU cores. The main disadvantage of GPU cores is that the user is unable to manipulate with cores, i.e. assign a number of GPU cores for the task, as the CUDA architecture is responsible for handling this procedure.

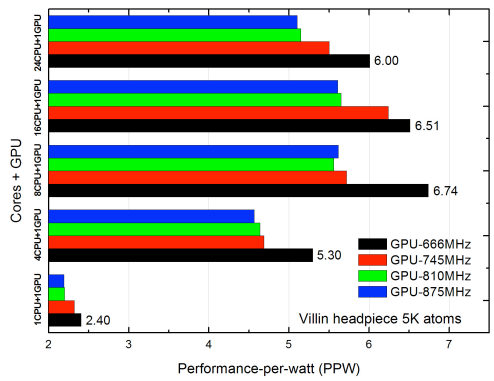

Figure 2. The performance-per-watt of a system with 5K atoms depending on a number of cores and GPU

We also measure the system power consumption (average, maximum and minimum) by nvidia-smi (Nvidia System Management Interface) with –q –d POWER tag, which outputs the maximal/minimal/averaged power in watts. The measurement results are shown in figure 2, where the so-called performance-per-watt (PPW) has been represented. Note that the PPW parameter means the performance divided by average power. The system power values for a smaller system vary from ~88W to 110W, where different frequencies were switched on. We argue that the usage of 8CPU/1GPU is more efficient with 666MHz frequency, which corresponds to about 25% of system's power reduction.

The benchmarking data on protein RNAse, which contains roughly 24K atoms, are exemplified in figure 3. If we increase the system size, we also observe a linear increase in production when GPU is not active. The corresponding values for speedup are; 3.49 (4 cores); 6.39 (8 cores); 7.3 (16 cores) and 9.87 (24 cores), which are a bit higher than in case of a smaller system.

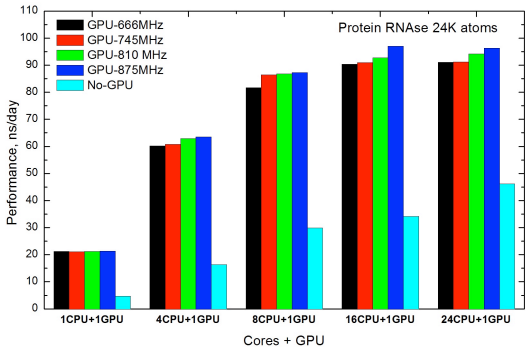

Figure 3. The performance of a system with 24K atoms depending on a number of cores and GPU.

When GPU is switched on, different behavior in contrast to a smaller one is tracked. Here, the acceleration is about 1.9 up to 4.5 times compare to CPU. By changing the processor clock values, we observe an increase in the performance with the increase of frequency. Hence, we argue that the maximum performance reached when we have 24CPU/1GPU and 875 MHz is used. However, from power consumption point of view, we see that 666MHz frequency is more efficient (see figure 4) when with PPW graphs are analyzed.

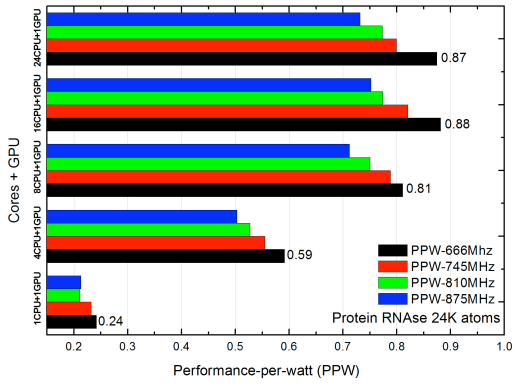

Figure 4. The performance-per-watt of a system with 24K atoms depending on a number of cores and GPU

Regardless of the number of processors, the best PPW is reached when a low frequency is switched on and the power measurement results reveal from about 87 to 131 Watts interval within a range of +/- 5 watts error precision. Figure 5 summarizes the benchmarking results of the system with 134K atoms (Alcohol dehydrogenase protein) are shown. In this case, the increasing of system size also leads to a linear increase in performance, and when the GPU is active, we recognize that the optimal performance reached when 24CPU/1GPU – 875 MHz set is enabling. As in case of small systems, here, we see that for a 134K system the optimal PPW is achieved for low-frequency GPU. The PPW curves for 134K a system are monitored in figure 6.

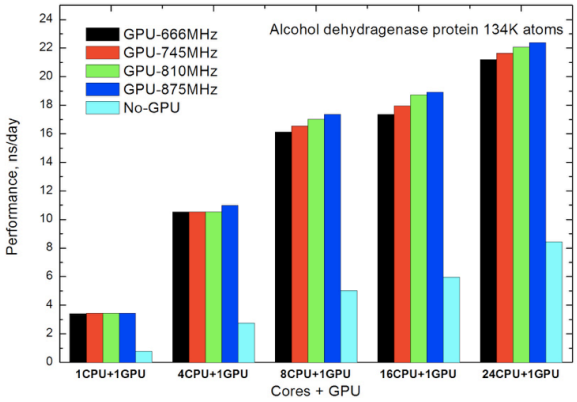

Figure 5. The performance of a system with 134K atoms depending on a number of cores and GPU

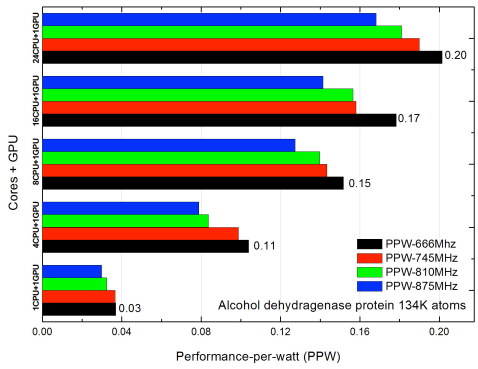

Figure 6. The performance-per-watt of a system with 24K atoms depending on a number of cores and GPU

To check the further influence of the system size and reveal the peculiarities, we have also tested the system consisting of more than 2.5M atoms (Surfactants in water). In figure 7, the benchmarking data are monitored. One can see that even for this huge system the behavior of a machine is the same, i.e. a linear increase in case of GPU is off and an increase of productivity exists when the frequency increases. Analyzing the PPW for a huge system, we argue that optimal ratio is done for low-frequency GPU (see figure 8).

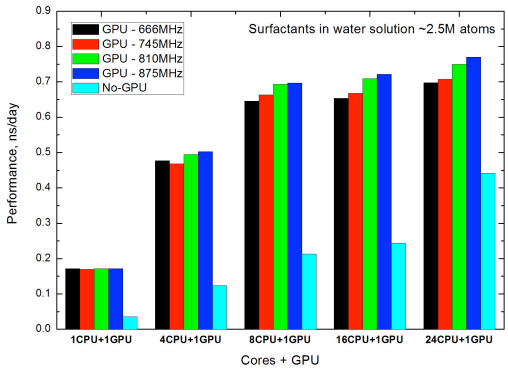

Figure 7. The performance of a system with ~2.5M atoms depending on a number of cores and GPU

The benchmarking data of enormous systems in the following different HPC resources are compared [30]:

- Bulgarian IBM Blue Gene/P supercomputer, consisting of 2048 PowerPC 450 based compute nodes, 8192 processor cores and a total of 4 TB random access memory (Rpeak about 27 TFLOPS).
- The Hungarian HP cluster - CP4000BL consists of 2304 cores with 14 TFlops performance (AMD Opteron 6174 type processors with 12-core Magny-Cours (2.1GHz) with the QDR 4x Infiniband internal high-performance communication).

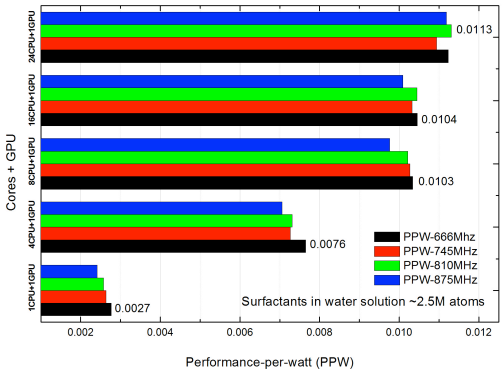

Figure 8. The performance-per-watt of a system with 2.5M atoms depending on a number of cores and GPU

In Table 1, the comparison of all data is shown. It claims that our testing machine with Tesla K40 can run a simulation as fast as on 1024 cores of IBM BlueGene/P supercomputer and more than 64 CPUs of HP CP4000BL cluster. Note that similar behavior for power consumption is seen in case of the huge system (see figure 8), although some small shift is obvious. To compare the benchmarking coming from K40, we utilize the capabilities of the newest card, provided by Nvidia (K80).

Comparative benchmarking data is provided in Table 2. Note, that the benchmarking on K80 was done using auto boost-disable feature, i.e. we have reached the exact comparison between two cards. As it is known, the Tesla K80 ships with an *auto boost-enabled* by default and this mode means that when the end user starts using the card,

the GPUs will start at base clock and raise the core clock to higher levels automatically (see manual at http://www.nvidia.com). Meanwhile, K80 supports a wide range of GPU clock speeds (about 25), for comparison, four various values (666, 745, 810 and 875 MHz) have been chosen.

Table 1. The benchmarking data for a huge system with ~2.5M atoms. The data were extracted from [10].

Bulgarian IBM BlueGene/P		**Hungarian HP CP4000BL**		**12DC Xeon E5-2620 with K40**				
Cores	Results ns/day	Cores	Results ns/day	Cores	Results ns/day			
128	0.132	16	0.149	4	0.124			
256	0.237	32	0.292	8	0.213			
1024	0.515	48	0.435	16	0.244			
2048	1.590	64	0.564	24	0.442			
		96	0.827	*Freq. MHz*	666	745	810	875
		128	1.100	4CPU+1GPU	0.477	0.468	0.495	0.503
		256	2.035	8CPU+1GPU	0.646	0.663	0.693	0.696
		512	3.655	16CPU+1GPU	0.654	0.668	0.709	0.722
				24CPU+1GPU	0.698	0.707	0.75	0.77

The data provided in Table 2 and in figure 9 assume that using Tesla K80 about twice as better results than in case of K40 is achieved.

Table 2. The benchmarking data for a huge system with ~2.5M atoms performed on K40 and K80.

Cores	**K40**				**K80**			
	Results, ns/day							
4	0.124				0.150			
8	0.213				0.258			
16	0.244				0.451			
24	0.442				0.516			
32					0.673			
Freq. MHz	**666**	**745**	**810**	**875**	**666**	**745**	**810**	**875**
4CPU+1GPU	0.477	0.468	0.495	0.503	0.7056	0.7078	0.7216	0.7296
8CPU+1GPU	0.646	0.663	0.693	0.696	0.9738	0.975	1.0008	1.009
16CPU+1GPU	0.654	0.668	0.709	0.722	1.293	1.308	1.3432	1.3594
24CPU+1GPU	0.698	0.707	0.75	0.77	1.0254	1.0788	1.114	1.1257
32CPU+1GPU	-	-	-	-	1.2232	1.2578	1.2776	1.3324

In case of active GPU K80, we track the acceleration up to 4.9 times compared to CPU results, which is, indeed, better than in case of K40. The frequency dependence curve (see figure 9) shows that the better speedup is reached when 16CPU/1GPU – 875 MHz set is enabling.

In contrast to K40, where the optimal performance reached at 24CPU/1GPU (875MHz), K80 shows the worst performance at 24CPU/1GPU case and even the increase of the cores does not lead to significant improvement in performance, as clearly seen in figure 9.

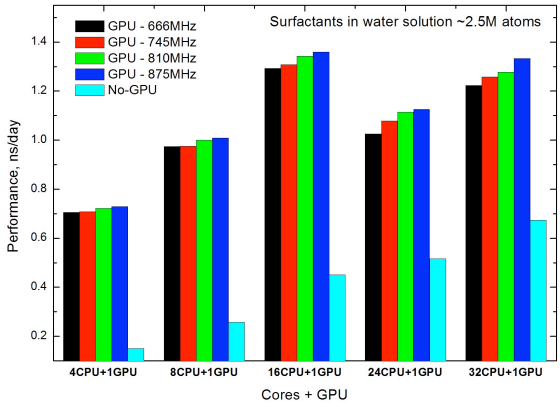

Figure 9. The performance of a system with ~2.5M atoms depending on a number of cores and GPU (K80 case)

As in case of K40, the PPW for K80 claims that the optimal is achieved for low GPU frequency (see figure 10).

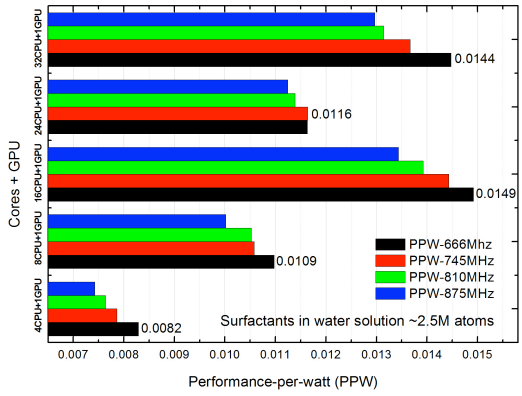

Figure 10. The performance-per-watt of a system with 2.5M atoms depending on a number of cores and GPU (K80 case)

V. CONLUSION

More than 500 simulations have been carried out to check the parallel performance of GROMACS software package on GPU equipped workstation. As the power consumption of such systems is crucial, the performance with power relation is more efficient than only taking into consideration the execution time.

The simulations have been carried out to reveal the nature of Tesla K40 graphical card with different frequencies and to estimate the energy efficiency. We stated that the performance hardly depends on the size of

the system studied and in case of a small system the parallelization is reduced. To avoid wasting computational power, it is recommended GPU with low frequency: few cores combination when the size of the system studied does not exceed the so-called "critical amount" of atoms.

The comparison of data claims that our testing server with Tesla K40 can run a simulation as fast as on 1024 cores of IBM BlueGene/P supercomputer and more than 64 CPUs of HP CP4000BL cluster. Moreover, the testing on latest Tesla K80 reveals that we have twice better performance than K40. Concerning to CPU calculations, we find high speedup using both K40 and K80. Based on the analysis of the simulations, the optimal power efficiency is achieved with the low-frequency GPU, especially taking into account the non-linearity of power consumption as we saw in the case of 666 MHz frequency for the small systems. Finally, the studies allow minimizing the energy consumption by designing effective DVFS schedulers for such systems, depending on the number of molecules.

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Memory-aware Multiobjective Design Space Exploration of Heteregeneous MPSoC

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Abstract **– This paper discusses multiobjective exploration of heterogeneous MPSoC design space using a method based on NSGA-II evolutionary algorithm. Key feature of the proposed method is separation of computation and communication which enables exploration of mapping computation to processors and communication to memory elements. In this paper two approaches to mapping and scheduling are presented and compared: (1) single–phased, where tasks and communication channels are mapped to processor and memories simultaneously, and (2) two-phased, where mapping of tasks to processors is done in first phase, followed by mapping of communication channel to memories in the second phase.**

Keywords – design space exploration, MPSoC, evolutionary algorithm

I. INTRODUCTION

Design space exploration is the most significant step in building heterogeneous multiprocessor systems dedicated to special purpose. Heterogeneous platforms offer different types of processors, memories and interconnections, all of which are suitable for different types of computation and communication. By choosing the right combination, and with the correct mapping scheme, it is possible to achieve superior performance in terms of speed, energy consumption and cost compared to a homogeneous platform. However this is not an easy task, and for all but the most trivial problems, the solution to this problem cannot be achieved by an exhaustive search of all design points.

The problem of efficient DSE for MPSoCs has been an active research topic for more than a decade. Evolutionary algorithms are widely accepted for solving DSE problems due to their versatility. They can be adapted to suit any kind of problem at hand, and easily search over several different criteria in a reasonable amount of time. One big challenge in this approach is to minimize or completely avoid infeasible solutions in order to guarantee that the process once finished will provide a feasible solution.

Fast and efficient design space exploration process implies that both application and platform model are given on a high level of abstraction [1]. Application model is given in a form of task graph, while platform model consists of processing elements connected to the communication architecture. Memory elements and their topology is mostly represented using idealised communication channels. This mapping has well defined rules. Processes map to processing elements (PEs). Channels between processes are mapped to routes consisting of buses, bridges, and interfaces. For the channel to be implemented, a valid route must exist between the PEs hosting the respective communicating processes. A set of possible routes for each application channel can be easily generated by analysing the platform. Impact of memory configuration on system performance has been recognized by many research groups who have tried to offer different methods of properly incorporating memory access impact on overall system performance into design space exploration (DSE) process. However, most work still focuses on mapping tasks to processing elements and either assume a default communication route between two processing elements or and deal with memory resource allocation afterwards.

In this paper we have implemented a design space exploration method based on a multiobjective evolutionary algorithm NSGA-II with focus on memory mapping and its impact on result quality. Separation of computation and communication enables exploration of mapping computation to processors and communication to memory elements. Two approaches to mapping are discussed and compared: (1) single –phased, where tasks and communication channels are mapped to processor and memories simultaneously, and (2) two-phased, where mapping of tasks to processors is done in first phase, followed by mapping of communication channel to memories in the second phase.

II. RELATED WORK

The dominant approach during mapping and scheduling phase of design space exploration primarily focuses on mapping tasks to processing elements while communication mapping is secondary. The two most prominent DSE frameworks Daedalus [2] and MAPS [3] also follow this approach. In both frameworks, the process of generating mapping and scheduling scheme does not take into consideration existence of multiple connections between processing elements via different types of memory elements. If needed, additional memory configuration and data allocation scheme is done manually in the later stages of design and implementation process.

Some authors focus solely on memory resource allocation

but do not consider methods of integrating this process into design space exploration. Verma et al. [4] propose a workflow which, using static data-flow analysis and ILP, generates a cache-hit model to give cache-aware solutions of scratchpad memory allocation in embedded systems. They present a greedy algorithm for efficiently finding good solutions - Cache Aware Scratchpad Allocation (CASA) algorithm and report an average reduction of 8-29% in instruction memory energy consumption compared to a previously published technique for benchmarks from the Mediabench suite. The approach does not consider the topology of the architecture nor bandwidth issues. Falk and Kleinsorge [5] use an ILP model to minimize worst-case execution time (WCET) on scratchpad memory-based systems which considers only a single scratchpad memory. Similarly, Suhendra et al. [6] present an approach using static data-flow analysis which generates and solves an ILP model for scratchpad allocation minimizing WCET, as well as a heuristic for finding good solutions. These models neglect bandwidth and complex topologies. Their allocation model is very simplistic, only considering if a specific basic block of source code should be reallocated on the scratchpad memory or not. It does not consider the topology, differences between the individual memories or bandwidths. Ozturk et al. [7] present a holistic workflow that not only generates a mapping, but also analyses the source code to get the relevant information to compute it. However, the employed memory model is only partially aware of the architecture's topology.

More recently, studies have started to focus on integrating memory partitioning into design space exploration process. Salamy and Ramanujam [8] present a heuristic that integrates task scheduling and memory partitioning of embedded applications on heterogeneous MPSoC with scratchpad memory (SPM). Compared to the decoupled approach, their integrated approach shortens the execution time by 12% on average (up to 47% depending on the structure of application). However, the authors have considered only a rather simple memory architecture with one SPM divided between processors and a large off-chip memory. Jovanovic et al. [9] consider real heterogeneous MPSoC systems with different types of processing and memory elements but memory allocation is done after the task-to-processor allocation is complete and does not consider the possibility of evaluation of processor-memory pair simultaneously. Although the authors report an improvement by 18% over several common benchmarks (FIR, IIR, MPEG4, compression et al.), their optimization method is based on ILP meaning that for more complex problems it will take considerably long time to run. Goens et al. [10] use Mixed Integer Linear Programming (MILP) to improve application performance by optimizing allocation of data to memories in a heterogeneous platform. Again, memory allocation scheme is generated after task-to-processor mapping. The focus is on streaming applications and thus the optimization goal is not to find the best solution, but the solution which will satisfy given constraints. This relaxation decreases the runtime of MILP solver but it has been reported that for larger memory space the solver couldn't find a solution even after 4 days on a supercomputer.

III. PROBLEM MODELLING

A. Application model

The application is modelled as a Directed Acyclic Graph (DAG), $AG = (T, Ch)$. For each node $t \in T$, which represents one task, a set of edges is defined $Ch_t \subseteq Ch$ connected to t that represent communication between tasks. Edge weight, given by a weight function:

$$wch : Ch \rightarrow \mathbb{R} \quad (1)$$

is the amount of data transacted (in KB) between two tasks. Figure 1 depicts an example application graph.

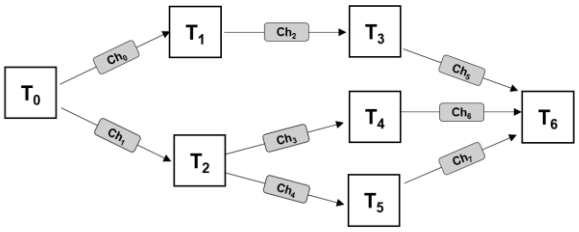

Figure 1 Application model

B. Platform model

The platform is modelled as a directed graph $PG = (P, M, L)$. Node $p \in P$ represents a processing element, node $m \in M$ represents a memory. For every *p*, a set of execution times of each task from *AG* is defined as $T_p = \{T_0, \ldots T_n\}$. If a task cannot be executed on a certain processing element then its execution times is set to infinity. A memory element is characterized by a number of read, write or read-write ports.

Each edge $l \in L$ represents a one-way connection between processing and a memory element. The weight on an edge, given by a weight function:

$$w_l : L \rightarrow \mathbb{R} \quad (2)$$

represents write speed in kBps if the edge is directed from processor to memory given by a function, or read speed in case of opposite direction. Local processor

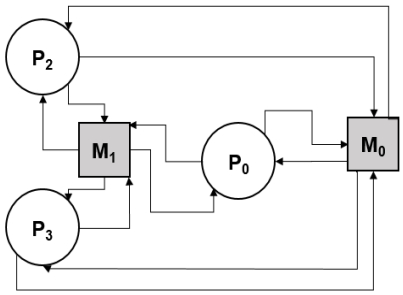

Figure 2 Platform model

memory (i.e. place where instructions and data are stored) is not represented on the graph.

C. Mapping and Schedulling

Given an $AG = (T, Ch)$ and a $PG = (P, M, L)$ a valid mapping is a pair of unique assignments ($m_t : T \rightarrow P$; $m_{Ch} : Ch \rightarrow M$). Mapping process tries to optimize two objectives: total execution time and total elements used. The idea behind a second objective is that having less elements will minimize total cost, energy consumption and improve reliability, although it is done in a very rough sense since there are no exact measures of cost, MTTF etc. The multiobjective optimization problem can be expressed as

$$min\{time(x), elements(x)\}$$
$$(3) minimize\ \{f_1(x), f_2(x), \ldots, f_k(x)\}$$

where *time* and *elements* are conflicting objective functions $f_i : \mathbb{R}^n \rightarrow \mathbb{R}$ to be minimized simultaneously. Objective vectors are images of decision vectors, consist of objective function values and are regarded as optimal if none of their components can be improved without deterioration to at least one of the other components. Because vectors cannot be ordered completely, all the Pareto optimal solutions can be regarded as equally desirable in the mathematical sense and a decision maker is needed to identify the most preferred one among them. An evolutionary algorithm NSGA-II [11] has been chosen for simultaneous optimization of these two objectives. It is one of the popularly used EMO procedures which attempts to find multiple Pareto-optimal solutions in a multiobjective optimization problem and has the following three features:

- uses an elitist principle,
- uses an explicit diversity preserving mechanism, and,
- it emphasizes non-dominated solutions.

In this paper the implementation of NSGA-II provided by MOEA framework [12] has been used. All crossover and mutation operators which support floating-point representation have been used together in combination and their parameters have been set to default values.

Two approaches to mapping have been implemented: (1) *single–phased*, where tasks and communication channels are mapped to processor and memories simultaneously, and (2) *two-phased*, where mapping of tasks to processors is done in first phase, followed by mapping of communication channel to memories in the second phase.

1) Single-phased mapping and scheduling

The chromosome consists of genes which represent tasks and communication channels between in order as illustrated in Figure 3. Each gene is encoded using a floating point representation. The value of a gene which represents a task is the id of a processing element on which it will run. The value of a gene representing a communication channel is the id of a memory element to which it will be mapped. In order to avoid impossible solutions during chromosome decoding, processors are decoded as a number in a list of processors which are able to execute a task and memories as a number in a list of memories which connect two processors. There is a possibility that there are no memories connecting two processors, but in this paper only cases with fully connected platforms have been studied.

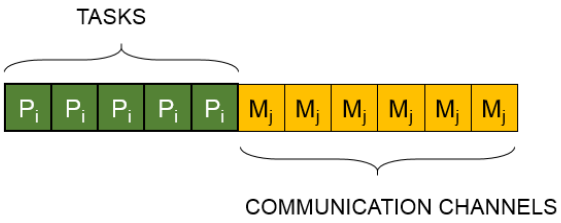

Figure 3 Chromosome structure

In order to calculate total execution time, all tasks must be also scheduled. Scheduling starts with decoding task-to-processor and communication-to-memory mapping. Tasks are ordered according to DAG and one task is scheduled at the time. Scheduling method is based on *slots* which represent a period in time during which a task communicates with other task via memory element – *communication slot,* or a task is executed on a processor – *processing slot.* The time required for communication between two tasks is also considered to be the part of total execution time. Since each task has to first read data written by all of its predecessors, compute its own data and write it in a shared memory for all of its successors, the processing slot will start when the tasks begins to read from memory data written by its first predecessor and last until the task has finished writing data in memory for its last successor. The goal of scheduling is to find free communication slots and processing slots at earliest time possible. During the attempt to find a free processing or communication slot three situations are possible as illustrated in Figure 4. In the first (a), a slot fits perfectly and there is no need for shifting. In the second (b), the memory or processor is not yet free at the desired start time but if a slot is shifted in time then it can fit between existing slots. The last case (c) is when there is not enough space between existing slots, so the new slot must be put at the end, after all other existing slots. The pseudo code of algorithm named *ScheduleTask* which represents the scheduling of each task is given in Figure 5.

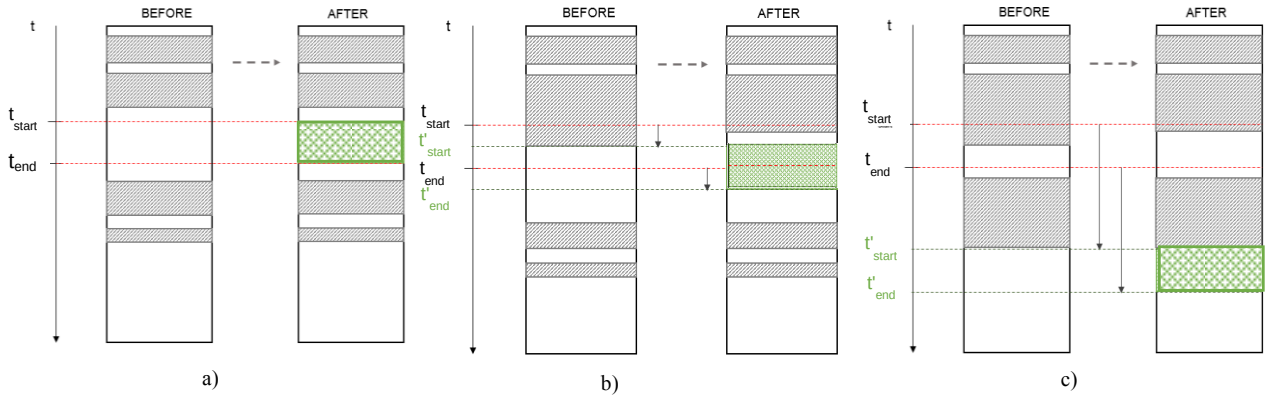

Figure 4 Finding a free slot

Scheduling of each task is an iterative process and it is possible that a schedule cannot be obtained in a single iteration because communication slots start and end times do not match those of a processing slot. In that case, scheduling of a task is reattempted with start time shifted according to earliest possible start of processing unit. The process is repeated until it is successful. In case of a fully connected platform, a feasible schedule is guaranteed, but in case of a sparsely connected platform, there is a possibility that there is no feasible schedule i.e. total execution time is infinity.

2) Two-phased mapping and scheduling

In two-phased mapping method, in the first phase the chromosome only contains genes that represent processors assigned to tasks, and in the second phase the chromosome only contains genes for memories assigned to communication channels. The scheduling algorithm is based on the same principle only this time in the first phase there is no need to have more than one iteration since only processing slots are assigned in that phase. The result of the first phase are mappings of tasks to processors which are analysed in order to find Pareto-optimal solutions. Solutions which form the Pareto front are chosen as the input for the second phase. In the second phase, the same scheduling algorithm is applied as in a single-phased approach.

```
function ScheduleTask(task, currProc, reservedSlots, startTime)
    if startTime == 0.0 then
        slotBeginTime= predecessors(0).endTime
    else
        slotBeginTime = startTime
    end if
    for all task predecessors T_p do ▷ predecessors sorted ascendantly according to finish times
        predProc = decode from chromosome                ▷ processor on which T_p executes
        if predProc! = currProc then
            commonMemoryList = get memories which connect predProc and currProc
            if commonMemoryList! = empty then
                mem = decode from the chromosome          ▷ memory used for communication
                commEndTime = comm. time between task and T_p via mem
                new communication slot(slotBeginTime, commEndTime)
                add slot to reservedSlots
            else
                throw exception ("solution not possible")
            end if
        end if
    end for
    commStartTime = commEndTime + execution time of task on currProc;
    for all task successors T_s do
        nextProc =decode from chromosome                 ▷ processor on which T_s executes
        if currProc! = nextProc then
            commonMemoryList = get memories which connect currProc and nextProc
            if commonMemoryList! = empty then
                mem = decode from the chromosome
                commEndTime = comm. time between task and T_s via mem
                new communication slot(commStartTime, commEndTime)
                add slot to reservedSlots
            else
                throw exception ("solution not possible")
            end if
        end if
    end for
    procSlot = new slot on currProc(slotBeginTime, commEndTime)
    return procSlot
end function
```

Figure 5 Task scheduling algorithm

IV. Experimental Setup

Experiments have been conducted using both artificial and real-world examples. Artificial examples have been taken from [13] and adapted to represent unrelated machine scheduling problems. Four distinct cases named *j301_1*, *j305_4*, *j3010_1* and *j3014_4* have been studied. Each case comprises of 30 tasks ordered in a DAG, with up to 7 tasks in parallel. Each task can be executed on one or more of 4 different types of processors. In case *j301_1* each task can only be executed on a single processor type, in case *j305_4* on 2 or 3 types of processors, in case *j3010_1* on 3 to 4 and in case *j3014_4* each task can be executed on all 4 types. In each case and for each processor type, execution time of each task is also given in advance. Each case has five subcases with different amount of communication between tasks, i.e. communication to computation ratio (CCR): 0.01, 0.1, 1, 5, 10 and 20.

Two different platform models have been developed: *Platform16* - with 16 and *Platform12* - with 12 processing elements. In both models, platform elements are arranged in clusters in such way that each cluster consists of one processor of each type (i.e. 4 processors in each cluster). On *Platform16*, there are 4 clusters, and on *Platform12,* there are 3 clusters. Platform16 contains 5 memory elements, and Platform12 contains 4 elements, one of which has big latency but also a lot of memory space, and the rest have lower latency (by a degree of magnitude) but also less memory space. However, the data size used in communication for all cases never exceeds the size of smaller memories. Each processor is connected to all memory elements on the platform.

Real world examples include JPEG and Ray Tracing

Table 1 PERCENTAGE IN UNIFIED PARETO FRONT

CCR		PLATFORM16				PLATFORM12			
		j301_1	j305_4	j3010_1	j3014_4	j301_1	j305_4	j3010_1	j3014_4
0,01	*single-phased*	66,67%	50,00%	80,00%	34,50%	66,67%	75,00%	85,71%	75,00%
	two-phased	33,33%	50,00%	20,00%	65,50%	33,33%	25,00%	14,29%	25,00%
0,1	*single-phased*	50,00%	50,00%	88,89%	72,73%	83,33%	100,00%	100,00%	85,71%
	two-phased	50,00%	50,00%	11,11%	27,27%	16,67%	0,00%	0,00%	14,29%
0,5	*single-phased*	50,00%	80,00%	100,00%	100,00%	71,43%	100,00%	100,00%	100,00%
	two-phased	50,00%	20,00%	0,00%	0,00%	28,57%	0,00%	0,00%	0,00%
1	*single-phased*	80,00%	100,00%	87,50%	100,00%	85,71%	100,00%	100,00%	100,00%
	two-phased	20,00%	0,00%	12,50%	0,00%	14,29%	0,00%	0,00%	0,00%
5	*single-phased*	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
	two-phased	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
10	*single-phased*	100,00%	100,00%	100,00%	100,00%	87,50%	100,00%	100,00%	100,00%
	two-phased	0,00%	0,00%	0,00%	0,00%	12,50%	0,00%	0,00%	0,00%
20	*single-phased*	83,33%	100,00%	100,00%	100,00%	85,71%	100,00%	100,00%	100,00%
	two-phased	16,67%	0,00%	0,00%	0,00%	14,29%	0,00%	0,00%	0,00%

algorithms and two different heterogeneous multiprocessor platforms: Xilinx ZedBoard Zynq®-7000 All Programmable SoC [14] and Adapteva Parallela III [15]. Zynq platform contains two ARM Cortex A9 processors and ten Microblaze processors implemented on FPGA. All processors are connected to one DDR and three BRAM memories. DDR is about ten times larger and three times slower than BRAM. Parallella platform contains one ARM Cortex A9 processor and 16 MIPS processors which are all interconnected using a shared memory for communication between ARM and MIPS cores, and a local distributed memory for communication between MIPS cores. Shared memory is around 10 times larger and slower the local distributed memories.

JPEG algorithm has been executed for two different picture sizes: 10 and 40 blocks with same block size - 64 pixels. Ray tracing algorithm has been executed for two different block sizes: 80x60 and 40x30 pixels on the same picture size. Each test case has been run 30 times because NSGA-II is a heuristic which can stuck in a local minimum and hence does not always provide same solutions.

V. RESULTS

Obtained results are compared using three common measures in multiobjective optimization 0: percentage of solutions in a unified Pareto front, Inverted Generational Distance (IGD) and Hypervolume (HV). All three measures are calculated by combining the results from both single-phased and two-phased methods, forming a unified Pareto front which contains Pareto optimal solutions from all sets and then comparing Pareto front of individual methods with the unified one. For percentage and HV measures, a higher value is better but for IGD, the lower value is better. Table 1 shows the comparison

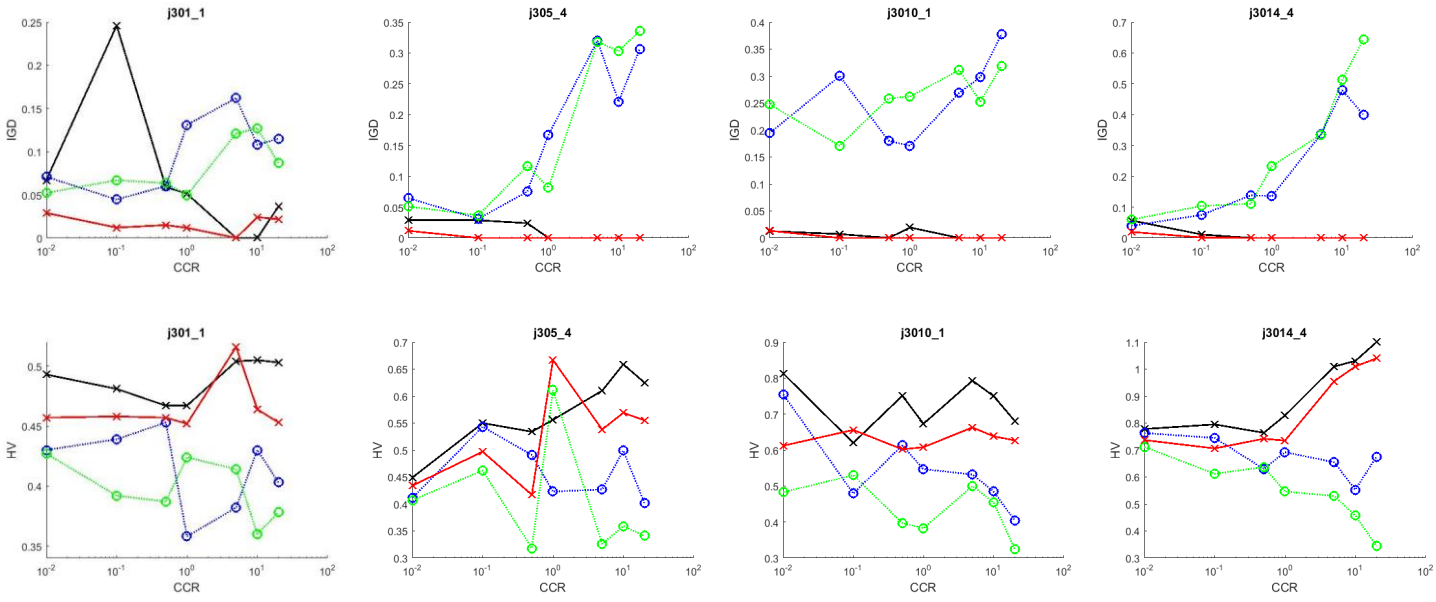

Figure 4 IGD and HV comparison

Table 2 RESULTS FOR REAL-WORLD APPLICATIONS

		JP40	JZ40	JP10	JZ10	RTP40	RTZ40	RTP80	RTZ80
single-phased	*percent in superfront*	71,43%	66,67%	100,00%	100,00%	27,27%	22,22%	50,00%	40,00%
	IGD	1,22E-02	1,09E-02	0,00E+00	0,00E+00	9,67E-03	7,11E-02	1,32E-02	2,57E-02
	HV	1,97E-01	3,77E-01	4,24E-01	8,62E-01	4,26E-01	2,98E-01	9,62E-01	5,06E-01
two-phased	*percent in superfront*	28,57%	33,33%	0,00%	0,00%	72,73%	77,78%	50,00%	60,00%
	IGD	7,77E-02	1,25E-01	3,23E-02	1,26E-01	7,72E-03	3,04E-02	3,03E-04	2,54E-03
	HV	1,97E-01	2,67E-01	4,03E-01	7,77E-01	4,32E-01	3,61E-01	1,02E+00	5,32E-01

of percentage in unified Pareto front for all artificial test cases. Figure 4 shows the comparison of IGD (a) and HV (b).

It can be observed that in most cases a single-phased approach is more successful by all three measures, except in cases when CCR is very low (0.01) and where both methods prove to be equally successful. The probable cause of this is that for low communication overhead, it is more beneficial to first focus on optimizing execution time on processing elements. Case j301_1 is more erratic than other cases, but it is possible that this comes from the fact that in this particular case each task can be mapped to only one out of four processor types and thus finding an optimal mapping scheme for this case is more difficult than for other three cases.

Real-world applications test results are shown in Table 2, confirm these observations. Experiments for JPEG start with letter "J", and for ray tracing start with "RT". The following letter "P" or "Z" denotes whether the experiments were conducted on Zynq or Parallella platform. The number indicates block number for JPEG and block size for ray tracing. Results generally match with observations made on synthetic benchmark. For both applications CCR is rather low: for JPEG with 10 blocks it is around 0.1, and for JPEG with 40 blocks around 0.01. In case of ray tracing it is even lower: around 0.01 for block size 80x60 and close to 0.003 for block size 40x30. As observed in synthetic benchmarks, for higher CCR single-phased mapping gives better results.

VI. CONLUSION

A multiobjective method for memory-aware design space exploration based on NSGA-II evolutionary algorithm has been discussed in this paper. Two approaches to communication-to-memory mapping have been compared and it can be concluded in most cases a single-phased approach is more successful by all measures, except in cases where communication-to-computation ratio is very low (~0.01).

It is important to note that in this work only fully connected platforms were considered. It is suspected that for sparsely connected platforms, design space will contain a lot of infeasible solutions and such a straightforward mapping and chromosome strategy will require certain modifications. This will be considered in future work.

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Gamification in sport – improving motivation for recreational sport

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***Abstract* – Nowadays, people find it difficult to get time and interest for doing sports activities in the form of recreational sport. The main problem is the lack of content which will make these activities more attractive to people. In this paper, gamification principles are used to enhance the experience in those activities. For this purpose, two applications are created which showcase organizing tennis matches, writing results and presenting statistics based on the collected data and comparing it with friends. The aim is to determine if gamification is going to influence positively on peoples' motivation for recreational sports activities.**

Keywords - gamification; game; sport; motivation

I. INTRODUCTION

These days a lot of people are trying to find a game or activity which will relax them during pastime. These activities are not necessarily related to sport, but primarily they belong to that group. When we consider that people nowadays organize everything using applications on their smartphones, we can assume they will also use applications for sporting activities.

In this paper, tennis will be used as an example for real life solutions. Tennis is used as an example because of its simplicity and the fact that many people know basic tennis rules. Also, it is the 4th most popular sport globally and the most popular individual sport [1].

Available solutions that currently exist on the market are used only for organizing sporting events or for tracking sporting results, but there isn't a known solution for combining those two elements in a unique form of experience. „Tennis Buddy“ is an application for organizing tennis matches and finding players by certain criteria [2]. „tennisTOUCH“ is an application for tracking results in tennis matches [3]. In this paper, certain elements of the gamified system which don't exist will be provided.

For clarity, a solution that will be provided is focused on recreational sport only. So, a lot of components used here exist in professional or amateur sport meaning that the ideas for some solutions came from mentioned types of sport, but they are simplified to be more user-friendly.

II. GAMIFICATION AND MOTIVATION

Earlier was mentioned that gamification elements are going to motivate users more than other applications could. These elements, as well as gamification itself, will be defined here and also, motivation in the sport will be explained in theory.

A. Gamification

Gamification is the use of game design elements within non-game context [4]. Authors see gamification as an innovative and promising concept that can be applied to a variety of contexts [5]. The term gamification appears in the early 2000s [6]. Global companies increased attention to the gamification since the beginning of the 2010s when the term started to be used in conferences around the world [7].

Some of the contexts in which gamification has previously been successfully implemented include the following: marketing [8], crowdsourcing [9], social networks [10], and healthcare [11]. Within all these contexts, it is expected that gamification can foster the motivation of the individual to achieve their goal [12].

Gamification elements are divided into three categories [5]:

- Components
- Mechanics
- Dynamics

Components are base elements which are used for every other high-level element. The main components are [5]:

- Points
- Badges
- Leaderboards

Players are collecting points for every achievement in the game. Points are measurable, so they are used for showing player's progress. They give feedback to the player, as well as the designer of the game who can improve the game by tracking the distribution of points.

Badges are a representation of achievements in the game. They can be earned by collecting a target number of points or by other achievements. Badges are visual components which have a message in their design.

Leaderboards are also a visual representation of achievements, but they can also show a player's position compared to the other players. On the leaderboards the player can see all the points, so he can calculate how much points he needs to be ahead of his opponent.

Mechanics are more high-level elements in the game which are action oriented. Known mechanics are [5]:

- Challenges

- Competition
- Feedback

Challenges define aims for the player so that he can make progress in the game. The ultimate goal of the competition is to win and earn a prize. Feedback is important for the player to be aware of the progress and to know who the winner of the game is.

Dynamics are the most high-level elements in the game responsible for enhancing enjoyment in the games. The main dynamics are [5]:

- Progression
- Relationships

Progression refers to the path from the starting point of the game to the final point. Relationships refer to the possibility of becoming friends with other players and also it refers to a possibility of competing with those players.

In this paper, the emphasis is on organizing sports events and tracking results using game elements described in this section.

B. *Motivation in sport*

Motivation refers to the causes of human behavior. Motivation directs an individual toward achieving his or her goal. In sport there are three different approaches to motivation [13]:

- Individual factors
- Situational factors
- The interaction between individual and situational factors

Individual factors are focused on needs, interests, and aims of players. They define how much a player is interested in some form of activity and if there is a need for that. These individual factors are used for showing preferences. Some people like activities with contact (e.g. soccer) and some activities without contact (e.g. tennis).

Situational factors define coaching style, possibilities which come from playing a chosen sport, wins and losses ratio. When we talk about possibilities, they can be observed through the possibility of participating in tournaments, winning prizes and acknowledgments for successful achievements.

The interaction between individual and situational factors leads us to one hybrid factor which defines the most realistic motivation for athletes. This means that player enters every sporting event with his individual preferences. Example for this can be seen in the research of sports students' motivation for participating in table tennis at the Faculty of Kinesiology in Zagreb [14].

When we look at motivation in a sport by using self-determination theory, we have to consider two types [15]:

- Intrinsic motivation
- Extrinsic motivation

Intrinsic motivation refers to the inner satisfaction. It is not measurable. In this type of motivation, we can strive for knowledge, achievements and stimulus experience.

Extrinsic motivation refers to the external goal. These are material things like money, medals and other kinds of tangible assets. External motivation, unlike internal motivation, is a short-term motivation because it does not satisfy as much as internal motivation does.

III. RESEARCH OF RECREATIONAL TENNIS ACTIVITIES

Recreational sport is a sports activity in which the main goal is to entertain a player so that he returns to that activity because it was joyful and relaxing.

For this paper research was done to find out if there is a need for enhancing the creation and tracking for organizing and playing tennis matches. The gamified system was used for three months and the research was conducted on the same group of people to see if there are some concrete benefits of using a new approach to improve tracking and organizing tennis matches. It should be noted that the research is focused on tennis and it doesn't include other sports activities.

The target group are employees of the Ericsson Nikola Tesla company. A lot of these employees are involved in some sort of recreational sports activities, so this should be a good sample for research. The subjects of this research are 200 Ericsson's employees. The results of the three asked questions which are focused on the current satisfaction and potential future improvements will be presented. After that, the results of the two more questions will be presented which refer to users' feedback after using gamification.

A. *Playing tennis before gamification*

The first question is very simple and is trying to find out how many people are already playing tennis. Possible answers are „Yes“ and „No“. Figure 1 shows that 22% of respondents are already playing tennis.

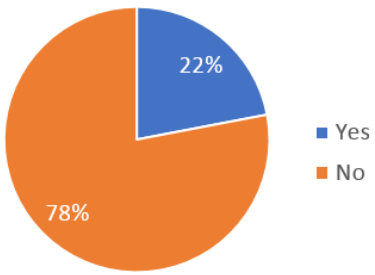

Figure 1. Percentage of people playing tennis before gamification

B. *Satisfaction with tennis organization before gamification*

The second question is focused on satisfaction with current organization of tennis matches. There are five possible answers from „very dissatisfied“ to „very satisfied“. Figure 2 shows the result of this question. On the X-axis of this chart are marked levels of satisfaction and on the Y axis are marked numbers of respondents. It is visible that only 18% of respondents (marked as “4“ and “5“ on Y-axis) are satisfied with the organization of tennis matches.

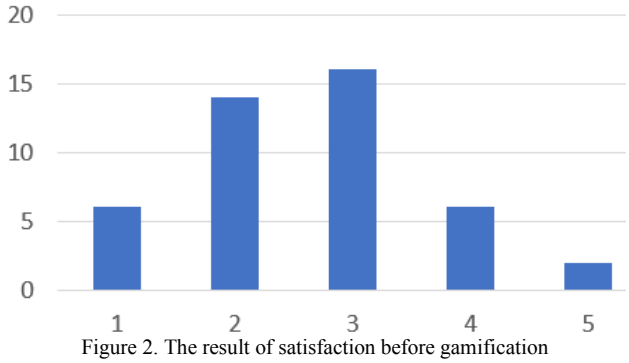

Figure 2. The result of satisfaction before gamification

C. *Tracking results using modern applications will cause more involvement in playing tennis*

The third question is trying to find out if respondents think that using modern mobile and web applications for tracking their tennis results will manifest in a way that more of them will be playing tennis in the future. Possible answers are „Yes“ and „No“. Figure 3 shows the result of this question on a chart where it can be seen that 54% of respondents think that using those applications will affect positively on them to play tennis in the future.

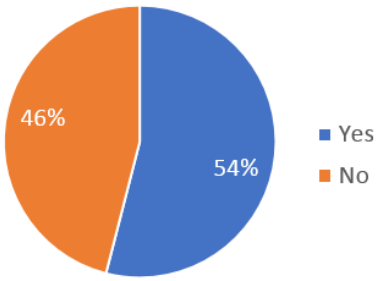

Figure 3. Percentage of people wanted to play using gamification

D. *Playing tennis after gamification*

The fourth question is the same as the first question described in the subsection A, but it is asked after using gamification for three months. Figure 4 shows that 36% of respondents are playing tennis now. It can be interpreted as a positive trend for people playing tennis.

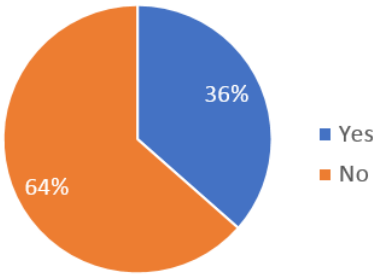

Figure 4. Percentage of people playing tennis after gamification

E. *Satisfaction with tennis organization after gamification*

In the last question, the users are questioned about their satisfaction level as they were in the second question described in the subsection B. Figure 5 shows that after using gamification for three months, 43% of respondents are satisfied with the organization of tennis matches. It is a big step forward regarding the results collected before using gamification.

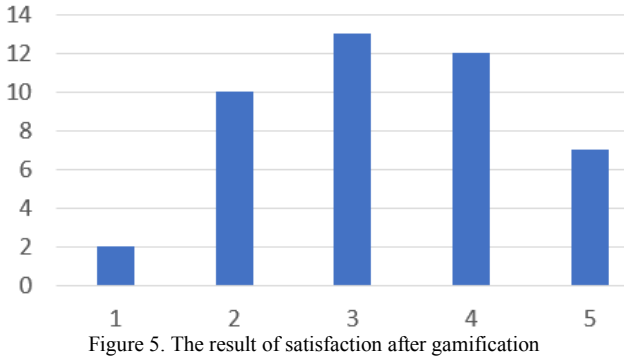

Figure 5. The result of satisfaction after gamification

IV. SOLUTION IMPLEMENTATION

After theoretical background considering this problem, a solution containing two client-side applications and one server-side application will be explained here. The solution combines all gamification elements listed in this paper.

A. *Technologies and user experience*

For server-side application ASP.NET Web API 2 Microsoft's framework is used. It is used for creating the RESTful type of application. It contains endpoints which are used for serving requested data and writing new data into Microsoft's SQL Server database.

The client side of this solution consists of one mobile application for Google's Android platform and one web application created in Facebook's library React. Both applications are using API calls to achieve communication with previously explained Web server [16].

For the design of client applications, Google's Material design principles are used. This is a common solution for today's applications and because of that, it is decided to be used for this solution. People are used to it and they are feeling comfortable in that user experience.

B. *Mobile client application*

The mobile application is used for organizing tennis matches and collecting data about played matches. It is designed to be used on the go, so the user interface is simple and intuitive. The mobile application has following functionalities:

- Sign up and sign in
- View and edit of personal information
- Searching players
- Making friendships
- Organizing, editing, and searching matches

The user has to be logged into the system to use it. It has to provide personal information which is helpful for other players to be able to find the desired opponent.

Figure 6 shows the screen in Android application for searching players by provided filters. Filters are city, gender, and skill. Every filter can be omitted. You can request friendship with target player or request a match with that player.

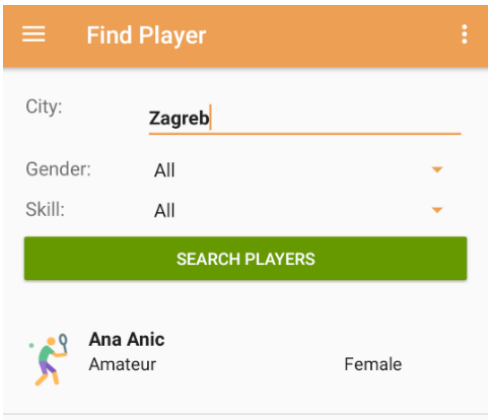

Figure 6. Find a player in mobile application

Figure 7 shows the screen in Android application for creating or editing a match. A player can pick a city, date and time. After the match, they can also write in their result. In the end, they can rate the match by giving it up to five stars and they can also comment on the match. The result is important parameter because it is used in further analysis of the played matches.

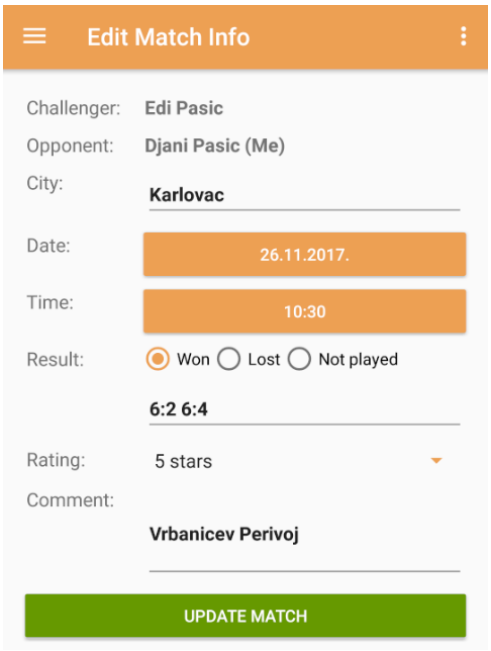

Figure 7. Edit match in mobile application

C. *Web client application*

The web application is used for an overview of results and comparing them with friends. Unlike a mobile application, this one is designed to be used on a bigger screen where it's easier to view the charts with statistics. This application is focused on three main gamification components. It has following functionalities:

- Sign in
- View of profile
- Comparing with friend
- Leaderboards with points and wins

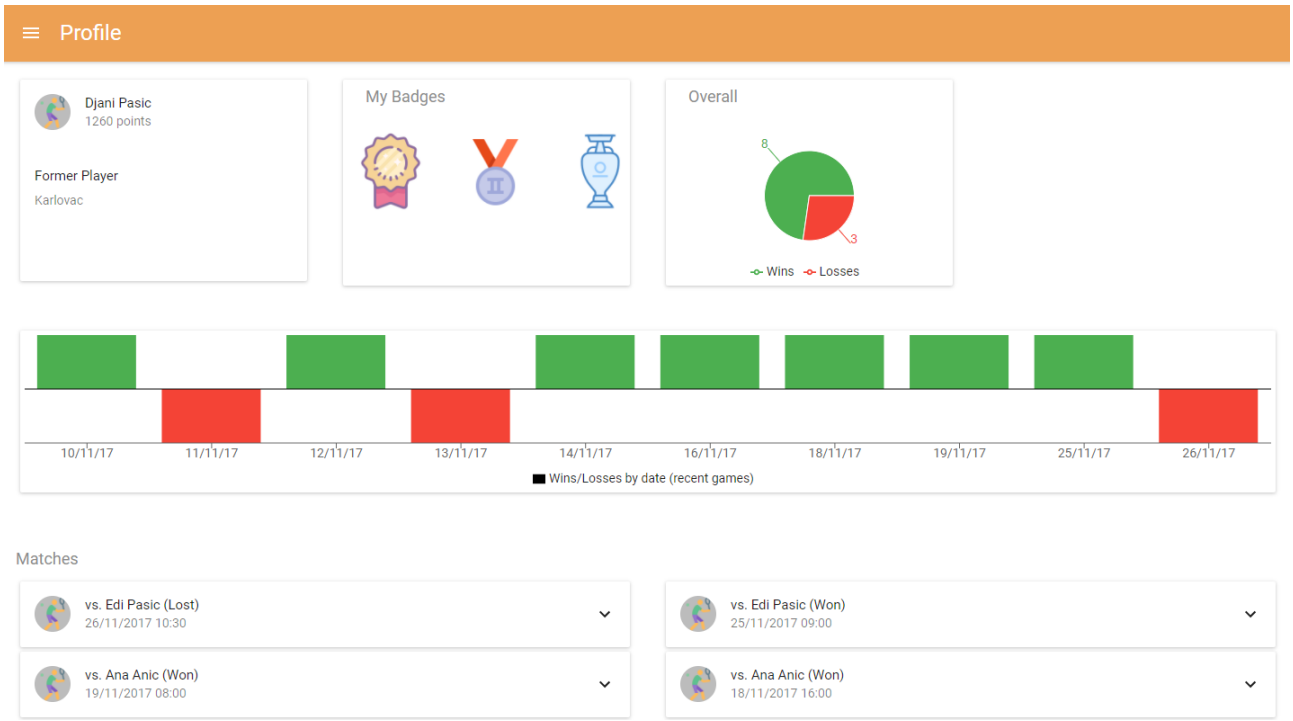

Figure 8. Profile in web application

After the user is logged in, he can view his profile, compare it with friends and see the leaderboards. Figure 7 shows a profile in React web application. There a participant can see basic player information, his badges, overall wins and losses ratio on the pie chart, results of the last ten matches on the bar chart and preview of all of the matches.

Comparing matches with friends has similar screen design as player's profile. The difference is that in the screen section for comparing matches you have to select a friend with whom you want to compare the results with and show data to and that information is only visible to the two comparing players.

Leaderboards screen is presenting the most successful players by showing points and wins and each player can see in which place they are in regardless of their ranking on the board.

V. CONCLUSION AND FUTURE WORKS

This paper describes a solution which improves motivation of individuals for recreational sport by using gamification elements. Research has shown that people think this approach is going to motivate them to start playing tennis and to play longer. The second part of the research shows a positive trend of employees playing tennis during their pastime, and their satisfaction with the organization of that events after using gamified applications for three months. The research was done in wintertime while there are a few global tennis events, so it can be assumed that the target group isn't necessarily motivated to be involved in tennis, so we can say that this system is mostly responsible for motivating the target group or employees to play tennis more.

This solution can be taken as a prototype for a more generic system which will be able to handle all popular sports. Furthermore, it can be integrated with existing systems responsible for booking sports' objects. Also, in the booking system, the data could be used to implement its valuable information with a gamified system which can then improve the connection between the players.

Additionally, the solution can be implemented for all mobile platforms (including iOS), as well as applications for smartwatches which can be used for accepting friendships and matches' requests.

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LoRa - A Survey of Recent Research Trends

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***Abstract* - Nowadays the Internet of Things (IoT) is one of the most promising application areas in information technology for future products and services. Therefore, it is not surprising that new technologies arise, which are marketed as "the most useful technology" for applications in IoT devices. In this study, we focus on the new communication technology called LoRaWAN. Our aim is to evaluate the usefulness of LoRaWAN technology in the field of IoT, and especially in sensor network solutions. The research methodology is a literature survey and primary articles were selected by means of a systematic literature review. More than fifty suitable research papers were identified. From these, the following research questions were formulated: "How to categorize LoRa research papers?" and "What are the application trends in LoRa?" This study presents a way to categorize research papers with diverse themes. In addition, this survey reveals the most recent trends in research and practical applications of LoRa. Finally, this study will give recommendations for researchers and practitioners on how the advantages of LoRa-based technologies could be fully exploited in the development of IoT systems and solutions.**

Keywords - Internet of Things (IoT), Wireless Sensor Networks (WSN), LoRa, LoRaWAN

I. INTRODUCTION

Wireless Sensor Networks (WSN) have developed at a fast pace in recent years and have also been one of the major focuses of research in wireless technology. This rapid development has been facilitated by the evolution of electronics miniaturization, growth in performance, wireless technologies, energy efficiency, and the development of protocols. The sensors that collect environmental information from the surroundings have been miniaturized thanks to the fast performance, optimization, and miniaturization technology of the hardware. The developments of new wireless communication technologies and falling prices have enabled brand-new uses for wireless sensor network devices.

This study is part of the WSN research series. Our former studies [1-4] focused on different topics under WSN. The present studies are performed in collaboration between the Tampere University of Technology in Finland and Keio University in Japan. The aim of this research is to be a review of LoRa studies.

This study introduces one Low Power Wide Area Network (LPWAN) technology – LoRa®. This technology is a rising technology for the transfer of data in implementing sensor network solutions for sensor data collection and transmission from end nodes to base stations. The objective of this study was to find out the usage of this new technology by mapping the current state of the art in the use of LoRa. During this research we first defined the research questions that we wished to resolve. Thus, we sought answers to the following research questions:

RQ1: How to categorize LoRa research papers?

RQ2: What are the application trends in LoRa?

To answer these questions, we performed a comprehensive literature study. We used the Systematic Literature Review approach (SLR) [5] to collect primary studies regarding this research scope. The main phase was to classify the papers and the selected primary studies were then analyzed and categorized using the content analysis method. The results of the classification were five main categories: Analysis, survey and factual discussion, Performance and technical evaluation, Real deployments with prototypes, Simulation, and finally Applications.

The structure of this paper is as follows: In Section II, we review LoRa technology and its main features. In Section III, we introduce the research approach used in this literature study. In Section IV, we present the analysis of the findings and categorization of studies. Section V includes a discussion and suggestions for future research on the topic and finally, Section VI summarizes the study.

II. LORA TECHNOLOGY

In this section, we present the basic concepts of LPWAN, LoRaWAN, and LoRa technologies followed by an introduction to the LoRa and LoRaWAN systems. This technical section is based mostly on "A technical overview of LoRa ® and LoRaWAN ™" [6].

LPWAN are designed to allow wide-area connectivity for low power at a low bit rate [7]. These features meet the requirements of Internet of Things (IoT) applications, such as sensor nodes that work with batteries. The common LPWAN technologies include LoRa/LoRaWAN, Sigfox, and NB-IoT. Fig. 1 characterizes the typical parts and architecture of an LPWAN network. The sensor nodes, an edge node or an end node, collect one or more

measured values and then send the data to the base station. The base station transmits the data through the backhaul gateway to some Internet cloud service. The end user or clients can use the collected data from cloud services.

The advantage of LoRa lies in the technology's long-range capability. A single base station can cover hundreds of square kilometers, but the range is highly dependent on the environment or obstructions.

LoRa modulation is based on spread spectrum techniques and a variation of the chirp spread spectrum (CSS) with integrated forward error correction (FEC). It operates in the lower Industrial, Scientific, and Medical (ISM) bandwidths (USA: 915MHz, EU: 433MHz and 868MHz). The LoRa modulation can be utilized by many different protocol architectures such as Star, Mesh, and 6lowPAN. Furthermore, the LoRa Alliance has standardized the MAC protocol called LoRaWAN. LoRaWAN (Fig. 2) defines the communication protocol and system architecture for the network while the LoRa physical layer enables the long-range communication link. The edge nodes of the LoRaWAN network can transfer data to multiple base stations. LoRaWAN is an open standard governed by the LoRa Alliance and the first version, 1.0, of the LoRaWAN specification was released in June 2015. Version 1.1 of the LoRaWAN specification was published in 2017.

LoRaWAN ensures data rates from 0.3 kbps up to 50 kbps, which are considered acceptable for transmitting real-time sensor data in the IoT, Machine-to-Machine (M2M), smart city, and industrial applications. However, transmission of real-time image data, or anything that requires high bandwidth, that may not be suitable on LoRa networks. This low data rate ensures the low power consumption of the edge node devices, therefore enabling the usage of battery for a seamless deployment.

Edge node devices can be configured with different features. LoRaWAN defines three classes of devices. These device classes can negotiate network downlink communication latency versus the battery lifetime. These classes are shown in Fig. 2 and, depending on the application needs, A, B, or C class can be chosen.

Battery-powered devices in "Class A" are intended for low powered devices such as sensors. These are the most energy efficient class but have the biggest latency time. It also includes devices that do not need to transmit data all the time. All the LoRaWAN-capable devices must support the functionalities of this class.

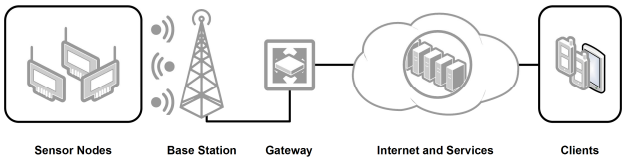

Figure 1. The communication protocol and system architecture of LoRaWAN [6].

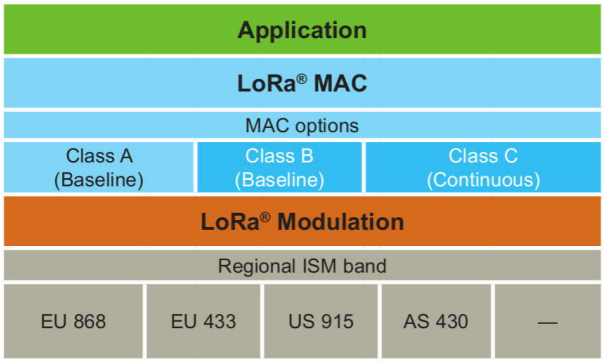

Figure 2. The communication protocol and system architecture of LoRaWAN [6].

The B Class is focused on battery-powered devices, such as actuators and sensors. These are energy efficient but with a latency-controlled downlink. The communication is slotted, synchronized by an external beacon, which allows the server to know when the end device is listening.

The C Class is used by bi-directional end devices with maximal receive slots. The end devices of Class C have almost continuously open receive windows, which are only closed when transmitting. These devices should be used with external power source, are capable of listening to the air interface the whole time, registering no latency over the receive or transmit mode.

LoRaWAN network protocol security is based on IEEE 802.15.4, and is also extended by using two session keys: a network session key and an application session key. Each LoRaWAN edge node device also has its own 128-bit AES key, known as the AppKey.

III. Research Approach

The above-mentioned research questions, RQ1 and RQ2, were formulated when we studied the targets of this research. To answer these research questions, we decided to perform a literature study in order to map the extant knowledge on this domain. We decided to use the SLR method to collect the relevant primary studies and followed the guidelines given by Kitchenham and Charters [5].

For the SLR, we decided to do an electronic search. The databases used were IEEE Xplore Digital Library (IEEE), Multidisciplinary Digital Publishing Institute (MDPI), Association for Computing Machinery Digital library (ACM), ScienceDirect, and others (Google Scholar and similar). All of these databases: IEEE, MDPI, ACM, and ScienceDirect, have their own search engine, but we also used the Google Scholar search engine, the results of which are under the heading "Others", unless the result directed us to databases mentioned before. The survey was started by selecting the main search term: "LoRa". The second search term was "IoT," "LPWAN," or Wireless Sensor Networks." So, the search sentence was: ("LoRa" AND "IoT") OR ("LoRa" AND "LPWAN") OR ("LoRa" AND "Wireless Sensor Networks"). We decided to use these simple keywords in order to obtain good coverage of potential primary studies. The targeted amount of related

studies was about fifty, because this amount would give us enough information for categorization and research trends.

In the second phase, we created several reasonable categories and classified the papers into those categories. The reason for this classification was that most of the papers published were relatively distinctive in terms of the research objective, methodology, and application. For the sake of simplicity, we created five categories of papers without ignoring the variations of themes. This way, we systematically examined the details of research papers that fell under the same category whereas too many categories would have made it difficult to compare the trends or research methodology logically. In this phase, we also made a selection of studies so that no single category became too dominant. The total number of suitable papers collected was 54. Please note that some of the papers could be classified into more than one category.

The research categories, and the total number of selected studies are as follows:

- Analysis / Survey / Factual Discussion – 7 papers
- Performance / Technical Evaluation – 29 papers
- Real Deployment / Experimental / Prototype Implementation – 37 papers
- Simulation / Modeling / Networking Stack / Software – 8 papers
- Applications – 20

In the remaining sections of this paper, we will first present the categorization of key studies (in Section IV). This is followed by a discussion section where the presented research questions will be answered.

IV. RESULTS

This section describes the relevant characteristics of each category. The next subsections present all five main categories. At first there is short description of the category followed by a discussion of relevant papers and findings from them. Some of the selected studies have a wider content and therefore the [8-11] studies were classified into three or more categories. The structure of these frequently occurring papers is first, the required technology of the application system is explained, then the system is designed and realized. Finally, the study presents the efficiency tests of the application.

These studies were selected because of the use of LoRa technology. During the processing, we tried to find the answer to a further question – Is LoRa the only possible technology to use? In some cases, the usage of LoRa is not the main focus of the study. There might also have been some other technology instead of LoRa. Because there are several possible technologies, the main result from these categories may also be the answer to the question: When to use LoRa?

A. Analysis/Survey/Factual Discussion

This category consists of research studies where the main part of research is the introduction of LoRa or LoRaWAN technology. In addition, these studies handled technology-based issues such as architecture and protocols, the functional components of the technology, the performance of the technology, and the security issues such as possible vulnerabilities. Most of the research studies also included a comparison with similar technologies.

The studies [8, 12-17] commonly highlight the general background of LoRa technology. These technology reviews summarize the A, B, and C classes of LoRa devices, the LoRa network architecture, and the LoRa network protocol stack.

Moreover, in [13], LoRa technology was compared exhaustively with other LPWAN technologies in terms of architecture, battery lifetime, network capacity, device classes, and security, where the LoRaWAN protocol is 3 to 5-fold more advantageous than Sigfox, NB-IoT, and LTE-M. In a more explicit survey, [16] provides a comparative analysis on LoRa and NB-IoT, claiming that there is no LPWAN technology that fits all requirements, but both LoRa and NB-IoT could be advantageous based on their appropriateness to the system requirements and features they could offer. This analysis shows that unlicensed LoRa has advantages with regard to the battery lifetime, capacity, and cost while the licensed NB-IoT offers advantages in terms of Quality of Service (QoS), latency, reliability, and range.

Interestingly, the security issues in LoRa were mentioned repeatedly in several studies, even though LoRa provides two layers of security, one for the network and another for the applications [12, 13]. The study performed by [14] investigates the potential security vulnerabilities in LoRa by analyzing the LoRa network stack and shows the possible susceptibility of LoRa devices to various malicious attacks. For instance, the analysis demonstrates that, simply by using a commercial off-the-shelf LoRa device, the physical layer can be vulnerable to interference due to the similar frequency and the spreading factor, which may expose the LoRa network to jamming attacks.

B. Performance/Technical Evaluation

This category deals with the wide variation of performance testing in which most studies present the real deployment of LoRa in a test environment. LoRa technology was mostly the key technology in the experiment. Typically, the study used LoRa technology to test some technological features, for example, the scalability of the network was tested in many studies [10, 18, 19] and the QoS was tested with prototypes in two studies [20, 21].

This category also includes several studies focused on testing the suitability of LoRa together with some other technology. These kinds of tests presented LoRa together with the Distribution Management System (DMS) [22], and with i-Car data gathering from the vehicle diagnostic system [23]. LoRa signal propagation was tested indoors [24, 25] and outdoors [26-28]. Mostly these were measured using the packet delivery ratio. Also, the issues of signal interference in LoRa within license-free ISM radio bands were discussed [11, 19, 29].

C. Real Deployment/Experimental/Prototype Implementation

This category consists of the wide variation of prototypes used by LoRa technology. The main idea of the category is that some kind of device has been built and used to collect research-related data. These studies present the deployments of LoRa or LoRaWAN implemented for an application of IoT in different kinds of systems. Mostly this application collected environmental sensor data [30-33]. Tracking applications were also presented [27, 32, 34, 35]. This category includes a few industry-specific prototype demonstrations such as a low-cost device for fault location in Medium Voltage power cables [36]. The reasons why LoRa technology was selected were low power devices with batteries or solar power [30, 37]. The most commonly used hardware was Semtech LoRa module with Arduino or Raspberry Pi.

D. Simulation/Modeling/Networking Stack/Software

This category handles Simulation/Modeling/ Networking stacks/Software. The most commonly used research method was simulation when one or more LoRa technology issues were tested. Normally, the actual device deployment was not fully implemented in this category. Typical simulation test cases were tests where a large amount of simulated devices and connections were tested with some program. Modeling used the same technique. Some of the network configurations were modeled by software without any real devices. Research related to networking stacks typically used the network protocol and included some special software combination which was tested or simulated.

The simulation research studies [11, 18] simulated the presence of a number of end devices. Likewise, [10] simulated the count and diameter of end devices where the coverage of probability dropped when using the same spreading sequence.

E. Application

Under the category of applications, we tried to identify the trends and variations of LoRa applied in real settings. Despite the various thematic applications, many targeted applications aimed to use LoRa as a long-range communication interface for real time monitoring.

Reference [38] used LoRa in their plug and play platform for monitoring the temperature of the blood fridges at a provincial center coordinating a blood transfusion service. Another healthcare application was described in [25]. In contrast, [39] used LoRa for a sensor node powered by vibration from an electromechanical energy harvester on a real bridge to monitor road conditions, such as the temperature of the asphalt and the presence of water or rain. Reference [40] aimed to monitor and control the temperature and humidity of different rooms, with the aim of reducing costs related to heating ventilation and air conditioning. Meanwhile, [30] presented real-time air quality monitoring using various gas sensors.

In references [31, 33], LoRa was used in sensor nodes to detect and prevent a destructive landslide. In a similar way but in a unique application, LoRa has been used to monitor the environment of sea and sailboats, including the speed and direction of wind and current, the location and orientation of the sailboat for sailing sports and races [32]. Reference [35] demonstrated a method of using LoRa for geo-location tracking without requiring GPS. Even though the specific target to be tracked was not clearly demonstrated, it showed great potential for various geo-location tracking applications, such as tracking animals or elderly people. Reference [27] demonstrated a whole object tracking system where the majority of components were implemented: the tracking device communicated with the gateway device using LoRa; the tracking data was collected in the database server, and users had an application for retrieving the data from the server. Reference [23] used LoRa in gateways targeting a vehicle diagnostic system for driving safety.

We found that LoRa has great potential for deployment in a physical environment both indoors and outdoors, whether as the interface for sensor nodes or the gateway. The results of this survey prove the universal application prospects of LoRa. Applications are diverse, ranging from monitoring in healthcare, tracking, environmental monitoring, to structural health monitoring.

V. DISCUSSION

The aim of this study was to evaluate the current state of the art in the use of LoRa-based technologies. The analysis is based on the collection of LoRa-related studies. The amount of studies was large, and the size of this study was limited. The amount was so large that some of the references were only mentioned in passing. However, the conclusion is that this collection of studies has potential for a more comprehensive analysis. This study shows that there are significant different ways to benefit from LoRa technology.

There are several key points peculiar to the LoRa wireless system. This literature review brings out the main benefits of using LoRa technology, namely the long-range communication from 10 to 15 kilometers in an outdoor environment, and the very low power consumption that enables the use of batteries. Of course, these features have a trade-off with other performance factors such as data throughput, which is low compared to, for example, Wifi or Global System for Mobile Communications (GSM) networks. Several studies show that there are still issues surrounding the practical security aspect of using LoRa. Several studies also simulate the limitation of the count of LoRa nodes. They show that one base station could handle a thousand nodes without significant problems related to reliability, such as collisions.

Based on our survey, the papers reviewed under category A provide a useful review for researchers and developers before adopting LoRa in their system by understanding how LoRa technology differs from legacy technology. This provides practical guidelines on deciding whether it perfectly matches the requirements of the proposed IoT system or not while recognizing future assessments in security.

From the survey of papers under category B, some papers present the common objectives of experimental evaluation using various LoRA devices. Most of the

research work adopted the experimental evaluation method. Reports from these studies provide a reliable empirical basis of LoRaWAN performance, especially on how LoRa works in a real environment and how various environmental factors affect its performance. This constitutes a significant preparation toward real implementation.

Meanwhile, papers in category C demonstrate the real implementation of prototypes using LoRa. All this research could provide insights on developing a real IoT system based on LoRa, especially on how LoRa works as a prototype in various applications under various conditions.

In category D, even though most of the research studies do not involve the deployment of real LoRa devices, there are many research problems related to large-scale networks that require research methodology based on simulation and modeling, as well as software. For instance, research on dense LoRa networks or the remote control of a LoRa device based on a Software Defined Network (SDN) may be interesting research topics.

The classification of studies in the application areas in category E gives us more insight into the diversity of LoRa applications and the trends of the future research direction. Smart city applications through real time monitoring of environmental and structural parameters or tracking have been highly attractive to date. These applications might be interesting for future research because there was a wide variation in smart city prototype studies. During this study, we observed 12 monitoring/tracking and 8 smart city papers which are included in the source material of this study. This is quite a significant amount. We also believe that there are more prototype projects using LoRa that remain unreported or ongoing.

As far as future work is concerned, we will exploit the results of this survey to devise new research studies with the aim of more practical IoT solutions using LoRa technology. Now that the research and technological bases have been clarified, we can continue to develop devices and systems that use these findings. The results of the RQs raised several new research topic ideas, one of which is sound volume measurement. During Pori Jazz, an international music festival held in the Satakunta region, it would be interesting to measure the sound volume from different places. The main idea is to test the suitability of LoRaWAN technology to transfer measurement data. In addition, because the LoRa technology has no significant limit regarding the count of sensor nodes, it would be interesting to deploy a low-cost distributed sensor network around the area of the Pori Jazz festival.

VI. SUMMARY

In this survey paper, we presented a comprehensive review on the most recent trends in the research and practical applications of LoRa technology. We systematically reviewed the most recent research papers related to LoRa covering a wide variety of research themes, objectives, and methodology and proposed a new method of classifying the research papers into several categories.

Based on the number of publications in each category, we can see that the recent research trends in relation to LoRa concern performance and technical evaluation, as well as real deployments through prototype implementation and experiments with LoRa technology. It could be stated that, currently, research on the technical evaluation and real deployment of LoRa is a hot research trend. This might be due to the high demand for real implementation of LoRa in various IoT projects. However, we also recognize the importance of the simulation/modeling/networking stack and software-based research related to LoRa. We expect that research in this direction will gain much more attention in the near future since the implementation of IoT systems not only involves the networking of LoRa, but an end-to-end system development up to the application layer, involving LoRa as one of the major networking elements in the IoT ecosystem.

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Low-cost ultrasound measurement system for accurate detection of container utilization rate

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***Abstract* - The increase in the availability of low-cost components has made it possible to design and implement new and innovative devices for the Internet of Things (IoT). Today, cost-effective and open solutions can be created to replace previous expensive and proprietary measurement systems. This study presents the prototype of an ultrasound measurement system. The purpose of the system was to make the surveillance process of waste management containers more effective and reliable. The system was built using commonly available sensor components in combination with a microcontroller, and the collected data was stored and analyzed in a cloud service. The configuration of the ultrasound measurement system is introduced in this study. The measurement results obtained from the tests performed in the actual operating environment are also presented. Based on these tests, the accuracy of the system was observed to be well-suited for the use case. The average systematic error of the results was -2.0 mm and the average of random error was within 0.9 mm.**

I. INTRODUCTION

The Internet of Things (IoT) is the expansion of Internet services, which connects everyday physical objects to a network. This connection between network and physical objects makes it possible to access remote sensor data and to control the physical world from a distance. The first mention of the term 'IoT' is said to have come from Kevin Ashton in 1999. A survey of the areas covered by the IoT was made by Atzori, Iera and Morabito [1].

Sensor networks are a highly researched application area in the field of the IoT. A key cost and resource factor in the development of IoT network sensor solutions is prototype implementation.

This study originated from the need for a waste management company to obtain information on the accurate utilization rate of its containers. Previously, the staff needed to check the utilization rate by visiting the site. The aim was to develop this process so that the surface level of the containers could be monitored via a cloud service.

When mapping the different measurement methods, the ultrasound technique was found to be more suitable for measuring the surface level than, for example, laser or infrared techniques. The use of ultrasound was considered more practical because the company prefers a system that does not require a contact or counterpart inside the waste container.

Ultrasound-based sensors are commonly used in the industrial, medical, and service sectors. Ultrasound sensors work above the human hearing range. The most common way to form and detect ultrasound waves is to utilize the piezoelectric phenomenon of some crystalline material, such as quartz. [2] When measuring distance, the ultrasound sensor transmits longitudinal sound waves toward the target by the pulse-echo method. The beam of the sound wave is conical and only objects within it are detected.

Distance measurements with an ultrasound sensor are based on transducer technology. The time spent by the ultrasound pulse traveling from its source to the measurement object and back to the sensor is directly proportional to the distance of the object. Temperature is the most important of the environmental factors that affect the propagation of ultrasound waves. A one-degree rise in temperature increases the sound speed by 0.607 meters per second. In warm air, the measurement result is smaller than in cold air. [3]

The aim of the study was to create a reliable ultrasound measurement system prototype based on open source and low-cost components. The prototype was expected to be able to measure within a margin of error (10 mm) given by the company. The design of the prototype largely takes advantage of the solutions created by the open source community and the literature in the field. The study does not take a stand on the cloud service, the enclosure of the measuring system, nor its installation in the test location.

Earlier studies are presented in Section II. Section III includes the practical part of the study, which consists of the requirements, design and implementation of the ultrasound measurement system and the system model, components and their features, and the connections between them. Section IV analyzes the measurement results produced by the system. Section V includes discussion and suggestions for future research on the topic. Section VI summarizes the study.

II. BACKGROUND

In the scope of this paper, 'Sensor networks' refer to distributed autonomous sensors that are used to monitor the physical environment, e.g., temperature or pressure. Sensor networks are a widely studied area. For example, the use of embedded Linux for sensor networks has been proposed [4] and a simple model of a sensor network has been introduced earlier [5]. There has also been research on long-range wireless sensor networks with geolocation tracking [6] and on a low energy algorithm for a sensor network [7]. Sensor networks have several development possibilities such as the one introduced in the Fog Gateway [8] study.

Earlier research by other authors related to this topic was searched mainly using Google Scholar, Scienceport [9] and Researchgate network services. The objective was to find an ultrasound sensor suitable for use with the Arduino Uno microcontroller and the Raspberry Pi 3 computer. The HC-SR04 ultrasound sensor [10] was chosen because it had references from several sources [11] – [13]. In this study, the HC-SR04 was used to measure distance, as in the following papers.

As examined by [11], the operation of an ultrasound measurement system within a PVC pipe. They found that the diameter of the pipe (23 centimeters) was sufficient for the ultrasound sensor to function without a tube. In their article they were unable to say how measurements were carried out (measurements, program code for the measurement, whether there was temperature compensation or not). They measured distances between 5 and 285 cm. The largest systematic error was -4 cm at distances of 283 cm and 285 cm. The measurement results are reported to centimeter accuracy because, according to them, the AT89S51 microcontroller is unable to handle decimals. When examining the results, many of the measured distances appear to be too large in comparison to the actual distance.

In [12], an ultrasound measurement system was assembled to take the temperature into account in the distance measurements. They have calculated the sound rate with using an adiabatic constant and gas constant. In their measurements they observed that a temperature of + 25 ° C in the test conditions increased the error. They also provided results to centimeter accuracy. They made six measurements between 50 and 250 cm. The biggest systematic error was +2 cm at distances between 75 cm and 200 cm.

An ultrasound measurement system was created in [13], and measurements that are more accurate were performed in laboratory conditions using the X-Y table. They measured 20 to 120 mm at intervals of 5 mm to millimeter accuracy, each distance being measured ten times. The largest systematic error was -8.9 mm at a distance of 80 mm. They performed uncertainty calculations as in this study. The maximum random error was ± 1.52 mm at a distance of 70 mm. In the measurement results, the random error was ± 0.64 mm on average.

These papers were selected because they contain measurement results that can be used as a basis for comparison when estimating the accuracy of the system presented in this study. However, in [11] and [12] the measurement results were expressed in centimeters, so it was uncertain whether the results were accurate enough. In addition, it was not clear how the temperature was taken into consideration. Thus, in this study it was relevant to perform tests to millimeter accuracy and with temperature compensation. On the other hand, according to [13] the ultrasound sensor was too inaccurate for commercial use as an electronic measurement device, but accurate enough for obstacle detection.

III. MEASUREMENT SYSTEM

A. Requirements

The purpose of this study was to implement a system of low-cost components and to explore new technologies. Ultrasound technology was chosen because it is a non-destructive method and no counterpart is needed in the measuring target. The material of the measurement object can be almost anything [14]. Ultrasound sensors are relatively inexpensive, compact and low-power. The components of the system, in addition to the ultrasound sensor, are intended for experimental use, but in some cases are suitable for replacing more expensive options. Fig. 1 shows the measurement system process.

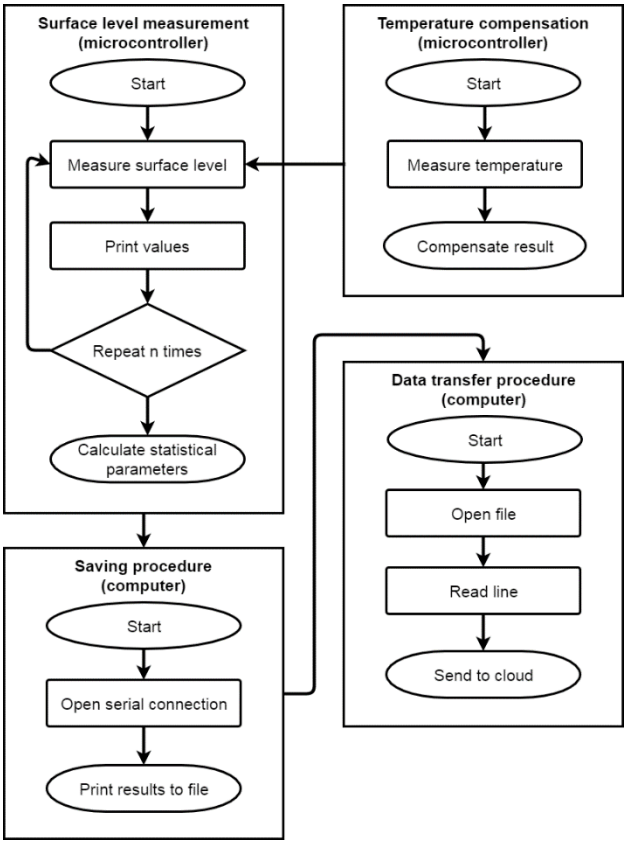

Figure 1. Process chart of the measurement system

When the prototype is started, the ultrasound sensor begins to measure the distance to the target at certain predefined intervals. The *microcontroller* in the system processes the measurement results obtained from the ultrasound sensor, taking into account the temperature received from the temperature sensor. This is repeated as often as it has been defined, after which the statistical results are calculated from the measurement results. The *computer* reads the values printed by the *microcontroller* via the serial port connection. Then it saves the received values to a file. After saving, the line in the file is read and sent to the cloud service.

B. Design

The measurement system consists of a microcontroller, a computer, an ultrasound sensor, a temperature sensor, and a 3G / 4G wireless modem. Based on earlier studies [11] – [13] the following components were selected: the Arduino Uno microcontroller, the Raspberry Pi 3 computer, the HC-SR04 ultrasound sensor, the BME280 sensor unit [15] and the Huawei E5377 wireless 3G / 4G modem [16]. The choice of system components was also influenced by their availability in the IT field, their affordability, low power consumption, physical size and customizability. Fig. 2 shows a deployment chart of the measurement system.

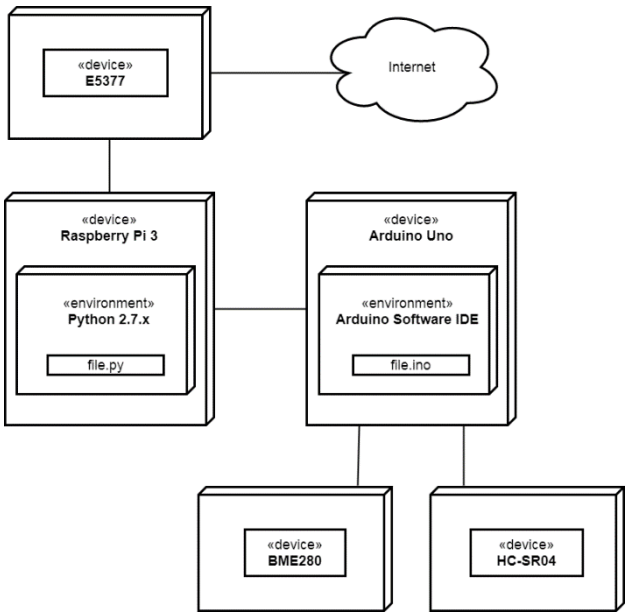

Figure 2. Deployment chart of the measurement system

The primary reason for choosing Raspberry Pi 3 was cost-effectiveness. Any other device capable of Internet connectivity could also replace Raspberry Pi 3. The Arduino Uno could also be directly connected to the Internet by using Ethernet or Wireless shield.

C. Implementation

The components of the measuring system are easily available in online stores, e.g., Amazon.com. In this study, the components were purchased from Finnish online stores. The assembly of the system was started by connecting the HC-SR04 ultrasound sensor and the BME280 sensor unit to the Arduino Uno. The ultrasound sensor's IC power supply pin (VCC) and ground (GND) pins were connected to the Arduino Uno's 5V pin and GND pin. Trig and Echo can be connected to any of the Arduino Uno's digital pins (2-13). The BME280 sensor unit's Vin pin and GND were connected to the Arduino Uno's 3.3V pin and GND pin. SCL and SDA pins can be connected to any of the Arduino Uno's analog pins (A0-A5). Table II shows the connections between the sensors and Arduino Uno.

TABLE I. CONNECTIONS BETWEEN SENSORS AND ARDUINO UNO

HC-SR04 ultrasound sensor	**Arduino Uno**
VCC	5 V
Trig	Digital 10
Echo	Digital 8
GND	GND
BME280 temperature sensor	
VIN	3.3 V
GND	GND
SCL	Analog A4
SDA	Analog A5

Arduino Uno is connected to Raspberry Pi 3 using a USB cable. There is a wireless WLAN connection between the Raspberry Pi 3 and the Huawei E5377 modem. Fig. 3 shows the system connections.

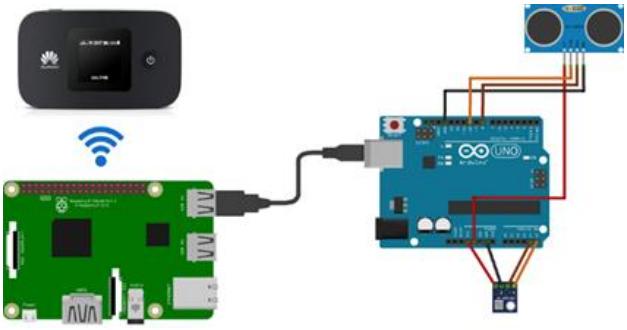

Figure 3. Connections

The Raspberry Pi 3 is equipped with a desktop version of the Raspbian operating system. After installation, it is recommended to upgrade the Raspbian operating system and package repositories instance to a python-serial library [17] that allows serial connection with Arduino Uno. Additionally, Arduino IDE development environment and the necessary NewPing [18], BME280 [19] and QuickStats [20] libraries were installed.

The NewPing library has drivers for many different ultrasound sensors, including HC-SR04. The drivers include the program code that controls the sensor operation. The code is freely available and editable, but its own implementations must be kept separate from the original version management branch.

BME280 is a software library for the BME280 sensor unit manufactured by Bosch. It reads temperature, humidity and pressure values as well as height and dew point. The code is compliant with the GNU GPL (General Public License), which entitles users to access, copy, modify and distribute programs and their source code.

The QuickStats library is a collection of functions used to calculate statistical key figures. It includes functions for calculating the mean, minimum, maximum, standard deviation, mean error, variation coefficient, median, and mode of the sample.

Python code is used to read, save, and send data and is executed on a Raspberry Pi 3 computer. The above tasks are divided into two Python files. The first one reads the serial port connection and saves the measurement results to the file. Then the second one reads the line of information that it sends to the cloud service.

IV. EXPERIMENTS AND ANALYSIS

The system test was performed in a warehouse building, where the values given by the system were compared to the values provided by using a tape measure. The accuracy of the measuring tape is 1 millimeter. Other devices used in the measurement were a forklift truck and a line laser. The ultrasound sensor was attached to the forklift and the level was set horizontally. The measurement was carried out at a temperature of 5.4 to 5.6 ° C and the humidity remained between 77.2 and 79.8 %. Samples were taken at 48 different distances between 18.0 and 3791.0 mm, and one sample included 90 measurements. Measurements 1 to 10 were done at intervals of approx. 10 millimeters and the remaining 11 to 48 at about 100 millimeters. The measurement results were stored on a Raspberry Pi 3 computer via a serial port connection.

A. Uncertainty analysis

Systematic and random errors were calculated from the measurement results using a spreadsheet program. The systematic error was calculated by subtracting the mean of the measured values from the actual distance.

$$\pm\sqrt{\left(\frac{s}{\sqrt{n}}\right)^2+\left(\frac{a}{2\sqrt{3}}\right)^2}*k, \quad (1)$$

The random error was calculated using an expanded uncertainty (1), where s is the standard deviation of the measurement results and is divided by the square root of the number of measurements. The measuring tape has an accuracy of 1.0 (a) mm and is uniform, so it was divided by the square root of three. The square root was multiplied by two because the aim was to obtain a total range. The standard uncertainties were raised to the power of 2 and the sum of the square root was calculated. This was multiplied by the coverage factor obtained from the Welch-Satterthwaite equation. A coverage factor was needed to extend the 68% probability in this case to 95.45% probability. With this probability and the number of degrees of freedom (89), a coefficient of 2.0285 was obtained. [21]

Using the statistical key figures in uncertainty calculations shows that the average systematic error of the results was -2.0 mm and the average of random error was ±0.9 mm. The largest systematic error is -8.3 mm at a distance of 1089.0 mm. The smallest systematic error was 0.1 mm at a distance of 3191.0 mm.

B. Unequal variance t-test

Unequal variance t-test, also known as the Welch's t-test, was used to analyze the measurement results to examine the means of the two independent groups. Welch's t-test is used when variances are unequal and there is an assumption of normality. It is an adaptation of Student's t-test assumption, where variances are equal and two groups have normal distributions. [22]

In this study, the groups were the actual distances and the measured distances. To determine the mean deviations of the groups, the ttest2 function of the MathWorks MATLAB R2016b numerical computing program was used. The measurement results were recorded in mat files of 48 samples. Each of them contained information about the actual distance (x) and 90 measurements (y). The null hypothesis H0 was used: mean deviations are less than the value of the *mm_maara* variable. As an alternative hypothesis, H1 was used: mean deviations are more than the *mm_maara* variable value. The parameters x, y, risk level (*Alpha*), type of alternative hypothesis (*Tail*), and variance type (*Vartype*) were passed to the ttest2 function.

In this case, *Alpha* can be either 0.05, 0.01, or 0.001. An alternative hypothesis can be used for the value *both*, which means that the differences between the mean values of the groups in each direction are explained. The variance type was *unequal* because the variance of the groups differs from one another. Fig. 4 includes a MATLAB code for evaluating mean difference variables compared to a set variable representing the measured error.

```
alfa = 0.05
mm_maara=3.0;
for i = 1:48
   load (['y_' num2str(i) '.mat'], 'x', 'y')
   temp_x = x * ones(1,90);
   if x>=mean(y)
      temp_x=temp_x-mm_maara;
   else
      y=y-mm_maara;
   end
[hyp_equal(i),p_equal(i)]=test2(temp_x,y,'Alpha',alfa,'Tail','both,
'Vartype','unequal');
end
hyp_equal
sum(hyp_equal)
```

Figure 4. MATLAB code for evaluating mean difference variables compared to a set variable representing the measured error.

The MATLAB code in Fig.4 was run at risk levels of *0.05*, *0.01*, *0.001* and measurement error values of 3 to 10 millimeters. Table 2 includes probabilities at a particular *risk level* and *measurement error*. The values of the risk level columns indicate how many samples are accepted by the null hypothesis, and the parentheses indicate the relative proportion of 48 samples.

TABLE II. THE PROBABILITY OF MEASUREMENT ERRORS AT DIFFERENT RISK LEVELS BETWEEN 3 AND 10 MM

Measurement error	**Risk level**		
	0.05	*0.01*	*0.001*
3,0	36 (75.0 %)	33 (68.8 %)	31 (64.6 %)
4,0	38 (79.2 %)	34 (70.8 %)	34 (70.8 %)
5,0	45 (93.8 %)	43 (89.6 %)	41 (85.4 %)
6,0	44 (91.7 %)	43 (89.6 %)	43 (89.6 %)
7,0	45 (93.8 %)	45 (93.8 %)	44 (91.7 %)
8,0	46 (95.8 %)	46 (95.8 %)	46 (95.8 %)
9,0	48 (100 %)	46 (95.8 %)	46 (95.8 %)
10,0	48 (100 %)	48 (100 %)	48 (100 %)

From the results of the Welch t-test, it can be seen that the accuracy of 3.0 mm provided by the ultrasound sensor manufacturer is best achieved at a risk level of *0.05* 75.0% of the distances measured in the cases. If it is desired that the measurement error could be met at a risk level of *0.05* within the tolerance allowed at all measurement distances, the tolerance should be increased to 9.0 mm. Given the original aim of this study, it can be stated that the measurement system produces sufficiently accurate results.

V. Discussion and Future Research

This paper presents a low-cost ultrasound measurement system, which utilizes an Arduino Uno microcontroller, HC-SR04 ultrasound sensor, BME280 sensor unit, and Raspberry Pi 3 computer. The aim was to test the accuracy of the results that the system produces. It can be said that results were accurate enough for the use case.

Although the measurement system provided statistical key figures, they are not presented in this paper. The statistical results as well as the mathematical theory of uncertainty analysis can be examined in previous research [23] related to this paper.

Another issue beyond the scope of this paper is energy efficiency. The components chosen for the example system have low power consumption, but extensive measurements regarding the power usage of the implemented system were not performed.

As a future study, measurements could be made using multiple sensors, different surface materials, shapes and temperatures. It is appropriate to perform a time series analysis of sensors to gain more information about their power usage. It is also recommended to carry out measurements over a longer term to test the durability of the system components under different conditions.

VI. Conclusion

In this study, a prototype of an ultrasound measurement system was created. It met its goal of staying within a margin of error of 10 millimeters when measuring the utilization rate of waste containers. The result of the study is that it is possible to implement a reliable and accurate ultrasound measurement system with low-cost components.

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Optimization of the structures locations using a genetic algorithm in the transmission line design

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***Abstract* - This paper presents an innovative approach to optimize the process of the transmission line towers spotting using genetic algorithms. The mathematical model as well as the process of setting and decoding the variables of the genetic algorithm in the Matlab program package is explained. Possible settings of the fitness function and other parameters of the genetic algorithm in Matlab are outlined and described in order to find optimal arrangement of the transmission towers with minimizing the cost of construction and future maintenance of the transmission line on a particular section. Restrictions imposed due to environmental and geological conditions, legal regulations, standardization and typification of structures as well as other factors imposed by public utility companies and investors have been taken into account.**

Key words – optimization; transmission lines; design; genetic; algorithm;

I. INTRODUCTION

A transmission tower is a tall structure, usually a steel lattice tower, used to support an overhead transmission line. Tower spotting is the process of choosing discrete locations and type of towers along of a transmission line route.

About half of the cost of transmission line constitutes the cost of towers and the depend labor. Hence optimum tower design and spotting will bring in substantial savings [7].

Spotting optimization is one of the most complex problems in the process of designing transmission lines. Although the processor power of the computer has grown exponentially over the last several decades, there has been almost no work to improve existing algorithms for optimizing the locations of the transmission lines structures that were developed 20 years ago. Currently the most used software for the design of transmission lines in the world with the module for spotting optimization is PLS CADD. The optimization algorithm in this software is based on the classic optimization method of dynamic programming with the aim of minimizing the total construction cost of a transmission line, which is described in more detail in [1].

The goal of this paper is to present an innovative method for the spotting optimization in designing a transmission line using a genetic algorithm as one of the modern methods for finding a global optimum solution in the Matlab program package.

II. MATHEMATICAL MODEL

The spotting optimization involves the selection of discrete location of structures of the appropriate type and height from given families of standardized towers on the selected route of the transmission line, along with minimizing the construction costs and the future maintenance of transmission lines, taking into account technical regulations and safety constraints, and all other constraints imposed due to environmental and geological conditions, and other restrictions imposed by public utility companies and investors.

Problem of the optimal spotting of towers in the transmission lines designing can be mathematically formulated as in [1]: For given a set of constraints, find a set of discrete structure locations (x_i, $I=1..n$) and the corresponding structures ($T(x_i)$, $i=1..n$) to minimize the total cost of the line. Where: n is the total number of structures in the line. The total cost to be minimized implies the total cost of the construction of the transmission line and the estimated costs of its future maintenance. The cost of constructing a certain type of tower $T(x_i)$, beside of the type and height, is significantly dependent on the location of the tower on the selected route of the transmission line. Additional costs related to the construction and future maintenance of the tower at a particular location on the route of the transmission line are defined by the geological structure of the soil, access roads to the location, property-legal costs and other costs related to that location. In order to take into account the costs directly related to the location of the tower, it is necessary to estimate the special location cost parameter for each different section of route and increase the cost of erecting the tower at a specific location, by multiplying the tower cost with this parameter. This can be achieved by a percentage increase the cost of erecting of the tower a certain type and height relative to the location at which the erection of this tower is most favorable. If we denote these location cost parameters with q_i, $i=1..n$, $q_i \geq 0$, then we can present the optimized total cost of building the transmission line as a function (1):

$$Copt = min \sum_{i=1}^{n} C(T(x_i)) \cdot \left(1 + \frac{q_i}{100}\right) \qquad (1)$$

Where is:

$C(T(x_i))$ – The minimum cost of erecting a tower type$T(x_i)$,

q_i – The location cost parameter indicate a percentage of increase the costs of erecting a tower $T(x_i)$ at locationx_i.

A. Constraints

Selected locations of towers must be on the central line of the transmission line corridor and they are defined by station (distance along corridor from the starting point of the transmission line).

In order to build a tower at a particular location, the following minimum constraints must be satisfied:

- Loads on the tower (horizontal and vertical) must be within the limits allowed for which the tower is designed for all prescribed load cases. To calculate the loads on a tower for a specified load case, a wind span and a weight span is usually used.

  The wind span is the arithmetic mean between the left and right horizontal distance from the adjacent towers. This wind span is used to calculate the horizontal (transverse) load on the tower due to wind pressure on the conductors. Horizontal wind load is calculated by multiplication of the prescribed wind pressure with the wind span [5].

  The weight span is the horizontal distance between the lowest points on the conductor in the left (back) span and the right (ahead) span. The weight span is dependent of the load cases defined by local regulations or by the investor. The weight span is normally calculated at the lowest and highest temperature without wind. The vertical load on the tower depends on the load cases and it is calculated as the multiplication of the weight per unit length of conductor and the weight span for each different load case [5]. The vertical load must not be negative for a suspension tower, i.e. must be greater than a minimum prescribed by design for the selected tower type.

  The vertical and horizontal loads on the tower must not exceed the maximum prescribed loads.

- The horizontal distance between the adjacent towers must be between permitted minimum and maximum values.

- The minimum vertical and lateral distance of conductors from ground and other objects (minimum clearance) must be satisfied for all load cases in each span.

- If the angle of deviation the route greater than 2 ° at that point an angle-suspension or tension tower must be used. The tension tower is a tower that receives the load of the conductor weight, unlike the suspension tower. Usually between the two angular towers there are several suspension towers. In one section (between the two tension towers), should be are no more than 10 to 15 suspension towers, because of better stability of the line from the influence of the transverse wind force and for faster and more economical stringing of conductors.

  Also, the tension tower must be on both sides of the crossings of critical objects such as highways, railways, other power lines, large span across the river, etc.

- On certain sections of the route such as, for example, rivers, roads, steep cliffs, it is very difficult to build a pillar. For such sections, it is best to set the location cost parameter q_i very high, so that the optimization algorithm is avoiding this location due to the extremely high cost of building at that location.

- The maximum swing of the insulators for specific climatic conditions must be below the permitted angle.

In order to accelerate the algorithm to find the optimal solution, we can introduce a discretization of the location of towers at intervals of 10 meter or at the highest points at these intervals [1].

III. GENETIC ALGORITHM

The genetic algorithm (GA) is a heuristic method based on a natural evolutionary process and is part of a group of evolutionary optimization algorithms. It can be applied to solve various optimization problems in which the objective function is discontinuous (or with discrete value), non-differentiable, stochastic or nonlinear [2]. The basic building element in GA is the population of a certain number of individuals, while the population at a given time is called a generation. Creation an initial population of individuals is done randomly. Each individual is a possible solution in the search space of a given problem. In GA, individual are usually encoded to form a string of bits a certain length (often referred to as a chromosome). Each bit represent an allele or gene. The quality of individuals in the population is assessed by the fitness function so that each individual chromosome within a given generation is assigned the appropriate degree of fitness.

The basic operators that perform gene operations in the chromosome themselves are: selection, crossing and mutation.

Selection is the process in which survival rules are applied so that the best individuals survive and their genes are candidates for the next generation, while the weakest individuals extinct. There are many different types of selection and the most commonly used selection type is "roulette wheel"[3]. In this selection process, each individuals get the appropriate surface on the roulette wheel, so the chances of transition to the next generation are proportional to their degree of fitness. Turning the wheel selects the appropriate number of individuals which are candidates for crossing and mutations.

After selection, the crossover operator applies to individuals that have passed the selection phase. The crossover is the operation of selecting a random bit position in the chromosome and replacing all the left or right bits of that position with the bits on the same position in the second chromosome. This position is called the crossover point. The method with the one or more crossover points is most often used for binary coded chromosomes [3]. Goal of the crossover is to create new strings (chromosomes) by exchanging information between the strings. All selected chromosomes do not pass through the crossover process. The probability of using a crossover operator is usually 70% to 80%, so that some parental chromosomes unchanged directly pass to a new generation. [3].

After selection and crossover operations, the mutation operation is applied only to a very small number of individuals in the newly obtained population. Usually the mutation probability is 0.1% to 0.2%. The mutation helps to return lost information or add new information to the population, thus avoiding GA finishing at a local minimum. The mutation is performed at the bits level, which in turn inverts the randomly selected bit in the chromosome. Mutations can lead to completely new individuals (i.e. solutions) or to creation of the degenerative individuals that will quickly die in next generations.

By the selecting, the crossover and the mutation the initial population, a new generation is created. Then these three operators are applied in the same way on the newly created generation to get the next generation. This iterative process continues until the stopping criterion is satisfied. In practice, the genetic algorithm usually interrupts after a certain number of generations or after a certain time interval. Then quality of the best individuals is checked. If the result is not acceptable, the search for new (better) solutions can be started again [4].

IV. SPOTTING OPTIMIZATION USING THE GENETIC ALGORIHM IN MATLAB

The Matlab - sophisticated software tool with the GA application enables solving optimization problems using a genetic algorithm. To solve the optimization problem of the structures locations in a transmission line using GA in Matlab software, it is necessary to define the fitness function, the linear and nonlinear constraints, the lower and upper bounds for variables, the type of population, the size of the population, and the operators of selection, crossover and mutation, as well as the criterion of interrupting the genetic algorithm. Figure 1 shows the screenshot of the Matlab optimization tool interface.

A. Representation of individuals (chromosome coding)

In implementing the proposed genetic algorithm, the population individuals are defined as a double vector with two integer variables.

The first variable represents all potential locations of the towers on the route ($xi,\ i = 0..s$). This variable is encoded to represent the station on the route of the transmission line and in fact it is an integer value in meters. In order to accelerate the algorithm, the stations can be discretized at intervals of 10 meters, taking into account the locations with the highest elevation at these intervals.

The second variable represents all the different types of towers that are allowed to be used on the given route of a transmission line ($Tj,\ j = 1..m$). Towers from the same family but of different heights (whether it is extensions of body or legs of the tower) are denoted as a different type. This variable is encoded so that for each tower type is assigned an integer value of *1 to m*.

B. Fitness function

As consideration of all possible solutions requires a large spatial and time complexity of the calculation, in

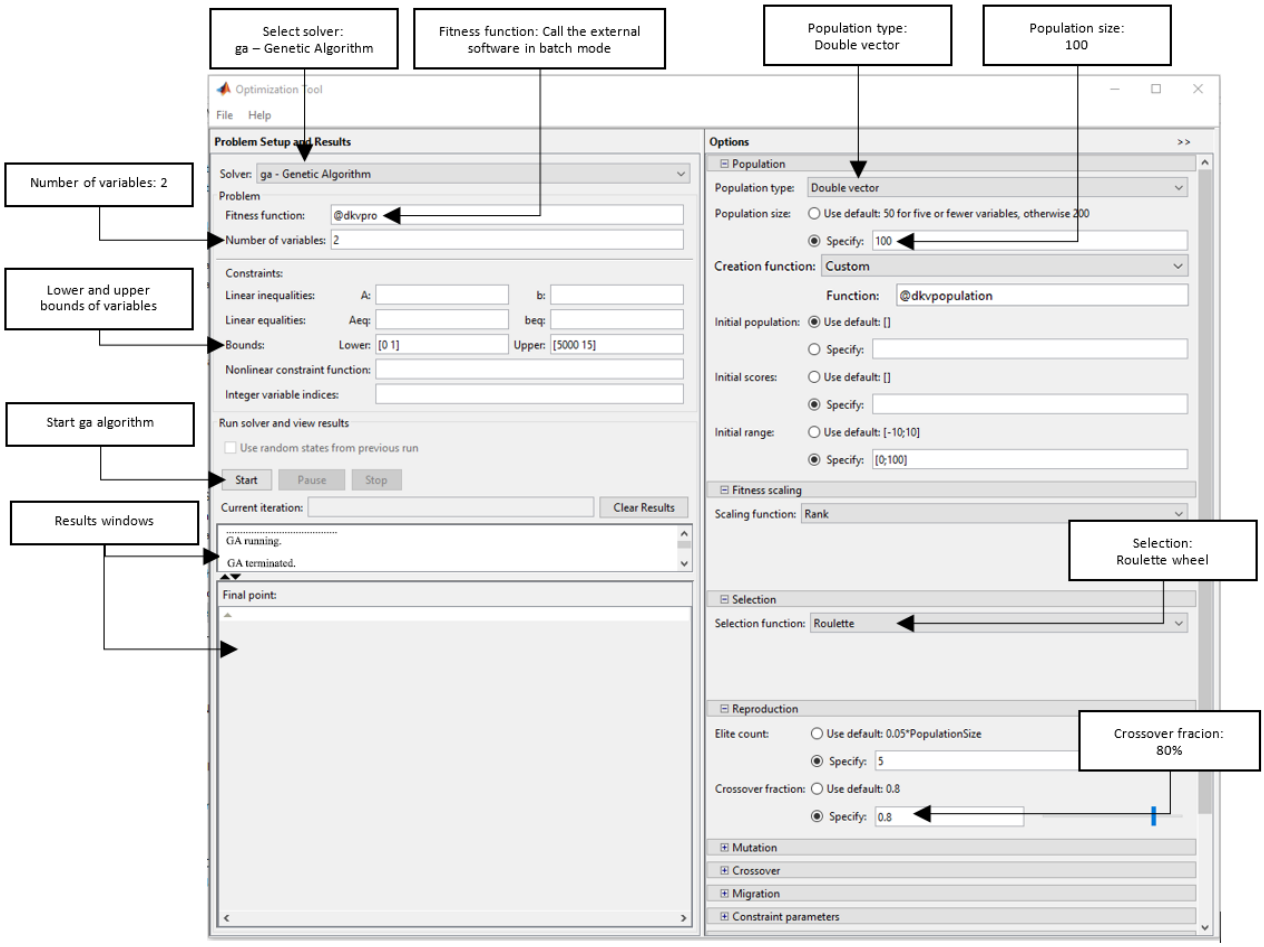

Figure 1. Screenshot of the graphical interface of the Matlab optimization tool

order to easily calculate the fitness function and accelerate the algorithm, it is necessary to eliminate as many potential solutions with poor quality as possible.

This is achieved by combining the appropriate genetic algorithm and the external software. At first GA generate the population of individuals (potential solutions) as population of strings that define the locations and type of towers with a minimum number of towers (n). Then the fitness function is calculated by using the external software, which also performs validation of each individual in the population as a possible solution in terms of meeting all the criteria and constraints set out in Chapter II.A. The external software returns the value of the total cost of constructing the transmission line for an individual if that individual as a potential solution meets all constraints, or returns the fitness with the zero value if that potential solution does not meet all the constraints and thus eliminates that individual in the next generation. The minimum number of towers (n) is determined by dividing the total length of the transmission line route with the maximum allowed span on that line.

If in this way all potential solutions are eliminated in a particular generation of the population, the genetic algorithm will stop, the minimum number of towers in a solution is increased by one (n + 1), and the genetic algorithm is resumed until it reaches the given maximum number of generations in GA, when one or more individuals with the best fitness are selected as potential optimal solutions for the towers locations and types on a given route of the transmission line.

C. Disadvantage of the algorithm and possible improvement

The main disadvantage of the proposed algorithm is the necessity of using an external software for calculating fitness functions outside the Matlab GA application, which additionally slows down the algorithm, especially if that external software is not efficient enough. In order to accelerate the process of calculating fitness functions, cache techniques can be applied. The cache technique was first applied in [6]. This technique does not affect the results that are obtained, but only reduces the execution time of the genetic algorithm. The genetic codes and the corresponding values of the fitness function are cached in their first occurrence during the execution of the genetic algorithm. In the event of the next occurrence of the same genetic codes, the fitness value is read directly from the cache instead of being recalculated.

D. Results

The proposed algorithm was tested on several sections of the already built transmission lines: TL 132kV GIMBI-MENDI (Ethiopia) with hilly terrain, and TL 60kV SALAH BEY-AIN AZEL (Algeria) with predominantly flat terrain. PLS CADD was used for designing these transmission lines. The results of the optimization of towers spotting obtained using the proposed GA algorithm are better in the hilly terrain, while on the flat terrain sections the algorithm yields almost the same optimization results as PLS CADD.

V. CONCLUSION

In the practice of designing the transmission line, the designing companies still relies heavily on the experience of engineers-designers, and on software that enables the manual spotting of the towers with the visual display of the 2D or 3D profile of the route of the transmission line. Spotting optimization software is mainly used on flat terrain, while for the towers spotting in the hilly and mountainous areas, the designers rely exclusively on engineering experience. This leaves a significant possibility that the manual spotting is not optimal and that significant savings on the costs of construction and future maintenance of the transmission line can be made by using the appropriate optimization method. Modern optimization methods, such as the genetic algorithm, are powerful and popular methods for solving complex engineering problem optimization and for finding global optimum. This paper presents the basic possibilities of using the genetic algorithm (GA) to solve the problem of optimizing the structures locations on the transmission line route and finding solutions with the lowest cost of construction and future maintenance of the transmission line.

A. Future Work

An additional test of the proposed algorithm is to be carried out on several examples of already-constructed transmission lines and to compare the optimization results with the results of some of the existing software such as PLS-CADD using optimization algorithm based on the classic dynamic programming methodology with the goal of minimizing the construction cost of the transmission line described more detailed in [1]. In accordance with the results obtained, additional adjustment of genetic algorithm parameters can lead to faster and more reliable algorithm convergence to optimum solution.

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Implementation of a management and scheduling platform for the waste management process in urban areas

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Abstract - In this paper we present a solution to the problem of garbage disposal in the urban areas via developing an autonomous scheduling and monitoring system. The main function of the system consists of utilising the Vehicle Routing Protocol (VRP) for navigating a fleet of garbage disposal vehicles to obtain the optimal routes for collecting garbage located in a city area, usually a municipality with the current configuration of the surrounding taken into consideration. The previously mentioned configuration consists of sensory data, gathered from the garbage bins, as well as the distance between individual locations with the most recent estimate of the respective current traffic conditions. Aside from the main functionality, the system takes care of the incoming time series data from the sensors and stores them in a Round Robin Databases (RRD), to preserve memory space as much as possible, as well as to support modular report generation on daily, monthly or custom time period basis. The system relies on the local garbage disposal service of the city at hand and as such provides a means for the recording of vehicles, personal etc. A possible implementation of the system will be presented on the use case of the canton of Sarajevo.

Keywords: Garbage disposal, Scheduling and monitoring system, VRP, RRD

I. INTRODUCTION

One of the top problems of urban areas, which if not handled correctly can cause a variety of other problems, is communal waste management. The nature of the problem implies tuning and synchronising multiple parameters which arise from it's complexity . It has been mostly solved in a old-fashion way, were the mutual experiences of the agents assigned with this task are being used for coming up with the solution. This approach has proven to be not robust enough to satisfy the ecological and fuel consumption constraints. Therefore , we will look at a more dynamic approach for solving it.

The other commercial options for solving the presented problem can be found at resource [5]. Some of the presented solutions are offering only monitoring services without any route disposal management and all aren't available at the regional market which includes Bosnia and Herzegovina. Therefore, we have decided to devise our own solution.

In this paper we will concern ourselves with the management and scheduling tasks for which we will assume that the data about the state of individual garbage container is being collected and sent at regular intervals to the Google Pub Sub Cloud. The structure of the platform is shown in the Image 1. and consists of following main parts:

- Django based Python web application
- Google Cloud Pub/Sub API
- Google Optimisation Tools (OR-Tools)
- Google Maps Distance Matrix API
- RRD tools database
- MySql database

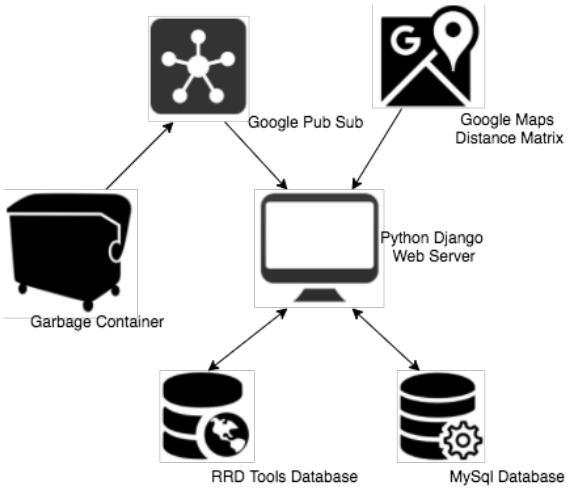

Image 1. Structure of the platform

The basic flow can be summarised into following steps:

1. Pulling measurements data from the Google Pub Sub Cloud
2. Processing the data and storing it inside the RRD tools database

3. Generating routes for vehicles via OR-Tools and usage of Google Maps Distance Matrix API
4. Defining the time for the next pull invocation
5. Displaying new routes on the UI

Beside the previous flow, other functionalities such as displaying the last 24 hours of measurements or adding new vehicles, employees etc. to the system are also available. Each step of the flow along with functionalities associated with it will be explained in the next chapters.

II. DATABASE SCHEME

Two types of data are being utilised inside the platform:

- Relational data
- Time series data

Relational data is described with the EER diagram in the Image 2.

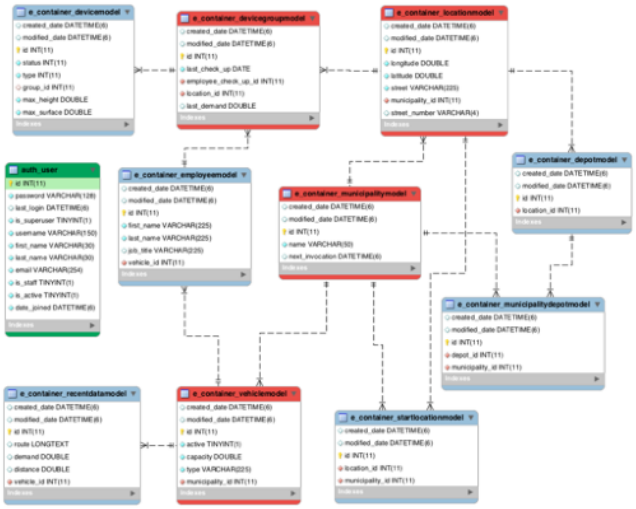

Image 2. EER diagram of the MySql database

The tables shown in red have greater significance to the basic flow functioning of the platform and describe the entities:

- Municipality
- Location
- Device Group
- Vehicle

The atomic unit on which the VRP algorithm is being performed is a city municipality which is further divided into locations which represent whole streets or part of them if they are longer in length. Each municipality has one or many vehicles associated with it. Each location has exactly one device group associated with it, which contains information about the measurements for every device installed inside that location. This approach has been chosen because of the practical nature when a vehicle comes to a location, it automatically can serve every device inside that location.

The user entity shown in green is primarily envisioned to be the administrator of the whole platform. As such, she/he will have the ability to add or modify every relational entity (except field measurements). This functionality, whose accessing requires authentication, is implemented "out of the box" with the Django web framework.

The presented database scheme is envisioned to be a basis for a information system applicable to the existing garbage disposal company. Record of employees work, vehicle usage, installed devices etc. are some of implemented functionalities.

Time series data consists of measurements collected from the devices attached to the containers, which implementation we will not cover in this paper. The measurements are of the distance sensor which measures the distance between the top of the container and the garbage inside it, at regular time intervals. Other parameters such as temperature, battery level can be transmitted and leveraged in the future. Because of it's non relational nature we have decided to choose the industry standard database for storing time series data, round robin database. The main advantage of it is the fixed amount of memory which it requires. That amount is determined at the moment of creation along with parameters such as sampling step, type of data, aggregation function etc. The ability to create time modular graphs showing the change in garbage fullness levels of individual or groups of devices is also a useful functionality leveraged by the platform. For more information about RRD we suggest the [6] resource.

III. DATA ACQUISITION AND PREPROCESSING

The data containing the measurements from the devices is being sent to the Google Pub Sub Cloud. The overview of the present components, with the corresponding message flow steps is shown on Image 3.

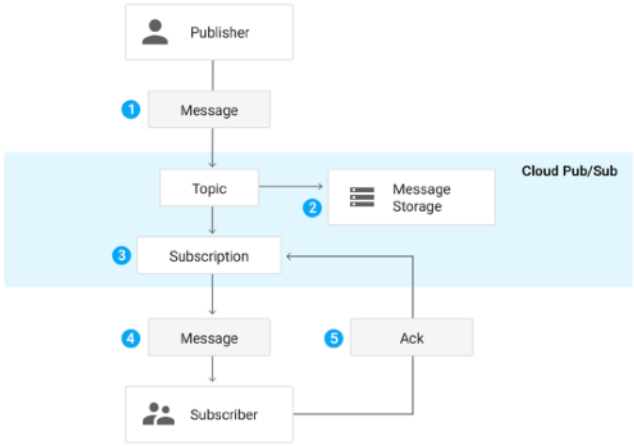

Image 3. Google Pub Sub structure

Every time a new municipality has been created a new topic is added to the project created inside the

Google Developers Console. Devices transmit the data, e.g. messages to the topics of their respective municipalities (step 1). Messages are persisted in a message store until they are delivered and acknowledged by our web server (step 2). The messages are being forwarded to each subscription associated to the topics (step 3). In our case, each topic contains only one subscription. When we initialise the pull, messages from every subscription are sent to our web server (step 4), when we also acknowledge the received message which in turn is being removed from the message storage (step 5). HTTP protocol is being used for data transmission. For further reading we suggest the [7] resource.

After the measurements have arrived, we sort them by respective municipalities and calculate the group demand for every device group e.g. location. The aggregate function is the mean of all the devices inside the group. We convert the data to the volume dimension because it has to align with the dimensions of the vehicle capacity. Next, we calculate the distance matrix which contains distances between every location inside a municipality using the Google Maps Distance Matrix API. We suggest the resource [8] for more information. Lastly, we send the demand data, distance matrix, along with all available vehicles grouped by municipalities to the OR-Tools constraint solver which will be explained in the next chapter.

IV. VEHICLE ROUTING PROTOCOL

The Vehicle Routing Problem is a well known NP hard problem formulated by Dantzig and Ramser in year 1959. for a truck delivery problem. Since then, many algorithms, both exact and heuristic, for solving different variations of the VRP problem have been devised.

The VRP problem that we are facing is a variation of Constrained VRP (CVRP) where instead of goods being delivered to locations, the goods i.e garbage is being taken from the locations. This alteration doesn't affect the main setting of the problem. The definition of the CVRP has been taken from [1]. The CVRP may be described as the following graph theoretic problem. Let G = *(V,* A) be a complete graph, where $V = \{0,...,n\}$ is the vertex set and A is the arc set. Vertices $i = 1, \ldots, n$ correspond to the customers, whereas vertex 0 corresponds to the depot. Sometimes the depot is associated with vertex $n + 1$.

A nonnegative cost, c_{ij}, is associated with each arc $(i,j) \in A$ and represents the travel cost spent to go from vertex *I* to vertex *j* . Generally, the use of the loop arcs,*(i,i),is* not allowed and this is imposed by defining $c_{ii}=\infty$ *f*or all $i \in V$. Each customer *i (*$i = 1, \ldots, n$*)* is associated with a known nonnegative demand, d_i, to be delivered, and the depot has a fictitious demand $d_o=0$. Given a vertex set $S \subseteq V$, let $d(S) = \sum_{i \in S} d_i$ denote the total demand of the set. A set of *K* identical vehicles, each with capacity C, is available at the depot. To ensure feasibility we assume that $d_i \leqslant C$ for each i = *1*,...,n. Each vehicle may perform at most one route, and we assume that *K* is not smaller than K_{min}, where K_{min} is the minimum number of vehicles needed to serve all the customers.

The CVRP consists of finding a collection of exactly *K* simple routes (each corresponding to a vehicle route) with minimum cost, defined as the sum of the costs of the arcs belonging to the routes, and such that :

- each circuit visits the depot vertex
- each customer vertex is visited by exactly one circuit
- the sum of the demands of the vertices visited by a circuit does not exceed the vehicle capacity, C.

$$\text{(1.3)} \qquad \text{(VRP1)} \quad \min \sum_{i \in V} \sum_{j \in V} c_{ij} x_{ij}$$

subject to

$$\text{(1.4)} \qquad \sum_{i \in V} x_{ij} = 1 \qquad \forall\, j \in V \setminus \{0\},$$

$$\text{(1.5)} \qquad \sum_{j \in V} x_{ij} = 1 \qquad \forall\, i \in V \setminus \{0\},$$

$$\text{(1.6)} \qquad \sum_{i \in V} x_{i0} = K,$$

$$\text{(1.7)} \qquad \sum_{j \in V} x_{0j} = K,$$

$$\text{(1.8)} \qquad \sum_{i \notin S} \sum_{j \in S} x_{ij} \geq r(S) \qquad \forall\, S \subseteq V \setminus \{0\}, S \neq \emptyset,$$

$$\text{(1.9)} \qquad x_{ij} \in \{0, 1\} \qquad \forall\, i, j \in V.$$

The most common set of equations for modelling the CVRP is the Vehicle Flow Model:

The in degree and out degree constraints (1.4) and (1.5) impose that exactly one arc enters and leaves each vertex associated with a customer, respectively. Analogously, constraints (1.6) and (1.7) impose the degree requirements for the depot vertex. The so-called capacity-cut constraints of (1.8) impose both the connectivity of the solution and the vehicle capacity requirements. In fact, they stipulate that each cut (V \ S, S) defined by a customer set S is crossed by a number of arcs not smaller than r(S) (minimum number of vehicles needed to serve the set S).

We operate under the following constraints, which are included in the base version of the CVRP:

- All vehicles and containers have identical capacities

- Per municipality, every vehicle has the same starting location
- No garbage pick up order exists
- The distance matrix is symmetric
- Time hold up time at each stop can be neglected

The algorithm for solving the CVRP we used is the well know "savings" heuristic constructive algorithm by Clarke and Wright. It is based on the notion of savings. When two routes (0,…,*i*,0) and (0,*j*,..., 0) can feasibly be merged into a single route (0,…,*i, j*,...,0), a distance savings $s_{ij} = c_{i0} + c_{0j} — c_{ij}$ is generated. This algorithm naturally applies to problems for which the number of vehicles is a decision variable, and it works equally well for directed or undirected problems. A parallel and a sequential version of the algorithm are available. The algorithm works as follows:

- Step1 (savings computation). Compute the savings $s_{ij} = c_{i0} + c_{0j} — c_{ij}$ for i, j= 1,...,n and $i \neq j$. Create *n* vehicle routes (0, *i,* 0) for i=1,…,*n.* Order the savings in a non increasing fashion.

- Parallel version
  Step 2 (best feasible merge). Starting from the top of the savings list, execute the following. Given a saving s_{ij}, determine whether there exist two routes, one containing arc or edge (0, j) and the other containing arc or edge (i, 0), that can feasibly be merged. If so, combine these two routes by deleting (0, j) and (i, 0) and introducing (i, j).

- Sequential version
  Step 2 (route extension). Consider in turn each route (0, i , . . . , j, 0). Determine the first saving s_{kj} or s_{jh} that can feasibly be used to merge the current route with another route containing arc or edge (k, 0) or containing arc or edge (0, h). Implement the merge and repeat this operation to the current route. If no feasible merge exists, consider the next route and reapply the same operations. Stop when no route merge is feasible.

V. USE CASE ON THE CANTON OF SARAJEVO

The canton of Sarajevo consists of nine municipalities, with total population of around 413 600 citizens. The whole canton has around 8000 available containers and the number of vehicles per municipality vary from 7 to 15. The platform operates in a way that all covered municipalities will have one active routes displayed on the UI at every time, where the operator of the system has the ability to switch between displayed routes. Here we will display the results for the municipality of Novo Sarajevo, where following parameters apply:

- The population of around 64 800 citizens or 15.67% of the total canton population.
- Around 1250 containers are available.
- The number of vehicles is 12,
- Each vehicle has a volume capacity of around 8 m^3,
- The volume capacity of each container is around 1.1 m^3,
- The work day is divided into three 8 hours shifts,
- The gathered garbage is compressed inside the vehicle to 1/3 of its original volume.

As mentioned before, we used the OR-Tools constraint solver for solving the CVRP, about which we point to the [9]. Following parameters apply:

- Arbitrary Start locations,
- Generation of new routes based on the previous,
- Distance function to be results returned by Google Maps Distance Matrix API,
- Savings algorithm as the one to be used,
- Algorithm duration to be four minutes.

Time point for the next route to be generated is established as the average of the vehicle travel duration between the start and next location of every route. This has been chosen to minimise the mistake equally for every vehicle for choosing a wrong location for the next one, based on the demand criteria. To save time on route generation we used the route in the previous iteration as a starting point for new route generation. This way we introduce a factor of dynamics to be able to respond to the dynamic nature of urban garbage disposal.

For demonstration purposes we have coded 20 locations in the municipality of Novo Sarajevo which is 1/4 of the estimated real number of container covered locations based on the fact that a location is usually covered with around 15 containers. Therefore, we have reduced the number of vehicles to three as well. On image 4. the proposed UI is displayed where beside the municipality of Novo Sarajevo, the municipality of Novi Grad is also displayed for the proof of concept.

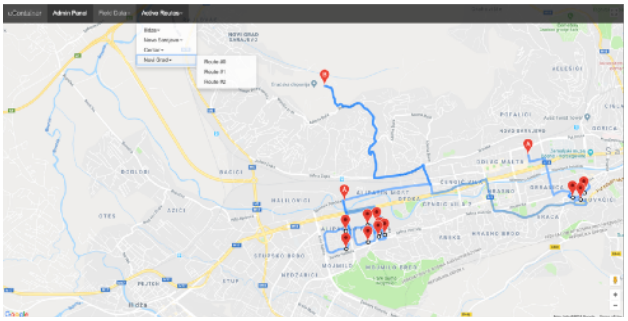

Image 3. Proposed UI of the eContainer platform

Results of the different variations for solving CVRP with the total distance for all three routes are as following:

- Global cheapest arc with greedy descent - No result
- Global cheapest arc with tabu search - No result
- Local cheapest arc with greedy descent - 29049
  - Vehicle 1: 1 -> 7 -> 8 -> 9 -> 10 -> 4 -> 20 -> 8 Distance: 9552 Demand: 8.902008,
  - Vehicle 2: 1 -> 12 -> 13 -> 18 -> 8 Distance: 7251 Demand: 6.406616,
  - Vehicle 3: 1 -> 2 -> 11 -> 6 -> 5 -> 3 -> 18 -> 19 -> 20 -> 15 -> 21 -> 8 Distance: 12246 Demand: 11.7706639
- Christofides algorithm - 27933['Route for vehicle
  - Vehicle 1: 1 -> 7 -> 2 -> 11 -> 20 -> 8 Distance: 9234 Demand: 9.02212,
  - Vehicle 2: 1 -> 12 -> 13 -> 18 -> 8 Distance: 7251 Demand: 6.406616,
  - Vehicle 3: 1 -> 4 -> 8 -> 9 -> 10 -> 6 -> 5 -> 3 -> 18 -> 19 -> 20 -> 15 -> 21 -> 8 Distance: 11448 Demand: 11.650552
- Local cheapest arc with tabu search - 27933
  - Vehicle 1: 1 -> 7 -> 2 -> 11 -> 20 -> 8 Distance: 9234 Demand: 9.02212,
  - Vehicle 2: 1 -> 4 -> 8 -> 9 -> 10 -> 6 -> 5 -> 3 -> 18 -> 19 -> 20 -> 15 -> 21 -> 8 Distance: 11448 Demand: 11.650552,
  - Vehicle 3: 1 -> 12 -> 13 -> 18 -> 8 Distance: 7251 Demand: 6.406616
- Savings algorithm - 28202
  - Vehicle 1: 1 -> 12 -> 13 -> 14 -> 15 -> 21 -> 8 Distance: 8032 Demand: 7.025856,
  - Vehicle 2: 1 -> 20 -> 19 -> 18 -> 3 -> 5 -> 6 -> 10 -> 9 -> 8 -> 3 -> 8 Distance: 11319 Demand: 11.5416,
  - Vehicle 3: 1 -> 7 -> 4 -> 11 -> 20 -> 8 Distance: 8851 Demand: 8.511832

Indexes 1 and 8 present the starting location and the depot respectively. Even tough the total distance generated by the savings algorithm isn't the lowest, we have chosen it because of it has proven itself to be faster and to generate more evenly long routes, which we can see from the examples above, where the difference between the longest and shortest route in Christofides algorithm is 9 where for the savings algorithm is 6.

VI. CONCLUSION

The validation of the achieved results couldn't be preformed on the real setting because of the inability of installation of the hardware devices, for which readings we have used estimated variations of container fullness. Nevertheless, we believe that an implementation of such a platform will greatly benefit the city in terms of fuel savings, traffic reduction and cleaner surrounding. The presented platform is modular in it's core in terms that it's easily attached to the already existing infrastructure of the local garbage disposal company. Furthermore, that data collected from the container could prove useful for analysis and prediction scenarios to help tune various parameters of the platform which could improve it's effectiveness greatly. We hope that in the future we'll be able to present the data acquired from the real use case.

VII. LITERATURE

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Cost-effective Mobile Manipulation System

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***Abstract* – Present trends in robotics favor machines that can interact with unstructured and dynamic environments. This requires superior mobility and manipulation capabilities in robotic systems which are met by using a mobile manipulator. However, commercially available mobile manipulators tend to be quite expensive making robotics research costly and reserved for a niche community of developers. In this paper, development of a cost-effective mobile manipulation system is proposed. The solution is based on low-cost hardware and open-source software that are both modular. It consists of a robot arm mounted on an omnidirectional mobile platform that can be controlled by a remote computer in order to provide computational resources required for demanding mobile manipulation tasks. The modularity of the proposed robot configuration based on the Robot Operating System (ROS) allows for effortless addition of various sensory devices.**

Keywords - omnidirectional; mobile manipulator; cost-effective; modular; open-source; ROS

I. INTRODUCTION

The emergence of affordable devices and sensors on the market has led to a growing community of robotics enthusiasts and developers. Today, it is easier than ever to implement research-grade solutions on inexpensive hardware using open-source software. With present trends in robotics favoring systems that interact in unstructured and dynamic environments, a need for sophisticated mobility and manipulation capabilities in robot systems arises. Having a robot that can move in space and handle objects allows for a wide variety of applications, especially if the system is modular and upgradeable.

Mobile manipulators are robotic systems capable of both maneuvering in the plane and environment manipulation. A gap exists between mobile manipulation systems on the market: performance-wise and in cost. Industrial mobile manipulators provide robustness and come with good performance, but are usually available at a premium. On the other hand, albeit lowering the cost, usage of affordable robotic systems introduces several challenges into the development process, mainly considering the robot's performance. Therefore, it is required to compensate for these limitations. For instance, in a mobile robot, odometry faults can be compensated by installing a depth camera onto the system, resulting in vision guided navigation. However, such workarounds make the development process much more involved.

In this paper, development of a mobile manipulation system is considered. The proposed solution is intended to be used as a platform for research-grade algorithm implementation and experimentation. Hardware and software modularity is important when designing a research platform that will interact in a dynamic and unstructured environment. Furthermore, modularity allows for various low-cost components to be integrated into the system and utilized by using appropriate open-source software. Consequently, a distributed architecture is proposed for the considered mobile manipulator. The proposed solution aims to make implementing algorithms on a physical system straightforward, allowing for a faster progression in related research. Towards this end, the proposed solution is designed as a backbone of the robot's control system, which can be easily built upon if need be.

The paper is structured as follows: in Section II, an overview of related research is given, which presents several cost-effective solutions in the field of mobile robotics. The proposed system is described in Section III, where its hardware components are listed and described, as well as its software architecture. The paper is concluded in Section IV.

II. RELATED RESEARCH

There are several commercially available mobile manipulators with built-in robot control that would be well suited for research in mobile manipulation, e.g., Asimov Robotics X-Terrabot [1], the Jaguar 4x4 Wheel with Arm Mobile Platform [2], the Commonplace Robotics SliderSRA [3], or the discontinued KUKA youBot [4]. However, few low-end solutions are proposed in literature that are able to run common robotics algorithms and support customization. Lazewatsky and Smart address this problem in [5] with an inexpensive telepresence robot. Their choice of hardware and software allows anyone interested in robotics to easily get involved in research and development. Still, the robot mainly provides a test bed for human-robot interaction (HRI) research and lacks manipulation capability.

The authors in [6] consider two low-cost manipulation systems and implement vision guided positioning as a means of compensating for the lack of proprioceptive sensors. It is emphasized throughout the paper how affordable solutions can help broaden the community of robotics developers and researchers. The proposed solutions have inherent limited operation range for object manipulation, as both robots lack mobility.

Low-cost robots were used in [7] for implementing a distributed autonomous gardening system. The authors describe how relying on off-the-shelf hardware and open-source software allows focusing on key algorithmic, system

and application aspects. The provided solution has open problems, e.g., robustness of the used hardware and the manipulators limited workspace.

III. Mobile Manipulation System

The proposed mobile manipulation system is described in terms of its hardware and software components. As the used software is open-source, the overall cost of the proposed system is determined by the used hardware.

A. Hardware Components

The mobile manipulator consists of a low-cost robot arm mounted on a comparably priced mobile platform. Both robots are connected to a Raspberry Pi single-board computer, which is favored among the maker community.

An omnidirectional mobile platform is used to attain impressive mobility of the overall system. The Nexus Robot 3WD Omniwheel, shown in Fig. 1, is considered. At around 520 EUR it is more affordable than its commercially available counterparts. It includes an Arduino-based microcontroller with an IO expansion board, three DC motors, three ultrasonic range finders, a power adaptor, and one USB cable. Its aluminum alloy body with pre-drilled holes makes further adjustments convenient. It can carry up to 15 kilograms of load on a 330 by 330-millimeter surface, and it drives at a maximum of 0.6 meters per second. The independently driven DC motors compose a three-wheeled drive, which is commonly referred to as a Kiwi drive if omnidirectional wheels are used. The platform can communicate with a computer via USB-UART, but other interfaces are available on the microcontroller as well (e.g. SPI).

Dobot Arm V1.0, shown in Fig. 2, is a commercially available 4-axis robot manipulator. It is priced at 725 EUR and includes the ready-made Dobot arm, a controller unit, five pieces of effectors, a power adaptor, USB cable, toolkit, an extension cable and base. The base, rear arm and forearm joints are driven by stepper motors, while the fourth joint is moved by a servo motor. It has appropriate weight of 3 kilograms with a 500-gram load capacity. The maximum reach of the robot arm is at 320 millimeters with +/- 0.2-millimeter repeatability. Control is achieved by an Arduino Mega 2560 microcontroller with an FPGA board. Communication with a computer can be established via USB-UART.

A Raspberry Pi 2 is used to host the robot's software. It is low-cost (45 EUR), low-power, and small enough to be easily installed on the robot. The Raspberry Pi acts as an on-board control unit for the mobile manipulator, which also enables teleoperation if connected to a suitable external device. Connection to a desktop computer or a laptop allows migration of resource-intensive tasks from the Raspberry Pi to a host with more computing power. Having a single-board computer on the robot is also convenient for connecting other devices (e.g. RGB-D cameras). Communication with additional devices is achieved via USB and Wi-Fi (a Wi-Fi dongle is necessary as the used Raspberry Pi 2 has no built-in wireless network adapter).

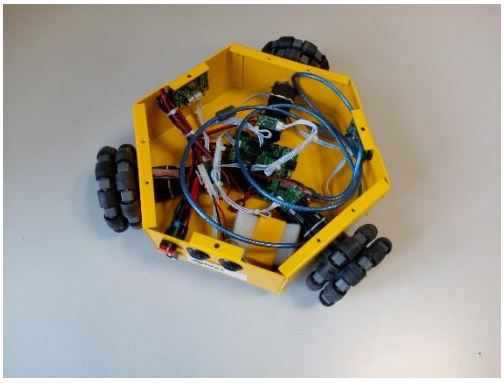

Figure 1. Nexus Robot 3 WD Omniwheel mobile platform

TABLE I. COMPONENT COST LIST

Component	Price (EUR)
Dobot Arm V1.0	725
Nexus Robot 3 WD Omniwheel	520
Raspberry Pi 2 Model B	45
Raspberry Pi USB Wireless Adapter	15
Total	1305

Using inexpensive hardware components, albeit lowering the cost, introduces several challenges into the development process, mainly considering the robot's performance, but its functionality as well. For example, there are no proprioceptive sensors on the mobile manipulator which are required if the robot is going to have some degree of autonomy, making it necessary for a vision guided positioning system to be installed [6]. This also provides a way for driving the robot through its environment avoiding wheel slippage, and minimizing positioning errors for the robot arm. However, not all performance issues can be compensated for (e.g. the manipulator's 0.5-kilogram payload).

The mobile manipulator comprised of a Nexus Robot 3 WD Omniwheel mobile platform, a Dobot Arm V1.0 robot manipulator and a Raspberry Pi 2 computer is shown in Fig 3.

B. Software Architecture

To attain user control over the mobile manipulator, the two primary functions, mobility and manipulation, must be

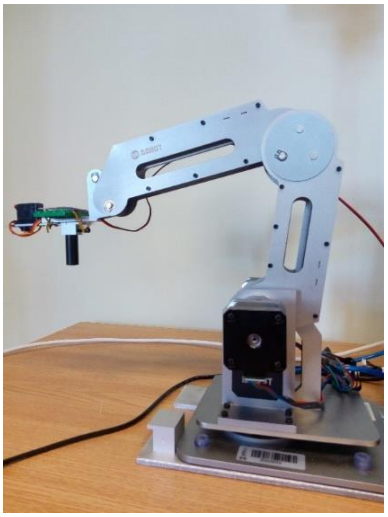

Figure 2. Dobot Arm V1.0 robot manipulator

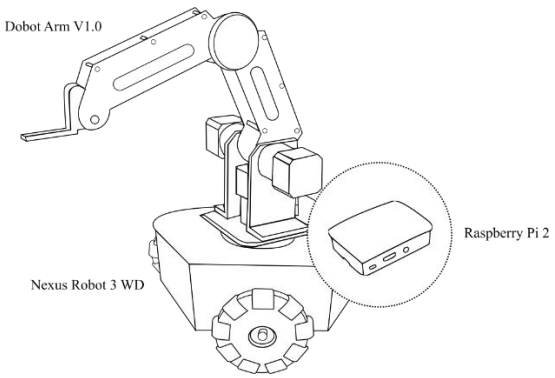

Figure 3. Omnidirectional mobile manipulator with Raspberry Pi 2 as a control unit

controllable through software: the user needs to be able to move the platform around, and control the position of the manipulator. This means that the user's input determines the velocity of the mobile platform and defines the goal for the manipulator's end effector as shown in Fig. 4.

The use case diagram depicted in Fig. 4 defines the requirements for platform and manipulator movement. The direction of movement for the platform is used to calculate the speed of all three wheels, because the platform moves in the direction based on forces exerted by its wheels. Likewise, the goal point given to the robot manipulator is used as input for kinematic operations that result in the desired positioning of the manipulator's end effector. The speed of movement for each robot subsystem is also user defined.

These actions can be intuitively grouped to form a sequence of tasks that leads to the movement of both mobile manipulator subsystems. One task reads user-defined data for the desired movement, another uses the read data to calculate the parameters for movement execution, while the last one executes the movement. In a general setting, the processing for all tasks is held in self-contained program nodes that can communicate data to each other. Unidirectional communication is used to propagate user input data resulting in mobile manipulator movement (Fig. 5).

In order to achieve remote control, the nodes need to be distributed over the mobile manipulator and the remote computer. This is done by connecting the Raspberry Pi embedded computer on-board the robot and the user-controlled remote computer via Wi-Fi. The remote computer holds nodes that receive user input and process the data so it can be used for computing the robot

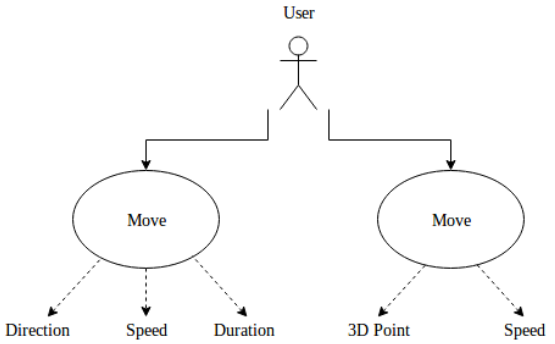

Figure 4. Use case diagram for mobile manipulator control

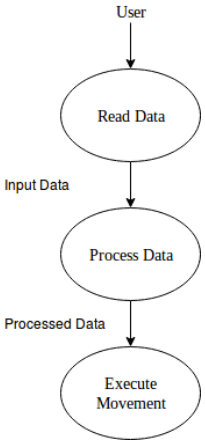

Figure 5. Generalized node pipeline

kinematics. The Raspberry Pi receives the processed data and executes the movement by sending messages to the robot controller via serial communication.

This configuration is implemented using ROS [8], with data being exchanged between the nodes in separate messages. Every message holds relevant data for the subsequent node (e.g. the kinematic node that computes wheel speed data needs to receive directional data beforehand). Fig. 6 shows the implemented system architecture with all the messages used within the system.

Computation of inverse kinematics for platform and manipulator movement is distributed to ensure modularity when opting for a different input method, e.g. driving the robot via joystick.

The Twist message holds directional data chosen by the user. Namely, a linear and a rotational vector that denote the platform's drive direction relevant to its coordinate frame.

The direction of motion is denoted with an x and y linear component, and a θ rotational component, where the robot

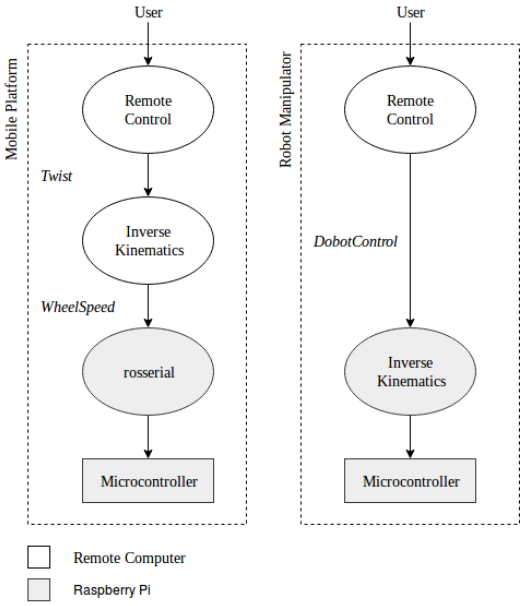

Figure 6. Mobile manipulation system architecture

is able to turn around its *z*-axis. Mathematically, this can be represented by a vector

$$\mathbf{v} = [\dot{x} \quad \dot{y} \quad \dot{\theta}]^T, \tag{1}$$

where $\dot{x}$ and $\dot{y}$ are velocity components, and $\dot{\theta}$ a rotational component, all relative to the platform's coordinate frame depicted in Fig. 7.

For testing purposes, the user can control the platform by using the numeric keypad on the remote computer's keyboard. The numbers on the keypad are mapped to general directions: up, down, left, right and diagonal. In order to drive the robot in an arbitrary direction on the plane, polar coordinates are used. The angle φ needs to be set by the user to steer the robot in the desired direction, with a constant *r*.

$$x = r\cos(\varphi) \tag{2}$$

$$y = r\sin(\varphi) \tag{3}$$

The *x* and *y* coordinates, as well as the angle φ, are given relative to the mobile platform's coordinate system (Fig. 8).

The next node receives the Twist message and uses inverse kinematics to compute individual wheel speeds. This computation can be described by

$$\mathbf{s} = \mathbf{M}^{-1}\mathbf{v}, \tag{4}$$

where **s** is the vector of wheel speeds, **v** is the directional data held within the Twist message and $\mathbf{M}^{-1}$ an inverse of the transformation matrix **M** that relates platform direction to wheel speed as explained in [9]. The message, named WheelSpeed, is then sent via Wi-Fi to the Raspberry Pi which forwards it to the Arduino microcontroller to drive the platform's motors. The WheelSpeed message holds three signed integer values representing vector **s**, with the sign denoting direction for wheel rotation. The ROS packet rosserial is used to establish serial communication with the platform's Arduino microcontroller [8].

Likewise, the microcontroller on-board the robot manipulator needs information for setting the motors in the manipulator's joints at desired angles. This computation is done intrinsically with an open-source library [10]. In order to move the manipulator's end-effector to the desired position, the user needs to provide information about the goal point in Cartesian coordinates, as well as the speed of movement. This information is stored in the message DobotControl which consists of four signed integer values denoting the *x*, *y*, and *z* coordinates relative to the robot's base, and the movement speed in millimeters per second. The relation between the goal point and the base frame of the robot manipulator is shown in Fig. 8, where S_R and S_A denote the manipulators base and end-effector coordinate frames respectively, matrix $\mathbf{T}_R^A$ represents the transformation between those frames, vector $\mathbf{g}_R$ represents the position of the goal point w.r.t. the base frame and vector $\mathbf{g}_A$ represents the position of the goal point w.r.t. the end-effector coordinate frame. These relations are implemented in [10].

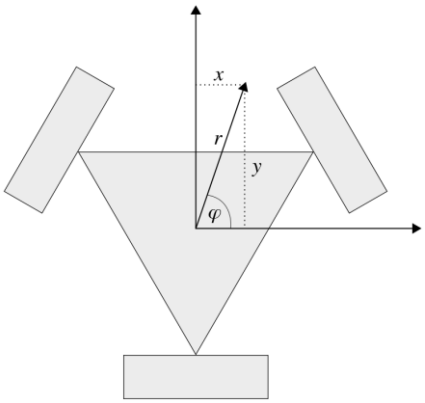

Figure 7. Cartesian (*x*, *y*) and polar (*r*, φ) coordinates denoting direction of motion relative to the mobile platform's coordinate frame

C. Multi-Machine Configuration

ROS nodes can be ran across multiple interconnected machines. Conveniently, this can provide additional computational resources required for demanding mobile manipulation tasks, as the more exhaustive processing is usually completed on a desktop computer rather than on-board the robot. In this configuration, one machine acts as a "master" and hosts the main control software which does the demanding computations, while the other receives processed data required to execute immediate actions in the environment.

IV. Conclusion

This paper presents a cost-efficient solution for mobile manipulation. It is shown that by combining inexpensive hardware with open-source software, a functional research platform can be produced. Using ROS enables straightforward development of robotics applications and allows hardware abstraction. Enabling control over the primary functions of the robot: mobility and manipulation, allows for the implementation of higher level behaviors like go-to-goal or obstacle avoidance. It is important to note that in order to have a system appropriate for research, hardware limitations of low-cost components need to be compensated for by appropriate software solutions.

Acknowledgment

This work has been fully supported by the Croatian Science Foundation under the project number IP-2014-09-3155.

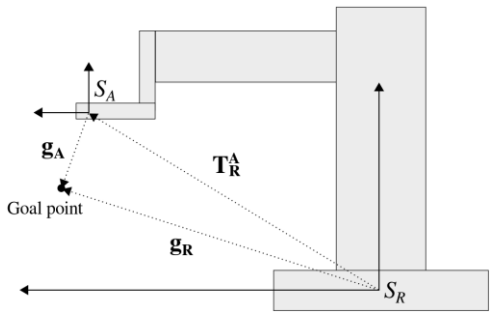

Figure 8. Base and end-effector coordinate frame in relation to the user-defined goal point

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Modelling Thermal Transients in Controlled Double Skin Façade Building by using Renowned Energy Simulation Engines

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***Abstract* - The paper is an analysis and overview of some simulation tools used to model specific thermal dynamics that occurs while controlling double skin façade. Research has been conducted on simplified construction with single zone where one side is glazed. Heat flow and temperature responses are simulated in three different simulation tools: IDA-ICE, EnergyPlus and HAMBASE. The excitation of observed system, used in all simulations, was a temperature step of adjacent zone. Air infiltration, insulation and other disturbances are excluded from this research. Although such isolated behaviour is not possible, experiments are carried out to gain novel information about heat flow transients which are not observable under regular conditions. Results revealed new possibilities for adapting the parameters of the regulator i.e. artificial neural network. Along numerical simulations, the same set-up has been also tested in a real-time experiment with a 1:18 scaled model and thermal chamber. The comparison analysis brings out interesting conclusion about simulation accuracy in this particular case.**

***Keywords - Double skin façade, experimental tests, heat control,*heat flow, simulated tests, simulation tools**

I. INTRODUCTION

The energy simulators are being commonly used to examine the building's behaviour in aspect of energy consumptions ([1], [2]). Since these simulators include HVAC system, the idea is to use theirs models in system control, similar as in [3],[4] and [5].

The authors of the paper are interested in special case of building's element called Double Skin Facade (DSF) were cavity air has controllable properties. Thin and transparent envelope of the DSF building brings an un-

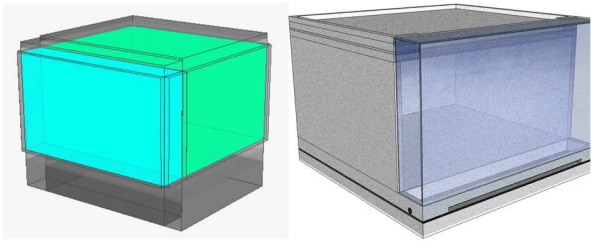

Figure 1. Temperature in scaled dimension model

efficient thermal isolation from external conditions as shown in [5], [8] and [8]. If the clients don't want to abandon benefits of the DSF, the only way to improve energy efficiency of such system is to equalise the heat loss in total envelope. Also, the user would feel smaller differences between micro zones of the inner space.

Usually this is resolved by placing HVAC actuators next to critical part of the envelope like in [9] and [3]. Still, most of the regulators work with one temperature measurement as a control feedback. The improvement of energy efficiency lies in a control that use heat flow as main input. To enable it, the heat should be measured with adequate precise and without extra ordinary expenses. One possibility to overcome the problem is an estimate of the heat flow aided with constant adaption. Such approach has become very often in alternative control systems, as may be seen in [11], [12], [13], [14], [15], [16] and [17]. One further step would be to insert thermally conditioned air directly into the cavity between skins what has sense only if the cavity is closed system and the DSF have function of heat economiser. This paper is analysing workable solutions and possible models that could be used as one of incomes of intelligent control systems for this kind of built. The different models from renowned simulators were tested under same conditions and similar set-up. Tested simulators are listed as follows:

- IDA Indoor Climate and Energy (IDA ICE),
- Heat Air and Moisture model for Building And Systems Evaluation, HAMBASE, and
- Energy Plus.

Energy Plus were initially meant to be used, but results of initial test had so low quality for given conditions, it could not be even compared.

IDA ICE is commercial software which is used for building modelling, as well as its systems, and controllers with the insurance of the lowest possible energy consumption and the best possible occupant comfort. IDA ICE is a detailed and dynamic multi-zone simulation application for investigation of thermal indoor climate and the energy utilization of the whole building. The physical models of IDA ICE mirror the most recent research and accessible models.

TABLE I. DIMENSIONS OF THE TESTED CONSTRUCTION

Zones	Dimensions		
	Room height (m)	*Floor area m^2*	*Sunlight, Occupancy, Devices (W/m^2)*
Office zone	3.6	33.57	0
Cavity zone	3.6	6.124	0

HAMBASE is a simulation model which is made in MATLAB environment. The simulator covers estimations of heat and vapour flows of building [18]. The input is similar to earlier mentioned alternatives: hourly data about exterior temperature and humidity, detailed description, building's properties etc. As result, the indoor air temperature, humidity and energy usage is calculated, even if heating and cooling of a multi-zone building is involved.

Simulator engines of both: HAMBASE and IDA ICE, are based on same energy equality (1) which is linearized and described with method of thermal networks, what is presented and explained in [19].

$$\text{LOSS+STORED} = \text{GAINS} + \text{AUXILIRAY} \quad (1)$$

Linearization is done around values of interest such as slower transient process and sinusoidal variation of temperature. Hence, using them in control means breaching defined limitations, so this research should answer how much non-recommended input effects the result, and is it possible to gather some useful information from such models.

II. SIMULATIONS

The simulation was performed to analyse thermal response of building's interior, caused by fast, unnatural change in temperature. Simulated excitation, such as step, cannot be seen in common usage, but this is a best method to compare behaviour of HVAC estimators.

A. Set Up

Tested object is representing modern energy efficient building structure, where model is made as a part of building with double-skin façade. Dimensions are listed in Table 1 and parameters in Table 2. Even though, the structure has only one interior "room", it is configured with two separate zones, because specific closed type of DSF building is not supported by any simulator. Zone 1 is the zone which is representing modern energy efficient building structure and Zone 2 is representing double-skin façade. More detailed descriptions may be found in paper [20] and [21]. In all performed tests, simulations were made with artificial weather conditions. Weather file was made in the way that temperature was constant for some period and then there appears huge temperature step from 0 to 35°C. The test was performed without solar radiation or any other disturbance with intention to isolate only one single event. Authors realise that solar influence is the main actuator in daily cycles, but still, in terms of HVAC control, it is just disturbance.

TABLE II. PARAMETERS OF THE TESTED CONSTRUCTION

Wall	Dimensions		
	U-value $Wm^{-2}K^{-1}$	*Thickness m*	*Number of Layers*
Concrete floor of cavity	2.39	0.18	2
Concrete wall of cavity	0.54	0.27	3
Interior wall between zones	0.62	0.15	3
Concrete floor	2.9	0.26	3
Concrete joist roof	0.17	0.35	5
Roof	1.41	0.02	2
Floor	0.05	0.77	2
Glasswall	4.65	0.04	1

First serial of simulations will involve IDA-ICE software and mentioned response with few different representations and variations. One of variation is dimension, where extreme reduction with scale of 1:18 is applied. Comparison analysis is performed on obtained results described in following subsections.

B. Temperature Simulation – IDA-ICE

Simulated response of the model with scaled dimensions, presented in Figure 2, shows that temperatures are equalizing after approximately 5 days. The difference between mean temperatures of zones is in signal gain, as well as the time required to reach steady states.

In the scaled model, Zone 2 was rising in temperature much slower than Zone 1, which can't be correct. Zone 2

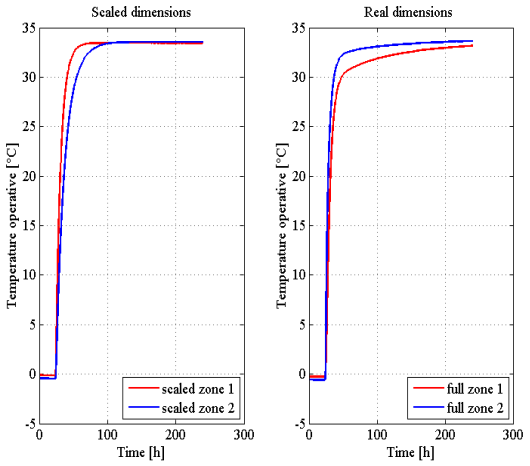

Figure 2. Full dimension model and scaled model temperatures in zones

is smaller and basically made of glass, so we must take in consideration that it needs less time to heat up. The temperature in full dimension model had smaller differences in equalization, as shown in Figure 2 b. Zone 2 has risen in temperature faster than Zone 1, which was

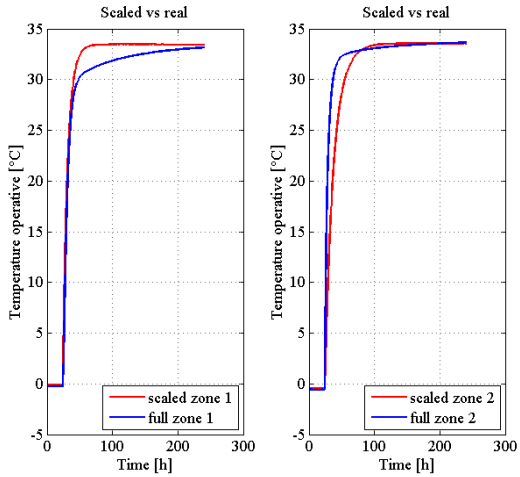

Figure 3 Temperature comparisons in full dimensional and scaled model

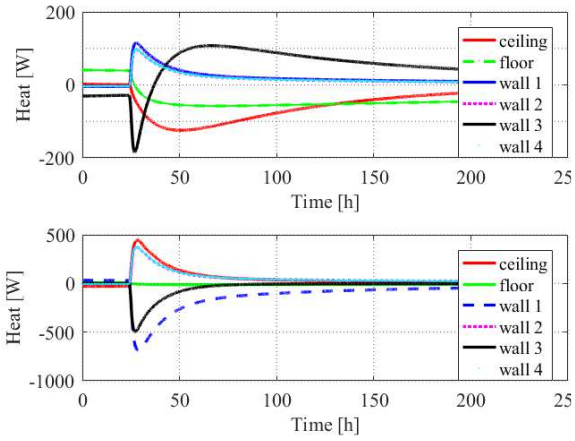

Figure 5 Heat loss through envelope of full dimension model a) Zone 1 b) Zone 2

expected. Weather simulation, building set-up and all other crucial factors were the same in both cases. As per comparison of both full dimension and scale models, some differences were noticed.

In graphs of Figure 3, there will be shown mean air temperature differences in scaled and full dimension models. From the results for the Zone 1, it's visible that in scaled model the necessary time for heating up the Zone is much faster than in the full dimension model. As for the Zone 2, the results seem unrealistic. Heating up of the Zone 2 in the scaled model is much longer than in full dimensional model, which can't be possible, because of much smaller dimensions.

C. *Heat simulation – IDA-ICE*

Further analysis was focused on surface heat of various parts of external construction. The simulation results were taken from previous case. In Figure 4, we can find heat losses and gains through all external parts of

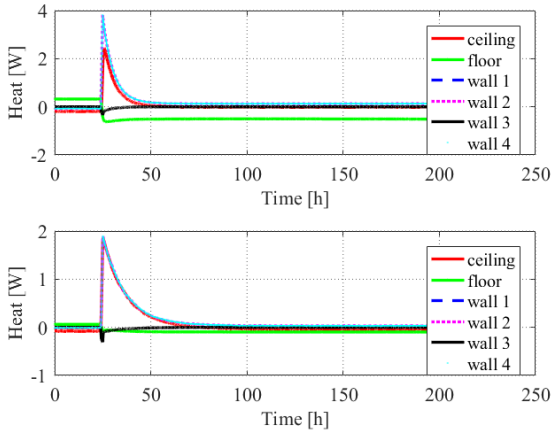

Figure 4 Heat loss through zone envelope of model with scaled dimensions a) Zone 1 b) Zone 2

both zones. The envelope's element noted as Wall 3 is in fact the interior glazed surface that divides two zones. Only this signal is identical in both graphs. The peak of heat gain of external wall elements in Zone 1 are higher than one of external glazed element with similar surface in Zone 2. This behaviour can't be possible due to same initial conditions and lower thermal resistance of the thin glazed surfaces. To resolve the cause, the same experiment is analysed also on model with full dimensions. Figure 5 presents heat flow through external parts in the full dimension model. Here, Zone 1 has much smaller heat losses than Zone 2, which was expected and is acceptable by the means of physics. The misbehaviour of the simulator in case of reduced size is caused by breaking the assumptions of model. The models are expecting the sinusoidal shape of temperature variation, and not a steady state, so that is why signals had trouble to reach it (See [20]). Additional negative post effect of violation in parametrisation is in incorrect values of settling times which is present in all experiments.

D. *Temperature Simulation – HAMBASE*

HAMBASE simulator was tested with same method as shown earlier with IDA-ICE. Figure 6 represents interior temperatures resulted after positive step. In a given display, both responses have comparable values. Beside simulation results, here is also given one experimental result made on scaled version. In the experimental test, one segment of DSF building was used as experimental model, and thermal chamber was used to change thermal conditions outside of the model. The model was built with same material and dimensional characteristic as one in simulation. One of the results, that are described in [20] with more details, is used in this research as a reference. Experimental and simulated results differ in almost all aspects: overshoot, gain, settling time and deviations in steady state. Neither HAMBASE or IDA ICE satisfies the requirement for direct usage in system control.

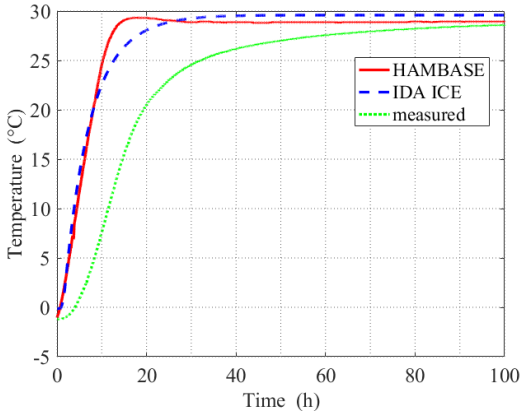

Figure 6 Temperature response of HAMBASE, IDA-ICE and experimental model, scaled dimensions

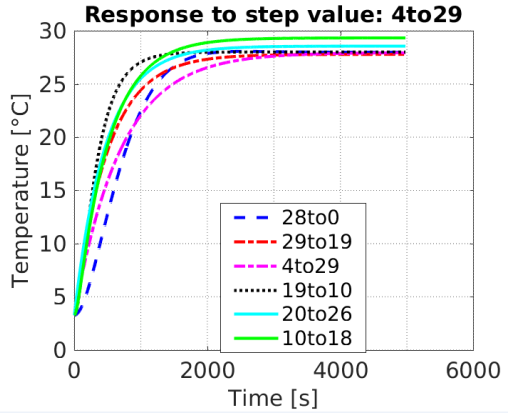

Figure 7 Thermal responses of custom models defined with different parameters

Because of negative conclusion, there was no sense to show all simulated variations of HAMBASE model. Thanks to the free access of HAMBASE source code, the mathematical model of the software is extracted and analysed. The analysis determined that heat transfer process in HAMBASE engine is described with second order function and its parameters are defined through Matlab optimisation function *fminsearch.* Optimisation function is highly depended on basic element properties such as wall resistance, capacities, inductivities etc. Authors decided to test if direct identification of such parameters would get better results even same second order function is used. Parameters are also identificated by *fminsearch*, but now with directly measured data. Input was thermal response on a step as in Figure 6.
Figure 7 shows six different curves as a response of differently parametrised model to the same step. Deviations increases if the values of identification step are more different. This behaviour points out to non-linear characteristics in wide range, but liner in small. By knowing this, authors say that control system may use simple model, but must be capable to adapt.

III. CONLUSION

This paper has given a specific analysis of two energy simulators for buildings but applied to a special case of fast thermal transient. The aim was to investigate a possibility of using the simulator's model as an aid to a control system. Experiments have shown that both models are very sensitive to reduction of dimensions value and to a time constant of the thermal process. However, shape of simulated curves remains equal under different model parameters, what indicates that system response is linear only for certain input range. In such range, second order transfer function is sufficient to estimate observed behaviour. Hence, simple model may be used for system estimation and control, but only in limited area. Everything else is too high over the model's limitations and would end up with demeaning results. Other solution is control method with ability to adapt and compensate non-linearities.

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E/2 IR module for regulation of temperature controlled cooking process

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Abstract **- E/2 stands for a technology dedicated to cooking that saves up to 50% of Energy and IR stands for infrared technology that is an update to standard wireless sensors. The IR measuring technology is integrated into the E/2 technology and it measures the temperature of the bottom of the cookware from inside the stove. Temperature regulated cooking is the industry goal because of the importance of the use of the correct temperature in cooking; using the correct temperature while cooking can produce healthy food avoiding overheating which destroys proteins in the food. Products that use IR technology exist; they are very expensive however they are not ready for mass production. Our goal was to upgrade E/2 technology with IR reading. We developed a unique, revolutionary sensor that is cheap for mass production with even better characteristics than today available and expensive state of the art. The IR Sensor and the method of calibration are patent pending and for the first time presented in this article. E/2 cooking plug-in sensor for stoves is presented in this article, together with experimental results and the unique calibration method.**

Keywords – IR sensor, E/2 technology, revolutionary sensor, cooking, energy saving, energy regulation

I. INTRODUCTION

The history of E/2 is very long considering today's perspective where wireless technology is presented in our lives and we see IOT everywhere. The Multisensor wireless technology has been developed based on our wireless vision 30 years ago. Passion for cooking and regulating energy in the cooking process in a proper way is still the goal. We received the first patent on wireless cooking sensors in 1995. Since our founding we have acted as a pioneer in the world of wireless sensors in cooking. E/2 proprietary wireless protocol for cooking, Gorenje Iqcook technology, E/2 cooker from Midea, E/2 IR sensor from Beko, BSH wireless Perfect sensor and many others are valuable steps in our continuous development. Our goal has always been and still is, is perfection. We achieve this with uncompromising work for making cooking better for people; with minimum energy needed and to produce food that is healthy with the unique temperature cooking philosophy. We have a difficult and hard path because we do not fit in the philosophy of today's market and industry producing cooking appliances whose single goal is to achieve the biggest profit on sales of cooking appliances.

II. TEMPERATURE REGULATED COOKING FROM BEGINNING TO THE STATE OF THE ART

Cooking food is as old as fire invention. Cooking food increases the range of foods we can eat.

There are a big number of good resources on importance of temperature in cooking [1]. Some of them are increasingly accepted, pushing the industry to think about temperature in the process of cooking. One example is the important field of heating oils - the correct temperature for grease. The heated temperature should not go over 150ºC for virgin olive oil, 170ºC for butter, and 190-220ºC for vegetable oils and so on. High temperature is causing the formation of acrylamide from proteins and sugars. Acrylamide may cause cancer. Many scientific articles [2] report about the influence on the ingredients in the food in the different ways of cooking. An example of standard terms: "preheat the pan on middle energy, add ingredients and gently cook to achieve the right taste…" Generally, all famous cookbooks and recipes are based on experience, without clear temperature data. One example of good praxis is the teaching book for cooking Tiptop with clear temperature definitions. [3] Few decades later, as electricity started to be used for cooking, the first temperature regulation was used. Figure 1 shows a cooker that is more than half century old and a user Manual [5] explains how to use it best for preparing the food.

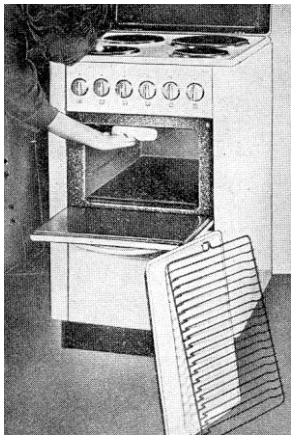

Figure 1. Tobi cooker from 1961

In cooking appliances like shown on figure 1 a power regulation switch was built in, and they are still present today. [6]. (3)

Figure 2. Energy switch EGO

From this great development of cookers, industry shifted to ceran (ceramic glass) cooking surfaces, and high-light heaters that speed the process of heating food. The important fact is that none of these new developments changed the way of regulating energy. The solution of the problem in high temperature that the industry found is in „cold" cooking surfaces - induction cooktops. They are becoming one of the most popular appliances. In this system, the pots are heated up by two dissipation phenomena: the induced currents and the ferromagnetic losses, both of them originated by varying magnetic fields generated by alternating medium frequency currents (30 to 45 kHz) flowing through a planar coil placed below the glass-ceramic surface. The temperature in the cookware is still a hidden variable to the control because no temperature probe can be placed in contact with the vessel due to product requirements. The temperature estimation system has to be located below the cooking surface. Physical temperature measurement system based on a thermistor located under the glass-ceramic is shown in Figure 3.

Figure 3. Typical NTC sensors – below ceramic cooking surface left EGO and right Beko

This system constitutes a simple and cost-effective solution, but it possesses some disadvantages, mainly due to the thermal inertia of the glass-ceramic, which introduces attenuation and time delays between the temperature of the cookware and the temperature of the glass. This effect becomes very critical in rapid heating transients due to the large difference between the measured temperature in the glass and the temperature in the cookware which implies that the cookware can reach high temperatures before the temperature sensor detects this situation.

III. IR TEMPERATURE REGULATED COOKING

Optical infrared (IR) sensors of different technologies, photo-resistors, thermopiles, in array format for infrared computer vision and including optical fibres have been analysed by many authors for other applications. IR sensors are developed in the last years with great speed. [7] There is a lot of science work done in this field with expensive sensors like InGaAs sensors, but that was never used in real production for market because the cost is much too high [8] .

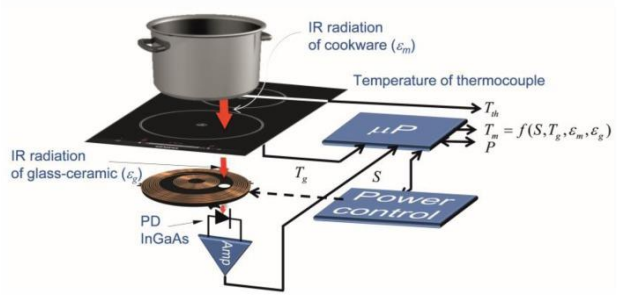

Figure 4. Example of regulation with InGaAs detector

Some IR solutions on the market are also integrated in cooker. One of the leading appliances is the Miele Tempcontroll cooker [9] Figure 5 that represents a very high price cooker with one single temperature controlled cooking surface and with only three different temperature levels : 160-200-220 ^{0}C . Second solution is the Panasonic Genius sensor with special IR Array. However, the systems based on the infrared radiation detection have rapid response however the cost for the industrial applications of this technique in the cooking appliances industry is a big issue.

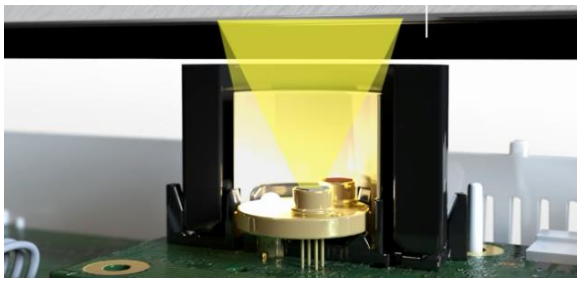

Figure 5. Miele Tempcontroll system

The aim of our E/2 IR development was to develop a temperature control system based on an IR temperature sensor that will be a cost-effective solution. The temperature measurement system, shown in Figure 6 is based on the detection of the infrared light radiated by the bottom of the cookware and spectrally weighted by the glass-ceramic optical transmittance. All our work is based on the practical development confirmed with experiment. The base of our development was to upgrade our existing E/2 system E/2 cooking sensors and plug-ins for stoves which were presented in article E/2 Wireless Regulation of Energy Based on Temperature Controlled Cooking Process [12] and the hardware was explained in the article Multi-Heater Induction Heating System with Sandwich Material Heater [13] . With our cooking

algorithms, saving of more than 50% Energy and 80% time is achieved. In the last years our wireless technology was accepted by few producers of hobs and pots. In 2012 Gorenje launched Iqcook technology, Midea is Producing E/2 cooker, Beko is integrating E/2 IR sensor, WMF and Tefal have E/2 prepared pots and pans as well as other producers are aware that E/2 is on the market.

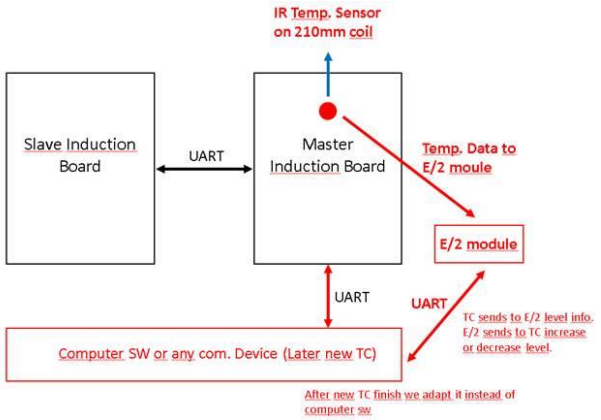

Figure 6 Integration of IR sensor in induction cooker.

The biggest challenge was to find the right sensor that can see through theceramic surface where the wavelength is limited to small window shown in Figure 7.

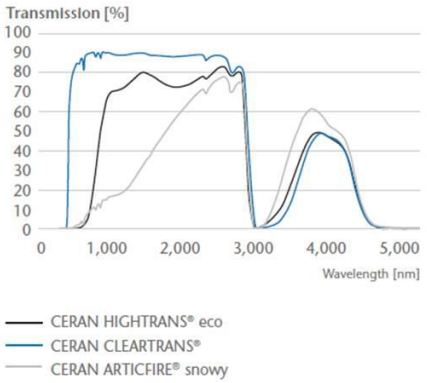

Figure 7. Transmission curves for ceramic cooking plate

IV. IR TEMPERATURE MEASURMENT

We developed unique sensor system that is cheap for mass production with better characteristics than today known expensive state of the art sensors used in cookers. IR Sensor and the method of calibration are patent pending and for the first time presented in this article. To calculate the temperature of the bottom of the pan from sensors with needed precision we used two IR sensors. First is MSX 0222 that is measuring temperature of the glass and the second is E/2 0622 that is measuring temperature of the bottom of the pot. Each of them have also integrated NTC reading. From these sensors we measure:

V_{ORI}: MSX 0222 thermopile reading voltage signal
T_{ORI}: MSX 0222 NTC reading temperature
V_{EXC}: E/2 0622 thermopile reading voltage signal
T_{EXC}: E/2 0622 reading temperature

Initial assumptions: After a specified time,

$$T_{POT} = T_{LID} = T_{GLASS} \quad (1)$$

The sensors are connected due to the construction of the measuring device and the characteristics of the sensors themselves at the same time $T_{EXC} = T_{ORI}$
After a specified time $T_{POT} = T_{LID} = T_{GLASS}$
The sensors are connected due to the construction of the measuring device and the characteristics of the sensors themselves at the same time $T_{ORI} = T_{EXC}$

Where
T_{GLASS}: Glass temperature (calculated)
T_{POT}: Pot temperature (calculated)
T_{LID}: Measured temperature of the calibration sensor

$$V_{ORI} = C \cdot (T^4_{GLASS} - T^4_{ORI}) \quad (2)$$

C, D : Calculation parameters

Based on C and the measured values of V_{ORI} and T_{ORI}, we obtain the calculated temperature of the T_{GLASS} glass having already taken into account the temperature compensation.

We change the basic equation by assuming that we can replace the temperature compensation and the energy that affects V_{exc} senor with V_{ORI} The equation reads

$$V_{EXC} = C \cdot T^4_{dPOT} + k * V_{ORI} \quad (3)$$

The calculation is simply the difference between the measured value of the current E/2 and the value of the V_{ori} . T_{dPOT} is the difference in temperature due to the difference between the temperature of the vessel and the glass. The final temperature was previously calculated

$$T_{POT} = T_{glassori} + T_{dPOT} \quad (4)$$

This algorithm shows very good results when used in experiments presented in Figure 9.

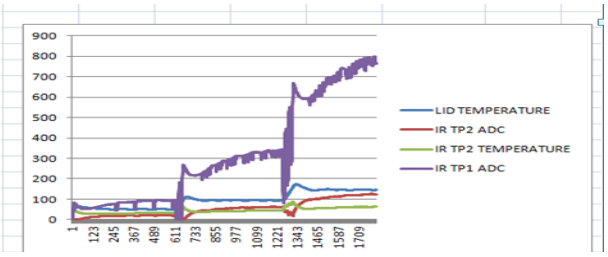

Figure 9. Experiment with calculating parameter C

V. IR DETECTORS

The price performance was the primary goal and Detector 0622B /5200 that is produced for MSX fulfils this goal. With small band filter it can measure the temperature of the pot through the ceramic cook top glass.

Figure 10. MSX E/2 detector

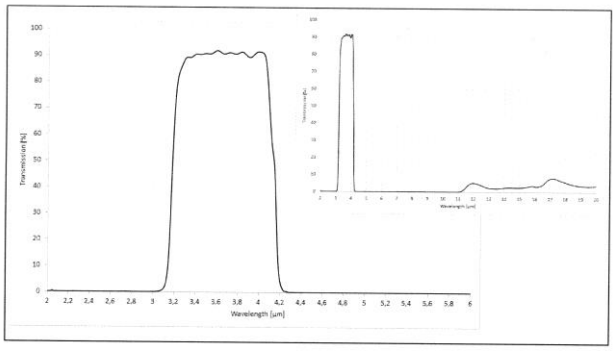

Figure 12. Filter characteristic on MSX E/2 sensor

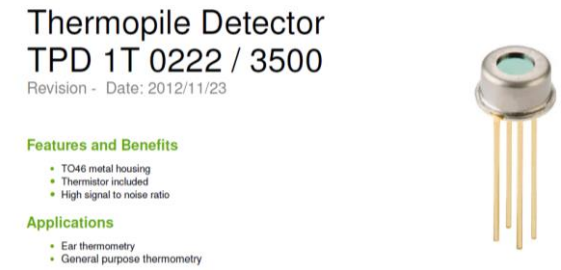

Figure 11. Standard low cost detector for measuring temperature of the glass

VI. ELECTRONIC IMPLEMENTATION AND TEMPERATURE CONTROL SYSTEM

Our regulation system of Energy is well developed and we did not have problems to implement data on temperature of the bottom to our cooking algorithms E/2. The output signal provided by the detector is low (a few nano amperes), therefore, the amplification and filtering of the signal is needed prior to the processing of the signal.

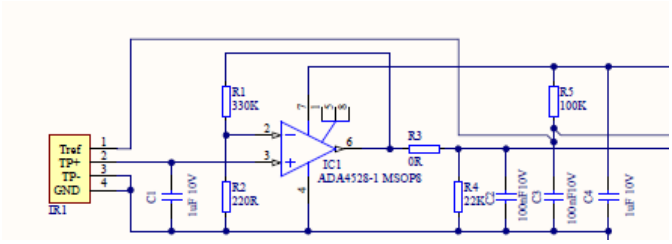

Figure 13. Simple schematic of amplifying circuit.

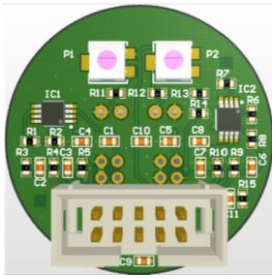

Figure 14. E/2 IR sensor part of our electronic pcb

Figure 15. E/2 Complete module for cooker with E/2 and standard sensor

VII. CALIBRATION OF TEMPERATURE CONTROL SYSTEM

Experimental setting (Figure 16) is developed for testing and implementing of calibration. Calibration is done automatically whenever the temperature begins to rise. When the requested temperature point is reached, V_{ori} and V_{exc} are adjusted and preset C is corrected. One example of calibration test is shown on Figure 17.

Figure 16. Experimental setting with external wireless sensor

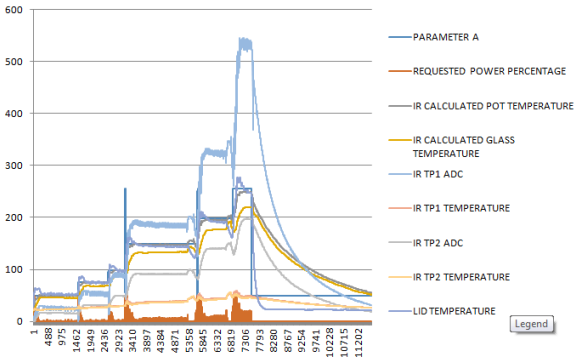

Figure 17. Results of calibration

VIII. MATERIALS OF COOKWARE AND INFLUENCE ON IR MEASURMENT

The main factor for IR measurement is emissivity of pots. To solve this dependency we developed a unique system to measure that is implemented in E/2 IR sensor. Emissivity depends on material characteristics and can be measured through reflexivity of the bottom. Here is a list of some common materials used in cookware and their respective thermal conductivity:

Material	Thermal conductivity
Copper	401 W/m*K
Aluminum	237 W/m*K
Cast Iron	80 W/m*K
Carbon steel	51 W/m*K
Stainless steel	16 W/m*K

Cookware made of materials with high heat capacity, will take longer to heat up, but will also have a significant amount of energy stored up when it is hot. The specific heat (the heat capacity of a material for a given mass) of cast iron is half of aluminium's specific heat, but because cast iron cookware is generally several times the mass of aluminium cookware, it has a much higher heat capacity. The thickness of metals used in the construction of cookware are often cited by the manufacturer (for example, 3 mm aluminium), but since heat capacity is a function of the mass of the material, density must be known to make comparisons between cookware of different materials.

Material	Specific Heat	Density
Aluminium	910 J/kg*K	2600 kg/m3
Stainless Steel	500 J/kg*K	7500 - 8000 kg/m3
Carbon Steel	500 J/kg*K	7500 - 8000 kg/m3
Cast Iron	460 J/kg*K	7900 kg/m^3
Copper	390 J/kg*K	8900 kg/m^3

Thermal diffusivity of a material is simply the thermal conductivity divided by the unit heat capacity (specific heat times density).

Material	**Thermal diffusivity**
Copper	120 * 10^{-6} m^2/s
Aluminium	100 * 10^{-6} m^2/s
Cast Iron	22 * 10^{-6} m^2/s
Carbon Steel	14 * 10^{-6} m^2/s
Stainless Steel	4.3 * 10^{-6} m^2/s

New sandwich materials are also a big problem because they have emissivity of the surface (stainless steel) but they behave like the inside materials (Aluminium)- an example is S/S 304 + AL + S/S 430. To our sensors, we added IR LED and phototransistor to add data on reflection. Figure 21 show schematic and Figure 22 the real construction drawing of the setting. Together with our data from wireless sensors the solution is working with double checking the calculated temperature.

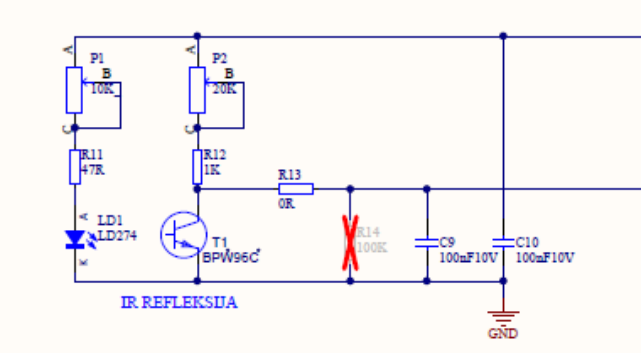

Figure 18 Schematic of IR reflection measuring system

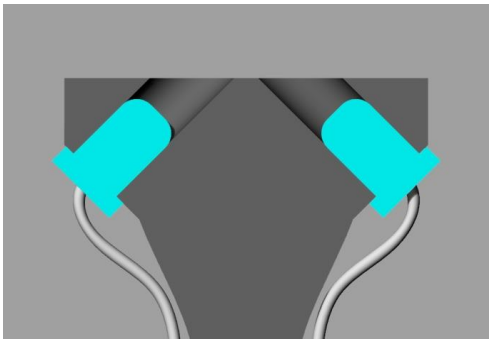

Figure 19 IR LED and phototransistor are build in sensor E/2 module

IX . IMPLEMENTATION OF IR READING IN E/2 REGULATION OF COOKING PROCESS

There are three configurations of devices in E/2:

- only thermo controller with an ability to adjust the temperature and time and the acoustic signalling when the set parameters are achieved and displaying it on the screen of thermo controller
- induction hob with the connection in E/2 technology – choosing parameters of cooking on the thermo controller and piloting the induction hob in E/2 technology

- Thermo controller plus induction hob plus application on Smartphone – piloting the cooking process with the help of the Smartphone and the constant overview of the parameters.

Figure 20. One simple button touch – cook for me – simple for the user

After choosing the cooking there is a possibility to set the temperature:
sous vide: 40-60°C
healthy: 60-80°C
traditional: above 80°C

Several user preset cooking modes allow additional simplicity in cooking and bring home-cooking and kitchen into the centre of family. Add-in is by definition also an accessory software program that extends the capabilities of an existing application. E/2 technology with revolutionary sensor wireless concept is added-in every today concept of cooking regulation. No matter what kind of regulation is in the controller it can be upgraded with E/2 add-in. With IR data on bottom of a pot, the regulation is even more accurate and safe [11].

X. CONCLUSION

Induction heater is often used in process of cooking in the household. Its' advantages are that it is very quick and it is energy efficient in heating of food. In standard cooking appliances heater is placed below the glass surface and they are energy controlled with electronic regulation. The power regulation is not precise and the user can very rarely find the right level of energy in different processes of cooking. Temperature regulation is the goal. E/2 multisensor system is a standard sensor network for precise definition of cooked food. with very precise automatic cooking control. of the bottom helps in the precision. A control algorithm is Software and IR reading developed based on needed cooking process, where very little power is needed in process of cooking after food is heated to boil. Such algorithm enables the use of cooker hardware are explained in this article.

Results of tests are done with thermodynamical analysis of real cooking processes/2 technology uses multi wireless sensors for determination of temperature of the food and state of cooking.

- E/2 is located in the cooker with IR reading
- E/2 regulation is the only technology in the world concentrated on boiling process and the only technology that can bring such high savings in comparison with other state of the art technologies.
- E/2 technology can be used for simple regulation of energy and also for most sophisticated definition of different temperature levels.

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Alternating Direction Method of Multipliers in Optimal Control of Systems of Systems

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***Abstract*—This paper investigates the usage of a distributed algorithm – the alternative direction method of multipliers – for control of system of systems, i.e. control of a complex system comprising large number of distributed and partially autonomous subsystems. The control algorithm is based on parametrization and decomposition of the central optimization problem into local optimization problems specific to individual subsystems, while taking into account the coupling constraints that link them. Local problems are solved offline using multi-parametric optimization methods, whereas the coordination problem is solved online at every sampling step and the optimal solution is applied to the system at hand in a receding horizon fashion. The method solves the optimal control problem online iteratively while exploiting the control system structure. The efficiency of the method is tested on a number of generated distributed optimization problems modeling large systems of systems.**

***Index Terms*—model predictive control, systems of systems, multi-parametric optimization, alternating direction method of multipliers, coordination methods.**

I. Introduction

Systems of systems (SOS) are large complex physical systems consisting of a large number of distributed and partially autonomous subsystems. The subsystems are coupled and interact through the flow of material, energy and resources [1]. Closely related is the term cyber-physical systems, which refers to the tight conjoining of and coordination between computational and physical resources. The subsystems of cyber-physical SOS are interconnected through a communication network that enables coordinated control and supervision of the subsystems but also sets a limit of the information flow in the SOS. Some examples of cyber-physical systems of systems are: rail and road transport systems and hydro, thermal and electrical energy supply systems.

To optimally control SOS one has to coordinate all subsystems and their interactions, while taking into account the constraints stemming from the subsystems coupling and their physical limitations. The lack of coordination can result in a system failure or undesirable behavior due to the complexity of the system dynamics [2]. An example of such a behavior is a blackout in a part of the electrical power grid.

The optimal coordination control problem can often be formulated as a model predictive control (MPC) problem. The main idea of a discrete-time model predictive control is to use prediction of the future behavior of the system over a defined (finite) prediction horizon. Based on the the current state of the system, which is measured or estimated at every sampling step, the optimal control sequence is found that minimizes a chosen cost function while satisfying system constraints. In a receding horizon principle, only the first element of the obtained optimal control sequence is applied to the system, and the entire process is repeated at the next sampling instant [3].

Clearly, the MPC boils down to solving the underlying optimization problem at every sampling instant, which is usually done in a centralized manner. Sometimes, however, the corresponding optimization problem can't be solved centrally (within the sampling period) because of its complexity or because of the lack of system information. Namely, to form and solve the central optimization problem a full access to all subsystem states is needed, which isn't always possible/practical (e.g. privacy issues, different ownership or management structures). Whenever such centralized coordination is not possible/applicable, another option it to use distributed control.

Distributed control methods separate the underlying central optimization problem into local control optimization problems attached to the local subsystems. All local problems can be solved in parallel (locally) and then iteratively coordinated (from one central place, via the distributed control network) to achieve the global control goal – optimal coordination. In this manner the major part of the processing workload is distributed to local subsystems.

One of the currently most efficient distributed optimization methods is the alternating direction method of multipliers (ADMM), [4]. The goal of this paper is to examine the applicability of ADMM in optimal control of SOS and to compare its efficiency with the centralized optimization approach.

II. Problem setup

We consider a SOS compromised of M locally controllable subsystems described by linear time-invariant dynamics:

$$x_i(t+1) = A_i x_i(t) + B_i u_i(t), \tag{1}$$

where $t \in \mathbb{Z}$ is discrete time, i is the subsystem index, $x_i(t)$ and $u_i(t)$ denote the state and input of the i-th subsystem at the moment t, while the matrices A_i and B_i are constant matrices describing the subsystem dynamics. The control optimization problem is formed of three separate parts: the local control

problem, coupling constraints and the coordination problem, see [5] for more details.

A. Local control problem

Every local control problem is directly tied to its local control subsystem and is defined as a model predictive control problem with a finite horizon, a quadratic cost function and linear constrictions on the states and inputs of the system. Such a problem can be formulated as a multi-parametric quadratic problem:

$$J_i^*(\Phi_i, \Theta_i) = \min_{U_i} J_i(\Phi_i, \Theta_i, U_i), \tag{2a}$$

$$\text{s.t. } C_i^u U_i \leq C_i^c + C_i^p [\Phi_i^T \Theta_i^T]^T, \tag{2b}$$

with a convex quadratic cost function:

$$J_i(\Phi_i, \Theta_i, U_i) = [\Phi_i^T \Theta_i^T] Q_{pp,i} [\Phi_i^T \Theta_i^T]^T + U_i^T Q_{uu,i} U_i + [\Phi_i^T \Theta_i^T] Q_{pu,i} U_i, \tag{3}$$

where $U_i \in \mathbb{R}^{n_{U,i}}$ is the vector of local optimization variables (e.g. local control inputs on the prediction horizon), $\Phi_i \in \mathbb{R}^{n_{\Phi,i}}$ and $\Theta_i \in \mathbb{R}^{n_{\Theta,i}}$ are the parameters. Matrices $Q_{pp,i} = Q_{pp,i}^T \in \mathbb{R}^{(n_{\Phi,i}+n_{\Theta,i})\times(n_{\Phi,i}+n_{\Theta,i})}$, $Q_{pp,i} \succeq 0$, $Q_{uu,i} = Q_{uu,i}^T \in \mathbb{R}^{(n_{U,i})\times(n_{U,i})}$, $Q_{uu,i} \succ 0$ i $Q_{pu,i} \in \mathbb{R}^{(n_{\Phi,i}+n_{\Theta,i})\times(n_{U,i})}$ are the cost matrices which describe the cost function. Matrices $C_i^u \in \mathbb{R}^{n_{c,i}\times(n_{U,i})}$, $C_i^c \in \mathbb{R}^{n_{c,i}}$ and $C_i^p \in \mathbb{R}^{n_{c,i}\times(n_{\Phi,i}+n_{\Theta,i})}$ describe the parameter space of Θ_i,Φ_i and U_i i.e. the constrictions of the local subsystems. $n_{c,i}$ indicates the number of constraints on the i-th subsystem.

Two types of parameters are defined for each subsystem:

1) Local parameters $\Phi_i \in \mathbb{R}^{n_{\Phi,i}}$ which contain all the local time varying data measurements (obtained or estimated at the sampling steps t).
2) Coordination parameters $\Theta_i \in \mathbb{R}^{n_{\Theta,i}}$ which describe the contribution of the i-th subsystem to the coupling constraints.

B. Coupling constraints

The mutual interaction of subsystems and the global control goal is described by coupling constraints consisting of n_{eq} scalar inequality constraints in the form of:

$$\sum_{i=1}^{M} K_i \Theta_i \overset{(\leq)}{=} K \tag{4}$$

where the matrix $K_i \in \mathbb{R}^{n_{eq}\times n_{\Theta,i}}$ and the constant matrix $K \in \mathbb{R}^{n_{eq}}$.

C. Coordination problem

The coordination problem collects all local control problems in the form of:

$$\min_{\substack{U_1,\ldots,U_M \\ \Theta_1,\ldots,\Theta_M}} \sum_{i=1}^{M} J_i(\Phi_i, \Theta_i, U_i), \tag{5a}$$

$$\text{s.t.} \quad C_i^u U_i \leq C_i^c + C_i^p [\Phi_i^T \Theta_i^T]^T, i \in \{1, \ldots, M\} \tag{5b}$$

$$\sum_{i=1}^{M} K_i \Theta_i \overset{(\leq)}{=} K \tag{5c}$$

The global cost function (5b) is the sum of convex quadratic local cost functions, which in turn makes it a convex quadratic function as well. All the local constraints are collected in the term (5c), while the coupling constraints are defined by the term (4). The goal of the coordination problem is to ensure optimal control of all the local subsystems while at the same time satisfying the constrictions provided by the local subsystems and their interaction.

D. Control system structure

A hierarchical structure of the control system is assumed and can be seen on Fig.1. Connections established through the communication network are marked with a blue color, and inherent physical connections between subsystems with a red color. The main elements of the control system structure are:

1) Local controllers. They are located at the bottom of the hierarchical structure and are interconnected with their specific local subsystems. Every subsystem has his unique local controller. That local controller has full access to the local control problem (2) defined for that subsystem and also has direct access to all the states, inputs and outputs of the local subsystem.
2) Central controller. It is located at the top of the hierarchical structure and is responsible for solving the global coordination problem (5). It communicates directly with all the local controllers, but doesn't have direct access to any of the local subsystems. It also collects all the data obtained from the local controllers and knows the coupling constraints (4).

III. Alternating direction method of multipliers

Alternating direction method of multipliers is a method for solving distributed convex optimization problems [4]. It

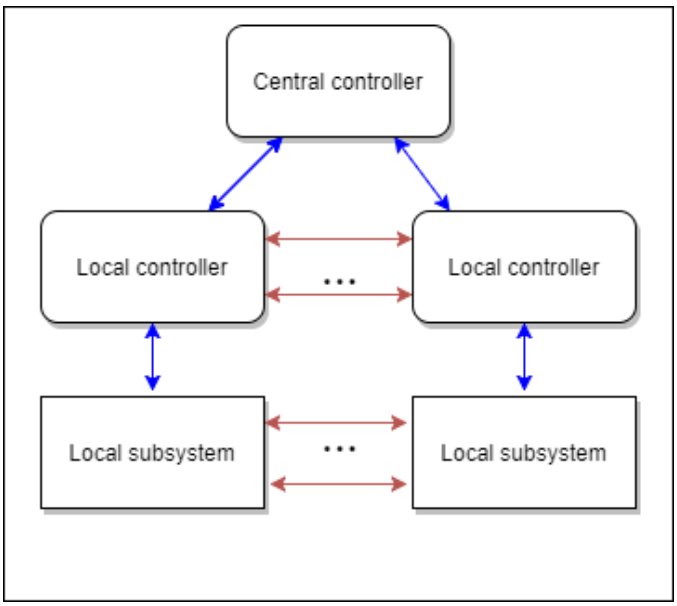

Fig. 1. Control system structure

is a separation-coordination method, in which several solutions of smaller problems are coordinated in order to solve the main problem. It combines the decomposability of the augmented Lagrangian method and the superior convergence of the method of multipliers. The general form of the problem for the ADMM method is :

$$\min f(x) + g(z) \tag{6a}$$
$$\text{s.t} \quad Ax + Bz = c, \tag{6b}$$

with vectors $x \in \mathbb{R}^n$ and $z \in \mathbb{R}^m$, matrices $A \in \mathbb{R}^{p\times n}$ and $B \in \mathbb{R}^{p\times m}$ and the variable $c \in \mathbb{R}^p$. Functions f and g are convex. This form differentiates from the classic optimization form because they are two vector x and z instead of one and the cost function is also separated by those vectors. The next step is forming the augmented Lagrangian:

$$L_\rho(x, y, z) = f(x) + g(z) + y^T(Ax + Bz - c) + (\rho/2)\|Ax + Bz - c\|_2^2, \tag{7}$$

where $\rho > 0$ presents the penalty parameter. The ADMM algorithm consists of iterations which all share three steps:

$$x^{k+1} = \arg\min_x L_\rho(x, z^k, y^k), \tag{8a}$$
$$z^{k+1} = \arg\min_z L_\rho(x^{k+1}, z, y^k), \tag{8b}$$
$$y^{k+1} = y^k + \rho(Ax^{k+1} + Bz^{k+1} - c). \tag{8c}$$

The ADMM has three steps. First the x-minimization step (8a), next the z-minimization (8b) and lastly the update of the dual variable y (8c). The method consists of separate minimization of the cost function by the x and z vectors. That's where the term alternating directions comes from. This separate minimization allows for a distributed approach when functions f and g are separable. The state of the iterations of the method are the values of the variables (y^k, z^k) because the value of the variable x^k is directly dependent on the values of (y^{k-1}, z^{k-1}), i.e. it is a mid-result of the iteration state.

ADMM is also written in a different form for implementation purposes. If a primal residue is defined as $r = Ax+Bz-c$ and a scaled dual variable as $u = (1/\rho)y$, a scaled form of ADMM can be established:

$$x^{k+1} = \arg\min_x (f(x) + (\rho/2)\|Ax + Bz^k - c + u^k\|_2^2), \tag{9a}$$
$$z^{k+1} = \arg\min_z (g(z) + (\rho/2)\|Ax^{k+1} + Bz - c + u^k\|_2^2), \tag{9b}$$
$$u^{k+1} = u^k + Ax^{k+1} + Bz^{k+1} - c. \tag{9c}$$

The scaled form is primarily used because in most of the cases it allows for a shorter and simpler form of iteration steps.

Necessary and sufficient optimality conditions for the ADMM problem (6) are:

1) Primal feasibility :

$$Ax^* + Bz^* - c = 0. \tag{10}$$

2) Dual feasibility:

$$0 \in \partial f(x^*) + A^T y^*, \tag{11}$$
$$0 \in \partial g(z^*) + B^T y^*. \tag{12}$$

It can be shown that the term (12) is always satisfied, and that for achieving optimality it is necessary to fulfill conditions (10) and (11). Satisfying term (11) is equal to the condition that the primal residue $r^{k+1} = Ax^{k+1} + Bz^{k+1} - c \to 0$ as $k \to \infty$, and for satisfying term (11) firstly a dual residue needs to be defined as $s^{k+1} = \rho A^T B(z^{k+1} - z^k)$. Expression (11) is satisfied if $s^k \to 0$ as $k \to \infty$.

For an adequate use of ADMM a stopping criterion must be defined. The stopping criterion is usually defined through the condition of sufficiently small primal and dual residues, i.e.:

$$\|r^k\|_2 \leq \epsilon^{pri}, \tag{13a}$$
$$\|s^k\|_2 \leq \epsilon^{dual}, \tag{13b}$$

where $\epsilon_{pri} > 0$ and $\epsilon_{dual} > 0$ are feasibility tolerances for the primal and dual feasibility conditions (10) and (11). These tolerances are most often chosen either to be sufficiently small fixed values or through a absolute and relative criterion as:

$$\epsilon^{pri} = \sqrt{p}\epsilon^{abs} + \epsilon^{rel} \max\{\|Ax^k\|_2, \|Bz^k\|_2, \|c\|_2\}, \tag{14a}$$
$$\epsilon^{dual} = \sqrt{n}\epsilon^{abs} + \epsilon^{rel}\|A^T y^k\|_2, \tag{14b}$$

where $\epsilon^{abs} > 0$ is the absolute tolerance and $\epsilon^{rel} > 0$ the relative tolerance. The relative tolerance is usually set to a value of 10^{-3} or 10^{-4}, while the value of the absolute tolerance depends on the standard range of variable values expected in the problem the method is being used for.

IV. Systems of systems control method

ADMM can be used as decentralized algorithm for the optimal control of SOS. Further in the text the method is described for use on SOS with type equality coupling constraints (4), this is because a inequality type constraint can be reduced to a equality type by adding slack variables.

ADMM solves problem (5) iteratively during which an iterative exchange of information between the central and local controller is done. After the optimal control values are evaluated the receding horizon control principle is applied. The description of the control method is as follows:

Firstly problem (5) needs to be reformulated to a form adequate for the use of the ADMM:

$$\min_{\substack{U_1,\ldots,U_M \\ x_1,\ldots,x_M}} \sum_{i=1}^{M} J_i(\Phi_i, x_i, U_i) + g_C(z), \tag{15a}$$
$$\text{s.t} \quad C_i^u U_i \leq C_i^c + C_i^p[\Phi_i^T x_i^T]^T, i \in \{1, \ldots, M\}, \tag{15b}$$
$$x - z = 0, \tag{15c}$$

where function $g_C(z)$ is the indicator function of the set $C = \{z|K_i z = K\}$ and x_i=Θ_i. Then an augmented Lagrangian is formed:

$$L_\rho(x,y,z)=\sum_{i=1}^{M} J_i(\Phi_i,x_i,U_i)+g_C(z) \quad (16)$$

$$+(\rho/2)\|x-z+u\|_2^2. \quad (17)$$

After that the ADMM iteration steps in scaled form can be stated:

$$x^{k+1} = \arg\min_x \sum_{i=1}^{M} J_i(\Phi_i,x_i,U_i)+(\rho/2)\|x-z^k+u^k\|_2^2 \quad (18a)$$

$$\text{s.t} \quad C_i^u U_i \le C_i^c + C_i^p[\Phi_i^T x_i^T]^T, i\in\{1,\dots,M\}$$

$$z^{k+1} = \arg\min_z (g_C(z)+(\rho/2)\|x^{k+1}-z+u^k\|_2^2), \quad (18b)$$

$$u^{k+1} = u^k + x^{k+1} - z^{k+1}. \quad (18c)$$

The x-minimization step can be decomposed by x_i:

$$x_i^{k+1} = \arg\min_{x_i} J_i(\Phi_i,x_i,U_i)+(\rho/2)\|x_i-z_i^k+u_i^k\|_2^2), \quad (19)$$

$$\text{s.t} \quad C_i^u U_i \le C_i^c + C_i^p[\Phi_i^T x_i^T]^T.$$

The decomposed x-minimization is a multi-parameter optimization problem specific to each local subsystem. This type of optimization problem can be solved parametrically [6] in reference to parameters $p_i = z_i^k + u_i^k$ and local parameter Φ_i, resulting in functions $U_i^*(p_i,\Phi_i)$ and $x_i^*(p_i,\Phi_i)$ which represent a parametric solution to the problem:

$$x_i^{k+1} = \arg\min_{x_i} (J_i(\Phi_i,x_i,U_i)+(\rho/2)\|x_i-p_i\|_2^2), \quad (20)$$

$$\text{s.t} \quad C_i^u U_i \le C_i^c + C_i^p[\Phi_i^T x_i^T]^T.$$

Every local controller evaluates functions $U_i^*(p_i,\Phi_i)$ i $x_i^*(p_i,\Phi_i)$ offline. The result of the z-minimization step is a projection on the set C:

$$z^{k+1} = proj_C(x^{k+1}+u^k) \quad (21)$$

Taking into consideration that the set C is an affine set the projection of a point on set C has a closed form [7] :

$$proj_C(x_0) = [I - B^T(BB^T)^{-1}B]x_0 + B^T(BB^T)^{-1}c \quad (22)$$

For the projection of a point onto affine set (22) a inverse of the matrix BB^T is needed. The efficiency of this step is directly linked to the matrix size. Since the matrix is of dimension $B \in \mathbb{R}^{m\times n}$, the dimension of the matrix BB^T is equal to $m \times m$. Taking into consideration that almost all coordination problems (5) are not expected to have a large number m of coupling constraints, step (22) should not represent a processing problem.

The control of the SOS is implemented online through a series of steps executed at every sampling instant t:

Input: M, $\tilde{x}$, $\tilde{U}$, K_i, K, ρ, ϵ^{abs}, ϵ^{rel}
Output: $x^\star = [x_1^\star,\dots,x_n^\star]$, $U^\star = [U_1^\star,\dots,U_n^\star]$
x_k, z_k, z_{k-1}, u_k=0;
while true do
  for $(i := 0; i \le M; i++)$ **do**
    $x_k(i) = \tilde{x}(i)(z_k(i)+u_k(i))$
  end for
  $z_{k-1} = z_k$
  $z_k = [I - K_i^T(K_iK_i^T)^{-1}K_i](x_k+u_k) + K_i^T(K_iK_i^T)^{-1}K$
  $u_k = u_k + x_k - z_k$
  $r_k = \|x_k - z_k\|_2$
  $s_k = \| -\rho(z_k - z_{k-1})\|_2$
  $\epsilon^{pri} = \sqrt{n}\epsilon^{abs} + \epsilon^{rel}\max\{\|x_k\|_2, \| - z_k\|_2\}$
  $\epsilon^{dual} = \sqrt{n}\epsilon^{abs} + \epsilon^{rel}\|\rho u_k\|_2$
  if $(r_k < \epsilon^{pri})$**and**$(s_k < \epsilon^{dual})$ **then**
    break
  end if
end while
for $(i := 0; i \le M; i++)$ **do**
  $U^\star(i) = \tilde{U}(i)(z_k + u_k)$
end for
return $U^\star(i)$, $x^\star := x_k$

Fig. 2. ADMM algorithm for SOS

1) *Local evaluation*: The measurements and estimations of local parameters $\hat{\Phi}_i$ are collected and the local solutions are evaluated for the values of $\hat{\Phi}_i$:

$$\tilde{U}_i(p_i) = U_i^*(p_i,\hat{\Phi}_i), \quad (23a)$$

$$\tilde{x}_i(p_i) = x_i^*(p_i,\hat{\Phi}_i). \quad (23b)$$

2) *Solving the coordination problem*: To solve the coordination problem (5) the ADMM is used with iteration steps:

$$x_i^{k+1} = \tilde{x}_i(z_i^k + u_i^k) \quad (24a)$$

$$z^{k+1} = [I - K_i^T(K_iK_i^T)^{-1}K_i](x^{k+1}+u^k) + K_i^T(K_iK_i^T)^{-1}K, \quad (24b)$$

$$u^{k+1} = u^k + x^{k+1} - z^{k+1}. \quad (24c)$$

after which the parameter $p_i^* = \Theta_i^* + u_i^*$ is forwarded to each local controller.

3) *Control input evaluation*: Using the evaluated values of the parameter $p_i^* = \Theta_i^* + u_i^*$ the optimal control inputs for every local subsystems are determined as follows:

$$U_i^* = \tilde{U}_i(p_i^*). \quad (25)$$

The control variables are evaluated locally through the local controllers.

The ADMM algorithm with the stopping criterion is implemented in the form of Algorithm (2).

First, in offline mode, every local controller parametrically solves problem (20), [8]. Then in online mode the coordination problem is solved through the ADMM. At every iteration of the ADMM the central controller sends the current value of

$z_i^k + u_i^k$ to each of the local controllers. The local controllers evaluate the value of x_i^{k+1} and send that information back to the central controller so it could evaluate the new values of z^{k+1} and u^{k+1}. The main flaw of this method is the possibility of a large number of exchanges of information occurring between the central controller and the local controllers. That happens because the number of ADMM iterations is dependent on the desired accuracy of the solution and number of coupling constraints. Because that means that more communication cycles will be executed, the communication delay accumulates, which drastically slows the algorithm execution time. The main benefit of this method is that they are no limits on the dimension of the coordination parameter Θ_i.

V. Simulation Results

The control method described is tested on randomly generated SOS control problems of the form (5). For the purpose of simple problem generation all the subsystems have the same number of local parameters $n_{\Phi,i}$, coordination parameters $n_{\Theta,i}$, control variables $n_{U,i}$ and the same dimension of local subsystem constraints $n_{c,i}$. Fixed simulation parameters were $n_{c,i} = 3$, $n_{U,i} = 7$ and $n_{\Phi,i} = 2$, while the values n_{eq},number of subsystems M and $n_{\Theta,i}$ are variable simulation parameters. The method is compared to a classic central method of control which is implemented using a state of the art commercial quadratic problem solver CPLEX (version 12.6). The comparison is done through the execution times of the methods. The simulations are implemented in Matlab 8.5.0 (R2015a) on a personal computer with a Intel(R) Core(TM) i7-3610QM CPU 2.3 GHz, with 4-GB RAM and Windows 10 operating system. For the formulation of the problems, the YALMIP toolbox [9] was used. It provides a simple and efficient construction of optimization problems in the Matlab environment. The control algorithm is implemented through a series of functions in Matlab. The multi-parametric solution are computed by using the MPT toolbox [6]. The simulation range goes to a maximum of 500 subsystems and each simulation is executed 50 times for different values of local parameters Φ_i. It is important to note that the time of execution of the x-minimization step is computed as an average value of the serial execution time. This is done so because a real practical system would execute the step parallel on all the local controllers. The communication delay between the local controllers and the central controller is ignored in the simulation. The values used for the stopping criterion are $\epsilon^{abs} = 10^-6$, $\epsilon^{rel} = 10^-3$ and the penalty parameter value is $\rho = 1$.

Fig. 3 shows the simulation results for systems with a dimension of the coupling constraints $n_{eq} = 1$ and dimension of the coordination parameter $n_{\Theta,i} = 1$. Fig. 4 shows the simulation times for systems with $n_{eq} = 3$ and $n_{\Theta,i} = 1$. Fig. 5 shows the simulation times for systems with $n_{eq} = 3$ and $n_{\Theta,i} = 3$. Circles represent the average time execution values, while the range of the values is marked. Unfortunately the classic approach is much faster than the ADMM method though the execution time ranges get closer as the dimension of $n_{eq}, n_{\Theta,i}, M$ grow.

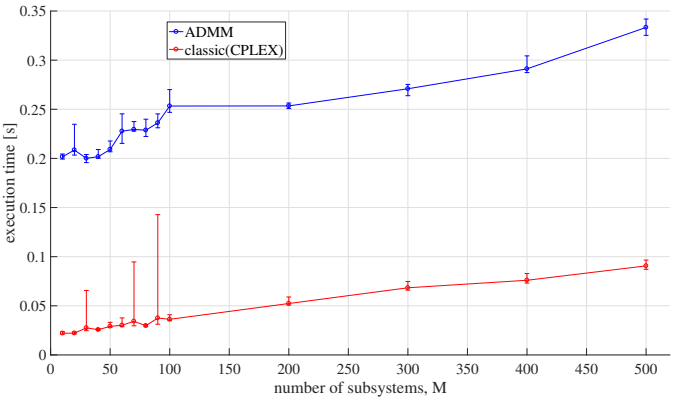

Fig. 3. Simulation results for $n_{eq} = 1$

Fig. 6 shows simulation results for different values of n_{eq}, $n_{\Theta,i} = 1$ and fixed number of subsystems $M = 100$. It demonstrates that the method can handle systems with a large dimension of coupling constraints. Execution time of the ADMM method is still significantly slower then the classic execution time and in addition the execution time of the ADMM method varies largely with n_{eq}. Fig.7 shows the number of iterations the method requires for the same simulation examples. It shows that the number of ADMM iteration steps is also largely dependent on the dimension of coupling constraints. Moreover the iteration number graph shares it shape with the execution time graph.

Fig. 8 shows simulation results for different values of $n_{\Theta,i}$, $n_{eq} = 1$ and fixed number of subsystems $M = 100$. The classical method is again faster than the ADMM and the execution time of the ADMM method grows much faster than the classic execution time. This happens because as the dimension of the coordination parameter grows the parameter space drastically increases.

Although the classic centralized method gives better results than our approach, one should take into account as mentioned that the central controller needs to have access to all local subsystem information, which is not desirable. It should also be noted that our method would have been more efficient if it

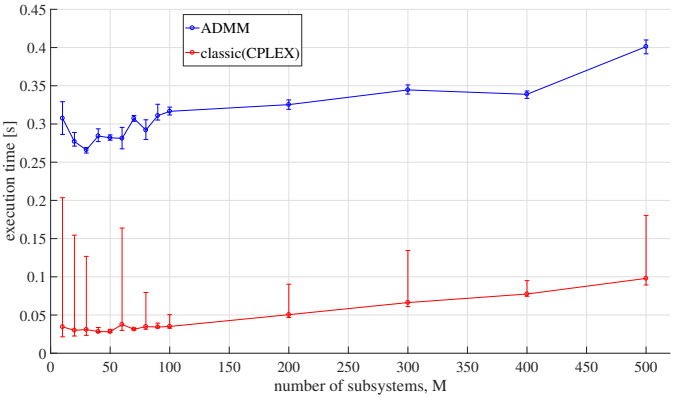

Fig. 4. Simulation results for $n_{eq} = 3$

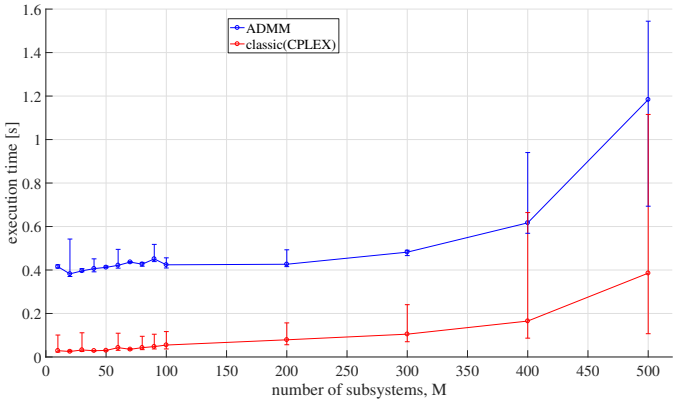

Fig. 5. Simulation results for $n_{eq} = 3$ and $n_{\Theta,i} = 3$

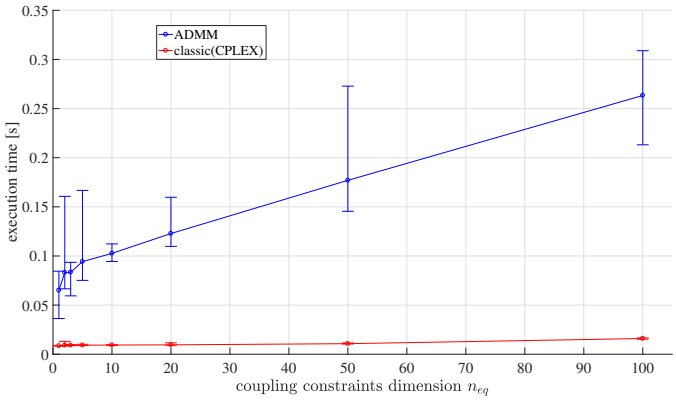

Fig. 6. Simulation results for different values of n_{eq}

was implemented in a highly efficient compiled programming language like C++ instead of a interpreted programming language like Matlab.

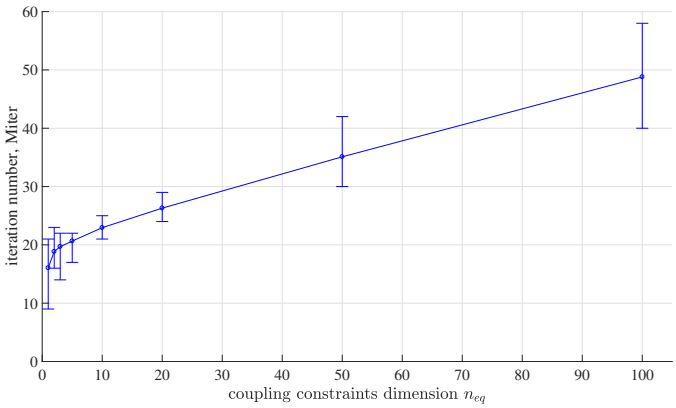

Fig. 7. Simulation results for different values of n_{eq}

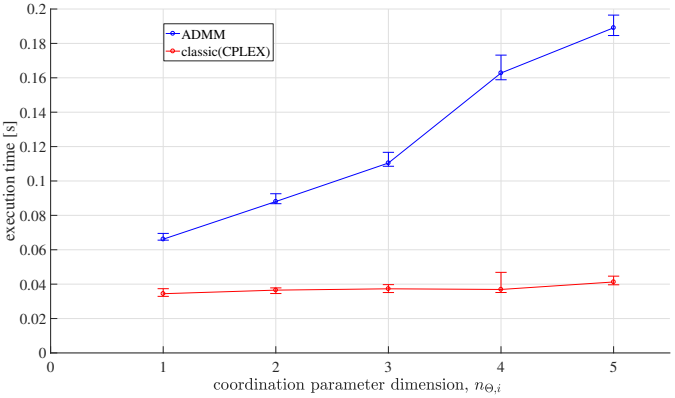

Fig. 8. Simulation results for different values of $n_{\Theta,i}$

VI. Conclusion

The paper describes implementation of the Alternating Direction Method of Multipliers for model predictive control of System of Systems. The implementation of the ADMM relies on the iterative communication between local controllers and a central coordinator. The ADMM, as a distributed algorithm, is applicable for control of large scale SOSs. However, due to the ADMM's iterative nature, its efficiency can be negatively affected in the presence of communication delays. Although reported results show that the classical approach can solve the MPC problem faster than the ADMM, one should always remember that the distributed algorithm does not need full access to all local subsystem information. Simulation results show that practical application of ADMM is possible for relatively small sampling times.

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Methods for Attenuation of Unmanned Aerial Vehicle Noise

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***Abstract* - Unmanned aerial vehicles (UAVs) like drones (quadcopters, hexacopters, octocopters etc.) can be a source of a significant acoustic noise. High noise makes them less suitable for use in densely populated urban areas, particularly during take-off, landing and low level flight, due to the noise annoyance. This paper reviews methods and proposes some concepts for attenuation of UAV noise. Both passive and active solutions are considered. Solutions with piston engine silencer, Q-tip propeller, more propeller blades, absorptive and reflective barrier, ducted propeller, sound absorbing ducts, synchrophaser, multichannel active noise cancellation (ANC) system with secondary sources circularly arranged around the propeller and the system with magnetically excited propeller blades are mentioned.**

Keywords* - *unmanned aerial vehicle, noise, propeller, sound absorption, active noise control

I. INTRODUCTION

An Unmanned Aerial Vehicle (UAV) is an aircraft with no pilot on board. It is also referred as an unmanned aircraft system (UAS) or more frequently, drone. There are many civilian, commercial, military, and aerospace applications for UAVs, [1,2]. UAVs often produce a significant amount of acoustic noise that interferes with their operation in urban and other inhabited areas, particularly during take-off, landing and low level flight, [3-6]. Annoyance may not be necessary caused just by the UAV noise level, but by the specific noise spectrum. Methods for reduction of UAV noise can be broadly categorized as passive and active. Passive methods are well known and proven, don't use additional energy, but are sometimes bulky and not suitable for counteracting low frequency noise, [7]. On the other hand, active methods promise much higher noise attenuation at lower frequencies, [8-10]. However, such concepts are mostly novel, unproven in the context of UAVs and require an additional energy source. The combination of these two approaches may be a way to go.

II. TYPES OF UAVS

UAVs may be broadly categorized as a fixed wing and rotary wing devices. First UAVs were a fixed wing, they were extension of remotely controlled small aircrafts, equipped with additional electronics for navigation and reconnaissance, [1,2]. One example of a heavy fixed wing UAV is illustrated in Fig. 1, (General Atomics MQ-9). Fixed wing UAVs are powered by a small piston (gasoline or diesel) or even turboprop engine, often in a pusher configuration, and rarely by an electric motor (due to the limited autonomy), [11-13]. Noise reduction for such vehicles is mostly directed toward silencing the engine and propeller. In case of a fixed wing UAV, the propeller can be front or rear mounted. In case of the rear mounted propeller and turboprop engine, there is an additional problem of exhaust going through the blades, producing nasty noise. On the other spectrum of UAVs are rotary wing devices, either a small helicopters or multirotor devices, Figs. 2-4. Multirotors can fly in every direction,

Figure 1 Fixed wing UAV (MQ-9) with turboprop engine (GA-ASI)

Figure 2 Quadrocopter (DJI)

Figure 3 Hexacopter (Yuneec)

Figure 4 Octacopter (DragonRC)

horizontally and vertically, as well as hover in a fixed position. Common configurations are quadrocopters (with four rotors), Fig. 2, hexacopters (with six rotors), Fig. 3 and octacopters (with eight rotors), Fig. 4. Quadrocopters and hexacopters are more simple and common in use, with quadcopter configuration, particularly becoming popular for small UAVs. They are of much simpler design, but less redundant in case of loss of motor. Octacopters, however, are far more powerful machines than quadcopters or hexacopters.

According to the used propulsion type, multirotor UAVs can be electric (using batteries to power their flight) or can use piston engine that very rarely drive propellers, but can drive a generator for electric motors, [14].

Regarding the weight they can be categorized as light drones (< 25 kg, < 150 kg) and heavy drones (> 150 kg).

III. SOURCES OF NOISE

The sources of noise for a typical drone are shown in Fig. 5 (some sources not applicable for a particular type of drone), [15]. A dominant source of noise is a propulsion system, i.e., combination of engine or motor and propeller.

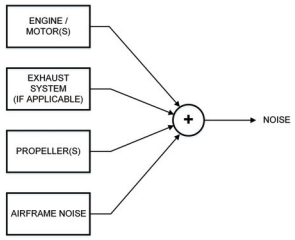

Figure 5 Contributions to aircraft noise

TABLE I. NOISE LEVELS FOR SMALL DRONES AT CLOSE DISTANCE

Drone	Noise level (dB) [1)]
Mavic Pro	98
Mavic Pro Platinum	93
Mavic Air	99

[1)] measured at 15 cm distance bellow the hoovering drone

Even small drones may produce significant noise at close distance, see Table I. Mavic Pro Platinum produces 93 dB (due to special tip vortex design of the Platinum) and Mavic Air 99 dB (has a higher RPM), [6] Larger drones produce even higher noise levels. In general the lighter the drone, the quieter it will be. It also depends on the prop size in relation to the weight, motor RPM, the prop design and the amount of prop/body overlap. An example of the noise spectrum for two popular small drones is given in Fig. 6 (distance of several feet). It is presence of high frequencies that add to subjective annoyance ratings.

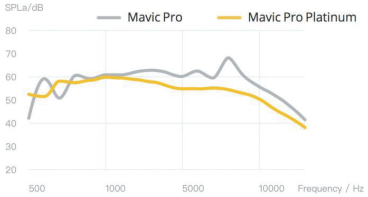

Figure 6 Noise spectrums of two popular drones (DJI)

Not all sources of noise are equally important. Some sources by far dominate the noise level, while others just symbolically contribute to the overall noise. Anything that is several dB lower than the other sources can be discarded, as it contributes negligibly to the overall noise level. Levels of sound pressure decrease with the distance from the sound source with 6 dB per distance doubling (depending on atmospheric and geographic conditions, can be a 3 to 7 dBA range), (1), where L_1 and L_2 are sound pressure levels in dB at distances d_1 and d_2 from the sound source, [7,16].

$$L_2 - L_1 = 20\log\frac{d_2}{d_1} \tag{1}$$

A. Piston Engine Noise

Piston engine noise is produced by pressure pulses at the intake and exhaust during the engine four cycles. The engine exhaust noise originates at the exhaust tailpipe opening. Noise from a small piston engine may be far in excess of 85 dB. Cylinder firing rate, f_{CFR}, is dependent on the rotational speed N_{RPM}, (RPM, rotations per minute) that is for a two stroke engine given by (2), [15]:

$$f_{CFR} = \frac{N_{RPM}}{60} \tag{2}$$

and for a four stroke engine is given by (3):

$$f_{CFR} = \frac{N_{RPM}}{120} \tag{3}$$

The engine firing rate, f_{EFR}, is dependent on the f_{CFR} and the number of cylinders N_C, (4):

$$f_{EFR} = N_C f_{CFR} \tag{4}$$

The perceived main frequency of the noise radiating from a 2 stroke engine at 10,000 RPM is 166 Hz, while from a 4 stroke engine at the same RPM is just 83 Hz.

B. Turboprop Engine Noise

Turboprop engines are turbine engines driving a propeller. The turbine engine noise is caused by the whining noise that comes from the intake, and the low frequency noise that comes from the turbine exhaust. Exhaust noise consists from both combustion noise, and the noise produced by the differential between the high velocity jet gases and the low speed outside air. The pressure/temperature difference of the air at the exhaust is the major contributor to a turbine engine noise.

C. Electric Motor Noise

Noise and vibration of an electric motor are caused by the structural deformation due to electromagnetic forces, moving parts (imbalance, gears, and bearings) and airflow through the motor, [17-20]. Today, mostly used are brushless DC (BLDC) motors, known for their wide application and energy efficiency. Stator excitation in BLDC motor drives can excite mechanical resonances of the motor and produce an acoustic noise similar to switched reluctance drives. Noise levels and spectrum are shown in [17]. Most popular BLDC motors use three phases. The motor speed

Figure 7 Set of electrical motors for a drone (Hobbymate)

control is accomplished using the PWM technique. Basically two methods are available for controlling the speed of a BLDC motor: sensor and sensorless control. Electronically commutated BLDC motor use information obtained from Hall sensors. Motors have a KV rating that relates to how fast it will rotate for a given voltage. Electric motors for powering drones are operating at quite high RPMs, [21]. RPM range of motors in Fig. 7 begins at 10,350 RPM and goes up to 41,400 RPM (unloaded).

D. *Propeller Noise*

Propeller noise is composed of tonal and broadband components. Sources of propeller aerodynamic noise are shown in Fig. 8. The greatest noise, in terms of directivity, is in the propeller plane. The basic frequency f_1 or f_{BPF} (Blade Pass Frequency), is the product of the propeller rotational speed and the number of propeller blades (5), [15]:

$$f_1 = f_{BPF} = \frac{N_{RPM} N_B}{60} \tag{5}$$

where is:

f_1, f_{BPF} basic frequency of tonal propeller component
N_{RPM} propeller rotational speed (rotations per minute)
N_B number of propeller blades.

The tonal components contain basic frequency f_1 and its harmonics f_n with spectral components shown in Fig. 9, (6), [15]:

$$f_n = Nf_1 \qquad N = 1,2,\ldots \tag{6}$$

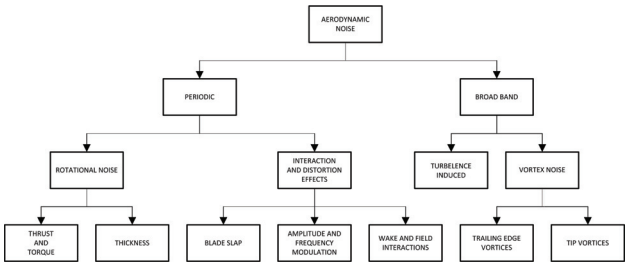

Figure 8 Sources of propeller aerodynamic noise, according to [23]

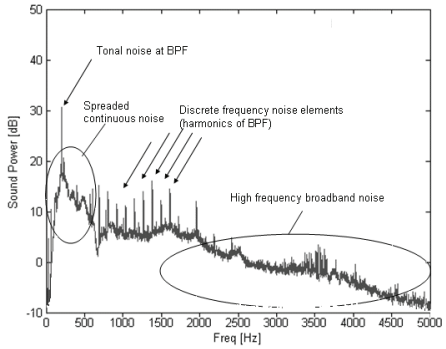

Figure 9 Noise spectrum of a propeller, modified from [24]

The propeller tip speed is determined by (7):

$$v = \frac{DN_{RPM}\pi}{60} \tag{7}$$

where is

v propeller tip speed
D propeller diameter
N_{RPM} propeller rotational speed

Propeller tip speeds (ms^{-1}) for various small propeller diameters and rotational speeds are shown in Table II.

TABLE II. PROPELLER TIP SPEEDS FOR VARIOUS PROPELLER DIAMETERS AND ROTATIONAL SPEEDS [1)]

Propeller diameter (inch)	Rotational speed (RPM)								
	2000	3000	4000	5000	6000	7000	8000	9000	10000
3	7.97	11.97	15.96	19.95	23.93	27.93	31.92	35.91	39.90
4	10.64	15.96	21.28	26.60	31.92	37.24	42.56	47.88	53.20
5	13.30	19.95	26.60	33.25	39.90	46.55	53.20	59.85	66.50
6	15.96	23.94	31.92	39.90	47.88	55.86	63.84	71.82	79.80
7	18.62	27.93	37.24	46.55	55.86	65.17	74.48	83.79	93.10
8	21.27	31.92	42.56	53.20	63.84	74.48	85.12	95.76	106.4
9	23.94	35.91	47.88	59.85	71.82	83.79	95.76	107.7	119.7
10	26.60	39.90	53.20	66.50	79.80	93.10	106.4	119.7	133.0
11	29.26	43.89	58.52	73.15	87.78	102.4	117.0	131.7	146.3
12	31.91	47.88	63.84	79.80	95.76	111.7	127.7	143.6	159.6

[1)] yellow color denotes noisy speeds >100 ms^{-1} (≈ 0.3 M)

Small drones use exclusively fixed pitch propellers, and changing its thrust is accomplished by changing the RPM of the electric motor that are driving them.

E. *Airframe Noise*

It is mostly negligible at low speeds and in comparison to other sources of noise (like a propeller and engine).

F. *Noise Levels From Multiple Sources*

Summation of sound pressure levels from multiple incoherent sound sources (e.g., propellers with different RPMs), [7], is defined by (8), n is the number of sources and L_n is the sound pressure level of the source n in dB:

$$L_{\Sigma} = 10\log_{10}\left(10^{\frac{L_1}{10}} + 10^{\frac{L_2}{10}} + \cdots + 10^{\frac{L_n}{10}}\right) \tag{8}$$

The increase of noise level ΔL from multiple equally loud incoherent sound sources is defined by (9).

$$\Delta L = 10\log_{10}(n) \tag{9}$$

Important are the contributions from the most prominent noise sources, other noise sources (if not numerous) can be neglected. The rise of the noise level by the contribution of more equally loud incoherent sound sources is illustrated in Table III.

TABLE III. CONTRIBUTION OF MORE EQUALLY LOUD INCOHERENT SOUND SOURCES

Sources	Δ noise level (dB)
1	0
4	6,0
6	7,8
8	9,0

IV. PASSIVE METHODS FOR NOISE REDUCTION

Following passive methods may be used for reducing the noise of UAV:

- Piston engine silencer (muffler),
- Modification of blade airfoil shapes (e.g., Q-tip propeller, saw tooth serrated trailing edge)
- Propeller with more blades (three, four, five, six …)
- Absorptive and reflective barriers (sound reflectors)
- Ducted (shielded) propeller with sound absorbers (absorbing surface materials and metasurface absorber based on a Helmholtz resonator)

A. *Piston Engine Silencer (Muffler)*

Piston engine may be silenced by use of absorptive (dissipative) and/or reactive silencer (muffler), [25,26], as in Fig. 10 and Fig. 11. Achieved noise levels for popular engine/muffler combinations are given in [27]. An

Figure 10 Small two stroke piston engine with a silencer (muffler)

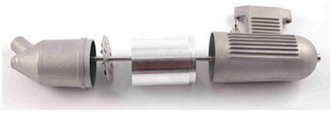

Figure 11 Interior of small reactive silencer

additional step for larger engines would be use of a silencer at the engine intake. Also, care should be taken that engine doesn't excite fuselage resonances. Results of application of silencer on a small aircraft are given in [28].

B. *Modifying Blade Shape (Q-Tip Propeller)*

Blade shape and airfoil section shape influence to a small degree (a few dB) the noise level produced by a propeller. Particularly popular is a Q-tip propeller, first developed in the 1970s, that uses bent tips (90º) to reduce the tip noise, [29]. It reduces the airflow, in the same way as winglets reduce wing tip vortices. Bent tip propeller inspired by the same concept is shown in Fig. 12. The influence of propeller blade geometry to propeller noise level is investigated in [29,30]. The effect of saw tooth serrated trailing edge propeller is analyzed in [31].

Figure 12 Q-tip style propeller (DJI Mavic Pro)

C. *Use of Propellers with More Blades*

Dual blade propellers are the most commonly used in drones. Same thrust can be achieved with a propeller with the smaller diameter, but more blades (three, four, five, or even six). Example of six blade propeller for the drone is shown in Fig. 13. Increasing the number of blades leads to a lower tip speed, but also to somewhat decreased efficiency. The lower tip speed reduces the noise generated by a propeller. Propellers with more blades may require more effort to balance, but the results may be dramatic in terms of achieving very low vibration levels and much lower noise levels. Changes in noise levels with increasing the number of blades, achieved in one general aviation aircraft, according to [28] are shown in Table IV.

Figure 13 Three blade propellers for a drone

TABLE IV. NOISE REDUCTION CHANGE WITH INCREASING NUMBER OF BLADES

Blades	Noise reduction
two to three	-4 dB
three to four	-4.5 dB
four to five	-4.5 dB

D. *Use of Absorptive and Reflective Barriers*

Noise from the drones emanates in many directions, some causing more annoyance than others. Using the sound reflectors, the noise may be partially reflected upwards. Reflective materials have hard surfaces that reflect the sound, [7]. Materials with various degrees of combinations of absorption and reflections may also be used. Depending on the material density and how porous it is, some degree of absorption may also take place, converting unwanted noise to heat. Sound reflector could be placed at an angle below the propellers, at the outer edge of the propeller ring.

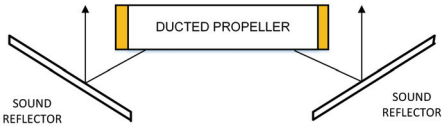

Figure 14 Use of sound reflector for reflecting propeller noise

With the use of sound reflectors, Fig. 14, propeller noise is partially reflected up, where it generally has no environmental impact.

E. *Ducted (Shielded) Propeller*

Ducted (shielded) propeller is an arrangement where the propeller, is mounted within a cylindrical shroud or duct propeller, Fig. 15, [32]. It is more efficient in producing a thrust than a conventional propeller of similar diameter. Often they also provide (but not always, due to interaction with the casing) a lower noise (shield the blade noise, and reduce the tip speed), [33,34]. Duct also offers great protection from propeller blades (safety factor), Fig. 16, [35]. There is an opportunity for acoustic treatment of the surfaces of the duct with sound absorptive material. Thickness of the material influences the absorption, but thicker material requires a duct with a slightly greater diameter ($^1/_4$, $^1/_2$ inch or more). Propeller duct also offers the possibility for the use of a circularly shaped perforated absorber (acoustic liner) and metasurface absorber based on Helmholtz resonator, Fig. 17, that may be quite capable (several dB) of reducing low and mid frequency noise, [36].

Figure 15 Ducted (shielded) propeller (Aerotestra MK10)

Figure 16 Futuristic IFO passenger drone concept with ducted (shielded) propellers (Jet Capsule), [35]

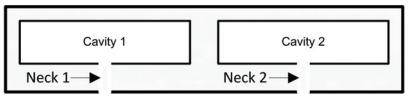

Figure 17 Metasurface absorber

V. ACTIVE METHODS FOR NOISE REDUCTION

Active methods for noise reduction are, due to the complexity, intended (but not restricted) for larger drones that produce high noise levels. Such methods include:

- Synchrophaser for reducing the noise and propeller beats (optional)
- Active noise control for reducing the propeller noise radiated into the environment using speakers in a circular arrangement placed around the propeller
- Propeller blades with small magnets that vibrate in the electromagnetic field produced by the coil in the propeller frame

A. *Synchophaser*

A synchrophaser is a device that precisely matches the RPM and the phase of all the propellers, Fig. 18, [37]. It compares the propeller to propeller relative positions of the propeller blades within their individual arcs and adjusts their angle to their optimum relative positions, [38,39]. The noise from one engine-propeller can be tuned to provide a canceling acoustic wave to reduce the noise generated from another engine-propeller operating on the same aircraft. As such, synchrophaser can be used for noise cancellation on multi engine/motor drones with variable pitch propellers rotating at the same RPM. The Air Force Research Laboratory (AFRL) has developed a second generation phase-locked-loop (PLL) digital synchrophaser in 1994. The synchrophaser achieved 3-5 dB reduction in exterior noise levels on a four engine C-130 aircraft, [40].

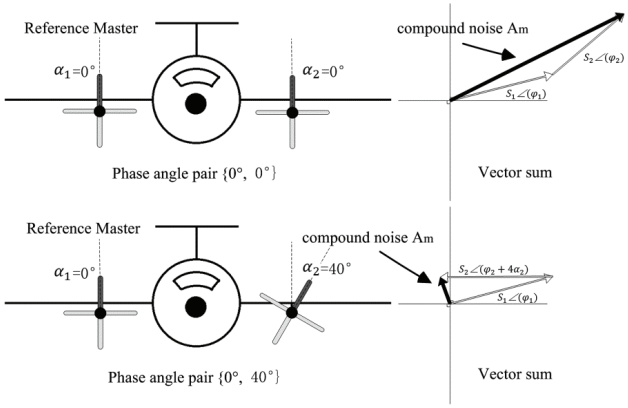

Figure 18 Synchrophaser operation and noise attenuation, [35]

B. *Active Noise Control*

Active noise control (ANC) is a method for the reduction of unwanted noise by generating an acoustic signal that interferes with the offending noise (use of destructive interference), [8,9]. Use of ANC has achieved a significant reduction of tonal noise components.

- Multichannel ANC

The multichannel ANC, with 12 speakers (number may vary), proposed by the author of this paper, can be used for active noise reduction, Fig. 19. Speakers are located in a circular arrangement around the propeller on the outside surface of the propeller duct, radiating sound at an angle (e.g. 45º) and driven by the multichannel ANC controller.

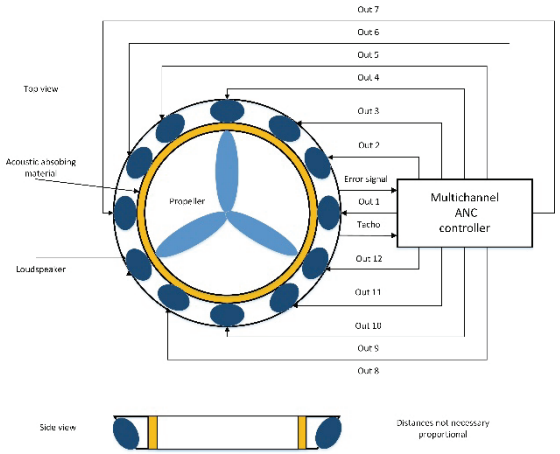

Figure 19 Multichannel ANC of propeller noise

Each of acoustic channels is driven by the waveform synthesis ANC, Fig. 20, supplying the same waveforms, but at different phase angles (e.g., in case of 12 channels, each channel is shifted by 30° from the previous one). In case of three blade propeller 12 channels can be grouped into 3 groups of 4 channels (channels in the same group are same). The waveform synthesizer, [41,15], has stored waveform samples (10), L is the period length in samples:

$$w_l(n),\ l=0,1,\ \ldots\ ,L\text{-}1 \tag{10}$$

Canceling noise waveform for the secondary speaker at the moment n is given by (11) and (12):

$$y(n) = w_{j(n)}(n) \tag{11}$$

$$j(n) = n \bmod L \tag{12}$$

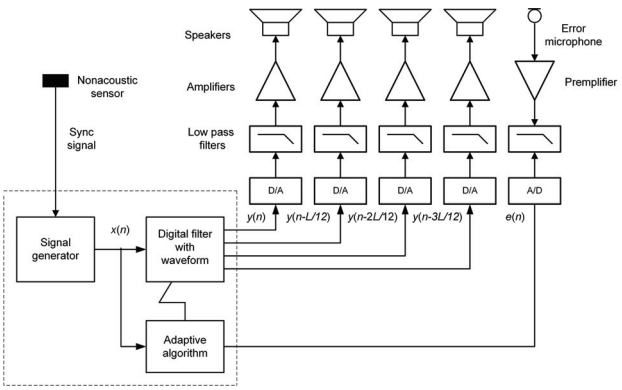

Figure 20 Multichannel ANC with four channels (delayed waveforms)

C. *Magnetically Excited Propeller Blades*

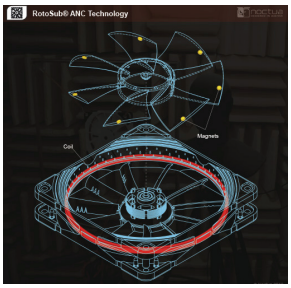

Figure 21 Blades vibrating in electromagnetic field (Noctua RotoSub®)

Very interesting approach for silencing computer cooler noise was proposed by Noctua and patented as RotoSub® technology, Fig. 21, [42]. Although primarily intended for computer cooling fans, a similar approach could probably be applied to small drone propellers as well. Switching on/off the electricity to the coil placed within the propeller frame interacts with small magnets inside the blade tips providing minute modulations of the rotary movements of fan blades. This allows the fan itself to emit the anti-noise signal through the blades, practically at the same position as the originating noise making it easier to precisely match its phase and rotation pattern.

VI. CONCLUSION

Drones have numerous applications that require them to operate in urban areas where noise annoyances are possible. To reduce occurrences of such events it may be necessary to implement some strategies for noise reduction, particularly during low level operations. Passive methods have its attraction in simplicity, reliability, low cost and require no additional power. Reduction of low frequencies may require ANC methods that can be, due to the power requirements, switched on only during take-off, landing and low level flight. Combining passive and active noise reduction methods to achieve greater noise reduction may be a feasible approach. Each of listed methods would contribute little to the overall noise reduction, but combined reduction may match the desired noise reduction target.

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Simple Secondary Path Modeling for Active Noise Control Using Waveform Synthesis

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***Abstract* - Active noise control algorithms for real world applications regularly use some kind of digital filtering and adaptation to compensate for the influence of the secondary path. Such is the FxLMS algorithm with techniques for off-line and on-line estimation of the secondary path, suitable both for broadband and narrowband noise. When silencing periodic noise using waveform synthesis, much simplified solution can be used. Instead of a long adaptive filter, a simple delay can be used. After initial off-line calibration, delay values are stored in a lookup table. These values are used later instead of adaptive filter and may change with the frequency of repeating waveform. It is a simple and intuitive solution that poses some restriction on phase response of used secondary source. Due to the low computational requirements it is suitable for implementation using simple and low cost microcontroller.**

Keywords - active noise control, secondary path, modeling, waveform synthesis, periodic noise

I. INTRODUCTION

Active Noise Control (ANC) is the reduction of unwanted noise by generating canceling acoustic signal that interferes with the original noise [1,2]. The noise encountered in a real world could be narrowband or wideband. It can be random, periodic or a combination of the previous two types. Noise can be stationary, with a spectrum not changing over the time or nonstationary. It can also be nonstationary, but with a slowly changing spectrum. Periodic noise is almost always narrowband noise, as periodicity constraint is much easier to satisfy in a narrow frequency bands for a limited number of frequency components. There exist various methods for ANC that can be classified as feedforward, feedback and hybrid, [1-3]. This paper deals with narrow band periodic noise. Such a kind of noise can be found in rotating machinery, like engines, turbines, propellers and cooling fans. One approach, particularly suitable for cancellation of periodic noise is the application of waveform synthesis, [2-4]. However, a secondary path, consisting of a power amplifier, microphone preamplifier, anti-aliasing filter, reconstruction filter, A/D and D/A converters and the acoustic path from the speaker to the error-microphone, has its own amplitude and phase frequency characteristics that further complicate, otherwise quite a simple concept. A secondary source does not convert an electric signal to a sound with the same efficiency at various frequencies. Also, even more important, phase of generated sound generally differs from the phase of electric signal driving the speaker, and is frequency dependent.

II. ANC USING WAVEFORM SYNTHESIS

ANC using waveform synthesis is based on a concept that electronic device resembles waveform of a periodic noise that is later fed with the opposite phase to a source of canceling acoustic signal, speaker, [2-4]. As the noise is considered to be periodic, its waveforms are repetitive. The goal is to generate an accurate waveform for counteracting original noise. This is achieved by playing stored waveform (either loaded initially or learned during the adaptation process). With this method noise cancellation occurs only at the fundamental frequency and frequencies of its harmonics, Fig. 1. The noise in frequency bands between the harmonics is not affected, [4].

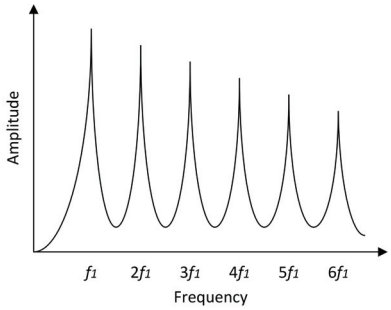

Figure 1. Frequency spectrum of the noise suitable for ANC using the synchronized waveform generator

A. Block Diagram of Waveform Synthesis ANC System

Block diagram of the idealized ANC system using a synchronized waveform generator, suitable for various analysis purposes, is shown in Fig. 2, [2].

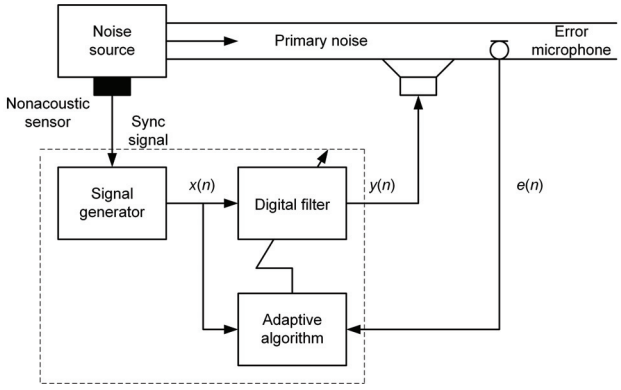

Figure 2. Block diagram

Two types of reference signals that are commonly used in such systems for analysis:

- Impulse train (Dirac delta, δ) separated by a time period equal to the inverse of the fundamental frequency of the offending periodic noise
- Sinusoidal waveform with the same frequency as the corresponding noise intended to be canceled

As no reference microphone is used, there is no hallowing and no need for feedback path neutralization.

B. Adaptation Algorithms

Adaptation process can be performed using the LMS algorithm or its variants.

- Traditional LMS Algorithm

The output signal from the filter of the length L is determined by (1), where w_{lk} are filter weights and x_{k-l} input signal at the moment k-l:

$$y_k = \sum_{l=0}^{L} w_{lk} x_{k-l} \tag{1}$$

The error signal ε_k is the difference between the desired output d_k and FIR filter output, y_k (2):

$$\varepsilon_k = d_k - y_k \tag{2}$$

or written in matrix notation, (3), (4) and (5):

$$\varepsilon_k = d_k - \boldsymbol{X}_k^T \boldsymbol{W}_k \tag{3}$$

$$\boldsymbol{X}_k = \begin{bmatrix} x_k & x_{k-1} & \dots & x_{k-L} \end{bmatrix}^T \tag{4}$$

$$\boldsymbol{W}_k = \begin{bmatrix} w_{0k} & w_{1k} & \dots & w_{Lk} \end{bmatrix}^T \tag{5}$$

using the following convention:

$\boldsymbol{X}_k$	input signal in matrix (vector) form at the moment k
$\boldsymbol{W}_k$	weight factors in matrix (vector) form at the moment k
y_k	desired value at the moment k
ε_k	error signal at the moment k
L	length of digital filter

An adaptation of adaptive filter weights using the LMS algorithm expressed in matrix notation using a gradient estimate, [5], is given by (6) and (7):

$$\boldsymbol{W}_{k+1} = \boldsymbol{W}_k - \mu \hat{\nabla}_k \tag{6}$$

$$\boldsymbol{W}_{k+1} = \boldsymbol{W}_k + 2\mu\varepsilon_k \boldsymbol{X}_k \tag{7}$$

- Sign-Error LMS Algorithm

Alternative to the traditional LMS algorithm is sign-error LMS algorithm, [4]. It is based on the criterion to minimize the absolute value of the instantaneous error signal, (8).

$$W_{k+1} = W_k + \mu sign(X_k) e_k \tag{8}$$

Sign-error LMS algorithm is numerically less intensive than traditional, but traditional LMS, but traditional provides faster convergence and lower steady state error.

- Coherent Averaging

Noise signal expressed by $f(t)$ can be decomposed into two components: deterministic signal component, $S(t)$ and noise signal component $N(t)$, (9):

$$f(t) = S(t) + N(t) \tag{9}$$

Coherent averaging, [6-8], can extract a periodic component of the noise and such reconstructed waveform can be used as a canceling signal, Fig. 3.

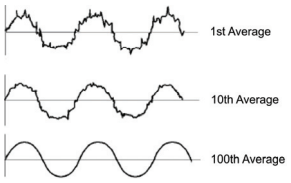

Figure 3. Noise reduction during coherent averaging process

Let the noise signal, $f(t)$, be sampled at time instants separated by one signal period of T seconds. Each sample at such instants is the sum of deterministic signal component and noise signal component, (i=1, 2, … , n) (10):

$$f(iT) = S(iT) + N(iT) \tag{10}$$

Averaging over N periods can be described by (11) - (13), x is the input signal and L is the period length in samples:

$$\hat{x}(1) = \frac{1}{N}\sum_{k=1}^{N} x(1+kT) \tag{11}$$

$$\hat{x}(2) = \frac{1}{N}\sum_{k=1}^{N} x(2+kT) \tag{12}$$

$$\dots$$

$$\hat{x}(L) = \frac{1}{N}\sum_{k=1}^{N} x(L+kT) \tag{13}$$

Over the time noise component, $N(t)$, averages out and only periodic signal component, $S(t)$, remains. Exponential averaging can be used instead of arithmetic averaging, [8], giving more emphasis on the new input signal sample.

A variant of waveform synthesis ANC system closer to the real world implementation, with low pass filters, preamplifier and amplifier, is shown in Fig. 4.

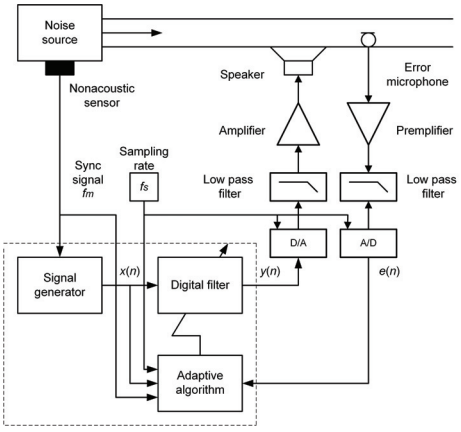

Figure 4. Waveform synthesis ANC system

C. *Influence of the Secondary Path*

Frequency and phase characteristic, [9], of one typical speaker is shown in Fig. 5.

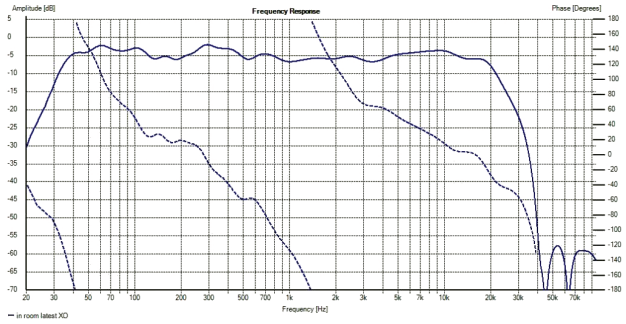

Figure 5. Frequency and phase response of typical uncorrected speaker

Frequency response is fairly stable, while phase response is approximately monotonic decreasing and deviates somewhat from linearity.

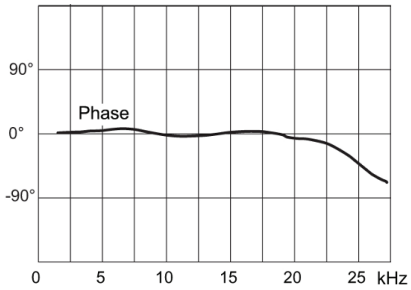

Figure 6. Typical microphone phase characteristics

Phase characteristic of a typical microphone is shown in Fig. 6. As can be seen, the phase response is mostly flat and adds no significant influence to the phase deviations of the secondary path. Filters, amplifier, and preamplifier should also have as much flat phase response as possible.

III. CONVERGENCE CRITERION

Canceling acoustic signal should attenuate original acoustic noise. That means that canceling acoustic signal should have equal amplitude, but the opposite phase (180º) of the offending noise signal. Such precision is often difficult to achieve. However, frequency components in the canceling acoustic signal should not deviate in phase more than 60º from its ideal variant, Fig. 7. Hence, phase shift introduced by the secondary path, $S(z)$, must be within the interval around the desired phase for all frequency components of the canceling signal, (14).

$$\theta \in [-60°, +60°] \tag{14}$$

If outside this phase tolerance, the canceling acoustic signal would increase the noise level, instead of diminishing it. It is important for the main frequency and its harmonics to satisfy this criterion. To assure that no frequencies outside the desired frequency range are used, high-pass (not needed for a waveform synthesis) and the low-pass filter can be applied to cut frequencies outside the range. Such filters are common elements within various systems with A/D and/or D/A converters anyway. For destructive interference to take place, some tolerances in amplitudes of the canceling acoustic signal are allowed

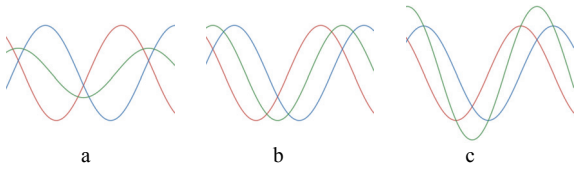

Figure 7. Noise cancellation for various phase errors between the noise and canceling acoustic signal: a) 45º (some cancellation), b) 60º(neutral), c) 90º (increase), blue - noise, red - canceling acoustic signal, green - sum

(e.g., up to 6 dB overshoot for 0º phase error, 3 dB at 45º and 0 dB at 60º). Amplitude undershoots just slows down the convergence process (dynamic reserve is needed to compensate it for full cancellation). Over the time, resulting cancellation will be much better than in Fig. 7 (just the beginning), as the cancellation process continues on and on with the already partially canceled noise.

IV. COMMON SECONDARY PATH MODELING

The influence of the secondary path has motivated the development of the Filtered-x LMS (FxLMS) algorithm, [5]. Instead of reference signal x, it uses its filtered version x' by the filter that approximates the transfer function of the secondary path. Block diagram of FxLMS algorithm is shown in Fig. 8, and its variant applied to ANC method employing synchronized waveform generator in Fig. 9. Implementations of ANC using waveform synthesis may not be suitable for application of the FxLMS algorithm (missing reference noise signal, it has just synchro signal). Modeling of the secondary path can be accomplished off-line or even on-line (the latter is more complicated). Off-line modeling of the secondary path is illustrated in Fig. 10, [4]. It involves system identification of $S(z)$, driven by the source of white noise. The secondary path is approximated by $\hat{S}(z)$ using the LMS algorithm. Use of the long adaptive filter and injection of white noise is somewhat complicated, both in adaptation and operation.

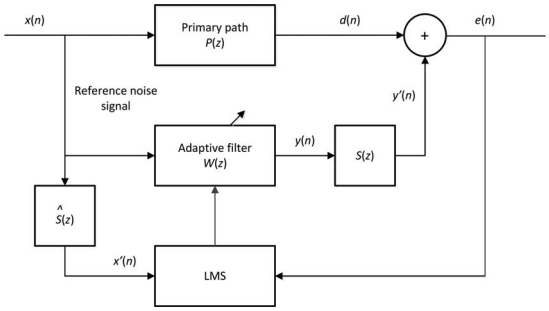

Figure 8. FxLMS algorithm

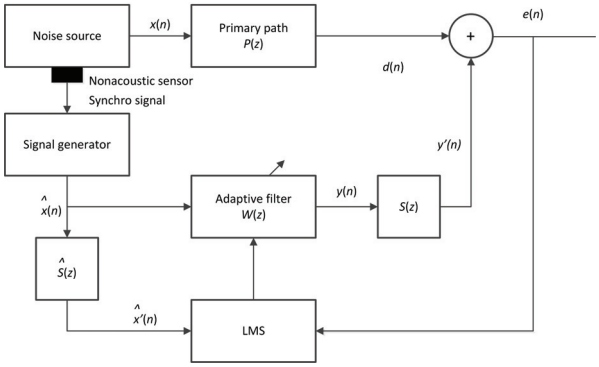

Figure 9. FxLMS applied to synchronized waveform generator

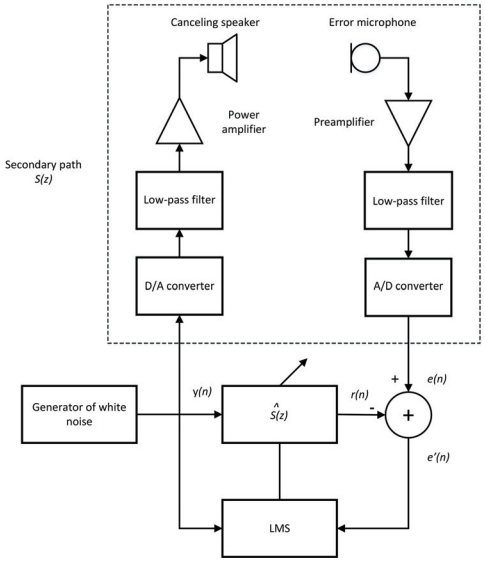

Figure 10. Off-line modeling of the secondary path

V. SIMPLE SECONDARY PATH MODELING

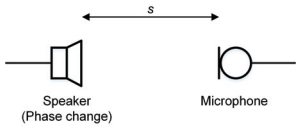

Figure 11. Sound propagation path between the secondary source and the error microphone with the corresponding distance

The synchronized waveform generator produces a signal that consists of main frequency and its harmonics. Secondary path modeling must satisfy convergence requirements for these frequency components. Instead of a rather complicated determination of the secondary path, under some restrictions (frequency range of the noise, absence of significant reflections), simple method can be used. There is a delay t of r samples caused by the sound traveling from the speaker to the error microphone, consisting of two delays, first that depends only on the distance s and is not dependent on frequency and a second one that is caused by phase shift of the secondary path and is dependent on the frequency, Fig. 11, [8].

Amplitude deviations across the frequency range of interest are usually relatively small and are not included in this approach (additional multiplication is not justified for a small gain).

It is necessary to introduce a delay between the output signal and the signal from the error microphone. Waveform memory with pointers separated by r samples (delay) is shown in Fig. 12, [8]. Phase shifts at sampling rates of 8000 Hz and 22050 Hz are shown in Table I. Better phase resolution per sample can be achieved by using a higher sample rate.

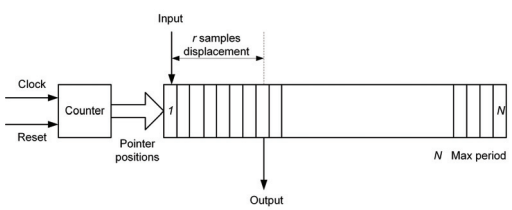

Figure 12. Waveform memory with pointers separated by r samples

TABLE I PHASE SHIFTS AT SAMPLING RATES OF 8000 HZ AND 22050 HZ

Frequency	Period (samples)		One sample equals degrees	
	f_s = 8000 Hz	f_s = 22050 Hz	f_s = 8000 Hz	f_s = 22050 Hz
100	80	4.5	4.5	1.6
200	40	9	9	3.3
300	26.7	13.5	13.5	4.9
400	20	18	18	6.5
500	16	22.5	22.5	8.2
600	13.3	27	27	9.8
700	11.4	31.6	31.6	11.5
800	10	36	36	13.1
900	8.9	40.5	40.5	14.7
1000	8	45	45	16.3

A. Calibration Process

Before the system is ready for use, it has to undergo a calibration process where time delays corresponding to phase shifts caused by the secondary path for various frequencies are determined. The calibration is performed using the sinusoidal pilot tone. It is achieved by calculating a correlation between the pilot tone x_1 and the signal from the error microphone x_2 for various time delays and picking the delay r for which the value of correlation between these two signals is maximal, (15) and (16), [8], s is the distance between the speaker and error microphone, v speed of sound, f_s sampling rate, f_p pilot tone frequency, τ_Δ is a delay and γ phase angle for search space (e.g, 90°).

$$r_{12}(\tau_\Delta) = \frac{1}{N-\tau_\Delta}\sum_{n=\tau_\Delta}^{N} x_1(n)x_2(n-\tau_\Delta)$$

$$\tau_\Delta = \left\lfloor 0.8\frac{sf_s}{v} - \frac{60f_s}{360f_p} \right\rfloor, \cdots, \left\lceil 1.2\frac{sf_s}{v} + \frac{60f_s}{360f_p} \right\rceil \quad (15)$$

$$r = \arg\max_{\tau_\Delta}\left(r_{12}(\tau_\Delta)\right) \quad (16)$$

Let f_{min} denotes the lowest frequency to be canceled (sync frequency f_m) and f_{max}, the highest frequency to be canceled. The calibration is performed for all frequencies between f_{min} and f_{max}. Signal period T (in samples) is related to frequency by (17):

$$T = \frac{f_s}{f} \quad (17)$$

Frequency sweep is performed decreasing in steps of one sample between the time periods T_{max} and T_{min}, corresponding to the frequencies f_{min} and f_{max}. Time delays τ_Δ used in calculation of correlation in each step of the frequency sweep must be from the proximity of the delay used in the previous step (e.g., a small fraction of the period) providing the approximate monotonic function and numerical efficiency. Values of r_i determined by (15) and (16) for each frequency f_m (i.e., for the corresponding period) are stored in a lookup table of phase delays.

There are two phase angles, α and β that are taken into consideration in simple secondary path modeling:

α is the maximal acceptable phase shift at the lowest frequency, f_{min}.

β is the maximal acceptable phase shift at the highest frequency, f_{max}.

From the frequency and phase response of the speaker (the main contributor to the frequency dependent phase delay), one can get an idea what frequency range is suitable for ANC operation. It should be a range with the

flat frequency response, where the phase response is approximately monotonic function (some deviations may be allowed), with the phase preferably close to the linear and with the corresponding phase range of $\alpha+\beta$.

B. Variants of Simple Secondary Path Modeling

Three variants for simple secondary path modeling are considered, one with a fixed and two with a variable delay. Phase delays in samples for angles α and β are:

$$r_\alpha = \frac{\alpha f_s}{360 f_{\min}} = \frac{\alpha T_{\max}}{360} \quad (18)$$

$$r_\beta = \frac{\beta f_s}{360 f_{\max}} = \frac{\beta T_{\min}}{360} \quad (19)$$

The phase interval $[-\alpha,+\alpha]$ has the corresponding interval in samples $[-r_\alpha,+r_\alpha]$, and the phase interval $[-\beta, +\beta]$ has the corresponding interval in samples $[-r_\beta,+r_\beta]$. Sensitivity to the phase expressed in samples is higher for high frequencies where one sample means a lot for the phase of the signal (period at a high frequency consists of a small number of samples compared to a low frequency), see Table I. The higher sample rate may help (e.g., $720/\beta$ or more samples per period of the highest frequency). It is assumed that the values of α and β are lower than 60º. The value of α should be much lower than 45º, as small as possible, ideally close to zero. The goal is to set the smallest phase for one frequency, and provide still satisfactory phases for other frequencies. Lower frequencies are more prominent in a noise and it is beneficial to achieve a lower phase shift for them, providing a faster convergence, hence $\alpha < \beta$. Tolerances on phase response, as an approximate monotonic and close to linear function, must assure that phase shift for all frequency components in canceling acoustic signal is less than 60º. Phase shifts θ for values of r_i and r_0 at frequency f are related by (20), f_s is the sampling rate:

$$\theta = \frac{360(r_i - r_0)f}{f_s} \quad (20)$$

- Fixed Value Delay

Phase compensation delay is determined just for one frequency. Delay r_0, determined for the lowest frequency, f_{min} is used for all frequencies, regardless of f_m.

The algorithm is as follows (all integers):

1. Get the stored delay r_0 and calculate r_α for the lowest frequency f_{min}, (18)
2. Get the stored delay r_i and calculate r_β for the highest frequency f_{max}, (19) /* f_{max} could be lowered in step 4 */
3. /* Check if the phase for the f_{max} is within $[-\beta,+\beta]$ */
   if $|r_i - r_0| \le r_\beta$ then go to step 5 /* Phase OK */
4. if $|r_i - r_0| \le (r_\alpha + r_\beta)$ /* $|r_i - r_0| > r_\beta$ */
   then /* Modify r_0 to get the correct phase for f_{max} */
   if $r_i > r_0$ then $r_0 := r_i - r_\beta$
   else $r_0 := r_i + r_\beta$
   else /* If not possible to get correct phase for f_{max} */
   It is not possible to determine the acceptable delay r_0 for the f_{max} within an acceptable phase shift for the $f_{min.}$, $[-\alpha,+\alpha]$.Goto step 2 with the next lower frequency f_{max} (higher T_{min}) from the lookup table.
5. Set the low pass filter cutoff frequency to the highest possible frequency f_{max}.
6. Store the value (r_0 mod T_{max}) /* mod is used for period limits protection */

- Frequency Dependent Value of Delay

A variable delay r_i is used, depending on the main (fundamental) frequency f_m of the noise. During the operation of the system, appropriate delay is selected from the lookup table according to the main frequency, Fig. 13, for adaptation (using the coherent averaging). As the main frequency is changing, it is selecting the most appropriate delay.

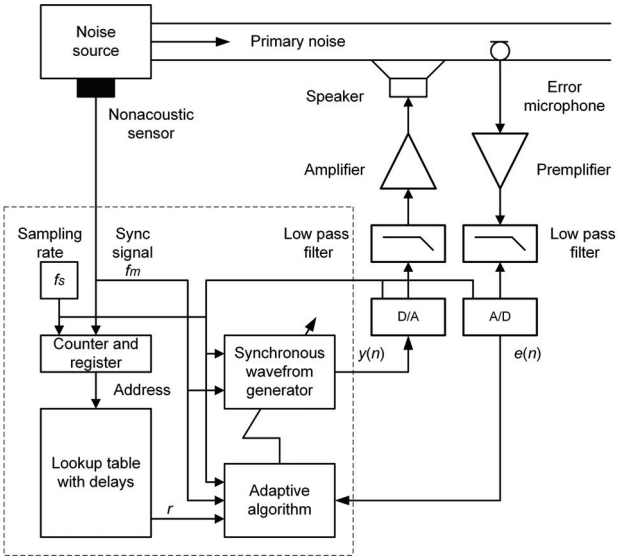

Figure 13. Waveform synthesis ANC system with lookup table containing frequency dependent delays (phase delay corrections)

The main frequency is equal to the frequency of sync signal f_m. Minimal and maximal values for the main (fundamental) frequency f_m are $f_{m,min}$ and $f_{m,max}$. (e.g., related to the machine rotation speed).

The algorithm is as follows (all integers):

1. Get the stored delay r_0 and calculate r_α for the lowest frequency f_{min}, (18)
2. Get the stored delay r_i and calculate r_β for the highest frequency f_{max}, (19) /* f_{max} could be lowered in step 4 */
3. /* Check if the phase for the f_{max} is within $[-\beta,+\beta]$ */
   if $|r_i - r_0| \le r_\beta$ then go to step 5 /* Phase OK */
4. if $|r_i - r_0| > (r_\alpha + r_\beta)$ /* $|r_i - r_0| > r_\beta$ */
   then /* If not possible to get correct phase for f_{max} */
   It is not possible to determine the acceptable delay r_0 for the f_{max} within an acceptable phase shift for the f_{min}, $[-\alpha,+\alpha]$. Go to step 2 with the next lower frequency f_{max} (higher T_{min}) from the lookup table.
5. Set the low pass filter cutoff frequency to the highest possible frequency f_{max}.

6. Loop: (for each period T_m from $T_{m,max}$ down to $T_{m,min}$) do steps 7-9. /* T_m is corresponding to the main frequency $f_m = f_s / T_m$ changing from $f_{m,min}$ up to $f_{m,max}$ */
7. Get the stored delay r_m and calculate r_β for the frequency f_m /*similar to (19), just use f_m instead f_{max}*/
8. if $|r_i - r_m| > r_\beta$
   then /* Modify r_m to get the correct phase for f_m */
   if $r_i > r_m$ then $r_m := r_i - r_\beta$
   else $r_m := r_i + r_\beta$
9. Store the value (r_m mod T_m) in the lookup table.

- Frequency Dependent Value of Delay for the Harmonic Content Only

Considering that only main frequency and its harmonics (due to the repeating waveform) are present in a canceling acoustic signal, procedure from steps 7-9 can be further elaborated in the new variant (steps 7-12):

1. Get the stored delay r_0 and calculate r_α for the lowest frequency f_{min}, (18)
2. Get the stored delay r_i and calculate r_β for the highest frequency f_{max}, (19) /* f_{max} could be lowered in step 4 */
3. /* Check if the phase for the f_{max} is within $[-\beta,+\beta]$ */
   if $|r_i - r_0| \le r_\beta$ then go to step 5 /* Phase OK */
4. if $|r_i - r_0| > (r_\alpha + r_\beta)$ /* $|r_i - r_0| > r_\beta$ */
   then /* If not possible to get correct phase for f_{max} */
   It is not possible to determine the acceptable delay r_0 for the f_{max} within an acceptable phase shift for the f_{min}, $[-\alpha,+\alpha]$. Go to step 2 with the next lower frequency f_{max} (higher T_{min}) from the lookup table.
5. Set the low pass filter cutoff frequency to the highest frequency possible f_{max}.
6. Loop: (for each period T_m from $T_{m,max}$ down to $T_{m,min}$) do steps 7-12. /* T_m is corresponding to the main frequency $f_m = f_s / T_m$ changing from $f_{m,min}$ up to $f_{m,max}$ */
7. If $T_m < 2T_{min}$ then exit /* no more harmonics $\le f_{max}$ */
8. Get the stored delay r_m for the frequency f_m
9. For each main frequency f_m determine the highest harmonic f_{har} :

$$f_{har} = k f_m \qquad k = 2, 3, \ldots \qquad (21)$$

(or for the period) $$T_{har} = \frac{T_m}{k} \qquad k = 2, 3, \ldots \qquad (22)$$

that is not higher than the highest possible frequency f_{max}

$$f_{har} \le f_{max} \qquad (23)$$

(or for the period) $$T_{har} \ge T_{min} \qquad (24)$$

10. Get the stored delay r_{har} and calculate r_β for the highest harmonic f_{har} :

$$r_{\beta,har} = \frac{\beta f_s}{360 f_{har}} \qquad (25)$$

(or for the period) $$r_{\beta,har} = \frac{\beta T_{har}}{360} \qquad (26)$$

11. if $|r_{har} - r_m| > r_{\beta,har}$
   then /* Modify r_m to get the correct phase for f_{har} */
   if $r_{har} > r_m$ then $r_m := r_{har} - r_{\beta,har}$
   else $r_m := r_{har} + r_{\beta,har}$
12. Store the value (r_m mod T_m) in the lookup table.

This method considers harmonics in the cancellation signal. It modifies delays r_i for the main frequencies f_m considering the highest harmonic $f_{har} \le f_{max}$ instead of f_{max}.

VI. Numerical Complexity Comparison

Numerical complexity (during the ANC operation, per each signal sample) is listed in a Table II below. Simple secondary path modeling methods in comparison with the FxLMS algorithm don't use additions or multiplications.

TABLE II NUMERICAL COMPLEXITY OF SECONDARY PATH MODELING

Method	Complexity	
	Additions	Multiplications
FxLMS	L [1)]	L
Fixed delay	0 [2)]	0
Variable delay	0	0
Variable delay (harmonics)	0	0

[1)] L is the filter length [2)] 0 means no operation

VII. Conclusion

Active noise control using waveform synthesis is an attractive method for cancellation of periodic noise that is easy to understand and implement, even on a low cost hardware. The influence of the secondary path makes this method a little more complicated. A simple method for the secondary path modeling is presented. Three variants have been proposed, one with a fixed delay and two with a variable delay. Variants with variable delay that changes with the main frequency of the noise are presented without and with considering the harmonic content of the canceling signal. During the ANC operation, main frequency selects a delay stored in a lookup table. Variable delay enables better phase accuracy of the canceling acoustic signal, providing a faster convergence over the wider frequency range. The method is suitable for the ANC using waveform synthesis that lacks the benefit of the available reference noise signal needed for the FxLMS method.

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INVITED PAPER

Some logic and related formalisms, programming paradigms, and development environments for the (new) AI

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Abstract - **Since its very beginnings, AI has more or less developed in parallel with two lines of research method paradigms. The first paradigm could be called *statistical* (pattern recognition, machine learning, also deep learning, which in the last few years has entered quite a vibrant phase of development). The second paradigm can be called *logical*. It (mostly) deals with automatic deduction systems and tool development in the environment of corresponding formal methods, which in particular encompass formal logic calculi. This paradigm partially uses these systems for the requirements of modelling and solving problems from the AI domain.**

There are many logic calculi that have found their application in modelling and solving a wide range of AI problems. These range from classical propositional calculi, their fragments (such as calculi of functional and multivalued dependencies, without which the relational data model wouldn't be possible), intuitionistic propositional logic and its many fragments and variants, superintuitionistic logics, multiple valued logics (Lukasiewicz logics), discrete as well as continuous, systems of modal propositional logics, first order predicate calculus (logic) and its variants, second order predicate Logic, F-Logic etc. In addition to these, we cannot avoid mentioning a whole spectrum of contextual domain logics such as fuzzy logics.

Many of the logic calculi mentioned above have themselves become foundations for building logic programming languages such as Prolog (and its relatives), hybrid programming languages and tools. Next to the logic component, they encompass classical linear programming (constraint logic programming languages) and also specialized tools such as SAT-solvers, languages that implement 2nd order predicate logic (HiLog) or tools such as Coq. Coq is based on a fragment of lambda calculus that for the last thirty years has been developed by INRIA, the world renowned computer science institute based in France.

Through this presentation of selected logic systems, related programming languages, development environments and specific purpose tools, the author wants to highlight the enormous potential of their application in modelling and solving AI problems.

Keywords – artificial intelligence; logic formalisms, formal methods, logic programming

I. INTRODUCTION

The purpose of this presentation is to provide a very brief, personal view of the state of development of formal logic systems, with an emphasis on automatic deduction methods and their use in solving problems in the AI domain. Its aim is to also point out some issues relating to education in this domain, that is, to look at the wider acceptance of symbolic (formal, mathematical) logic as a problem solving tool. This presentation does not assume a rigid, or even a commonly accepted definition of AI.

As a working definition, we take the one that posits that "*Artificial Intelligence (AI) is the capability of a machine to imitate intelligent human behaviour or cognitive functions, such as learning and problem solving.*"[1]

The ability of logical thinking to solve problems is certainly one of the most important human cognitive abilities. As such, already in classical European antiquity (Plato, Aristotle, ...), and perhaps even earlier there has been an interest in trying to formalize it (if not automate it). For a broader historical perspective see [1].

II. A BRIEF OUTLINE OF THE POSSIBLE ORIGIN OF LOGIC AND SOME IMPORTANT FEATURES OF FORMAL LOGIC CALCULI

A. The origin of logic and approaches to studying logical calculi

The origins of logic are still not fully explained scientifically. There are good indications that logic originated as a means of avoiding spatial-temporal obstacles and achieving goals through a series of consecutive approximations of the corresponding goal functions [2]. This is also indicated by the so-called logic of topoi [3], recently applied even in the domain of musical creation [4]. In the last few years, V. Voevodsky and his group at the Institute for Advanced Studies, Princeton, USA, has been developing the so-called *univalent foundations of mathematics*, as the fundamental framework for the development of mathematics in its entirety, using the theory of homotopy and theory of types [5].

[1]Chris Gottschalk, https://www.linkedin.com/pulse/artificial- intelligence-embrace-fear-chris-gottschalk,

B. The idea of formal logic systems and approaches to their study

The idea of a formal logic system in the modern sense (approached via syntax) was created by abstracting the corresponding models. An example everyone is familiar with is standard planar geometry, which, as an axiomatic theory, was presented (and partially developed) by Euclid. It is less known that the abandonment of the standard axiom of parallels (through a point outside of a straight line passes only one straight line parallel to it) gives two new axiomatic systems of geometry, hyperbolic (through a point outside of a straight line passes an infinite number of lines parallel to it) known as the geometry of Lobachevsky (well suited for Einstein's theory of relativity, for example), or elliptic geometry (in special cases, sphere geometry (no line parallel with a straight line passes through a point outside of that straight line), well suited for managing satellite navigation in Earth's orbit, aircraft navigation, etc.).

Formal logic systems (calculi), and here we are talking about the central currents of research, not about the fair number of "pathological" situations, can only be considered from the point of view of syntax, either solely from the point of view of semantics (content), or from both.

The approach from the standpoint of semantics presupposes the notion of truth. According to the results of the Polish mathematician and logician A. Tarski, the very concept of truth is not definable in the context of so-called Peano arithmetic[2] (Tarski's weak theorem). Nor can it be defined within even the much wider range of logic calculi which recognize the logical not as a logical connective and exhibit some form of self-referentiality, sufficient to establish Goedel's diagonal lemma (Tarski's strong theorem). Self-referentiality leads to paradoxes like the paradox of the liar. In a recent paper [6], M. Hsiung developed the theory of so-called Boolean paradoxes. Its potential consequences for paradox-free mathematics aren't as yet visible, but they most certainly will be.

The approach to studying logic calculi through syntax (superficially) presupposes an abandonment of the notion of truth, and thus of semantics. It is a kind of logic deduction game, and (for some time) a logic refutation game. Through using a formally defined language, a class of syntactically valid objects ("formulae") of the logic calculi are defined. From this set, a subset of formulae called axioms is extracted. Axioms are, as a rule, language formulae that are true in all possible models (although this is an "public secret" within the syntactic approach). With the help of a logic deduction rule, the axioms and the original set of formulae, the deduction of a specific formula can be defined. In the so-called Hilbert formulations, the most common deduction rule is Modus Ponens, while the so-called Gentzen style natural deduction systems know multiple deduction rules (one rule "introducing" a given logic connective and an another rule "eliminating" it). Formulae which can be derived from an empty set of formulae (using axioms only) are called theorems.

[2] Common, school arithmetic (but axiomatized) with an induction scheme as a means of proving arithmetic formulae.

The concept of logic deduction in the semantic approach is based on the notion of interpretation that includes the notion of truth. In this context, a given "formula" is a logical consequence of a given set of "formulae" if, and only if, it is true in all interpretations in which all formulae of the given set are true. Of course, such a definition of the notion of logical consequence goes beyond the framework of the logic calculus itself. It returns to it via so-called theorems of characterization of the notion of logical consequence at the level of semantics. One of these two theorems relies on the notion of tautology, while the other relies on the notion of contradiction.

C. Deduction through Syntax or through Semantics?

For the purposes of automated deduction, especially with regards to industrial level applications a semantic approach is more appropriate. This is in accordance with the famous saying "A lie has no legs." The specific reasons for this are the following:

i. Modelling "practical" problems necessarily involves "semantics" of a particular problem area

ii. Logic calculus formulae represent binary trees in terms of their data structure. Such a structure, in terms of the requirements of logical deduction, is very rigid. Thus, for instance, the proof of each formula implying itself is trivial at the level of semantics (being an immediate consequence of the definition), while such proof at the level of syntax requires particular, not entirely trivial "juggling" in terms of matching the formulas participating in the deduction according to the Modus Ponens rule pattern.

iii. Furthermore, the semantic approach, as a result of so-called primitive normal forms, especially conjunctive, and with the subsequent removal of the logical connective *and*, on the one hand enables the linearization of the structure of the formulas that are being operated with (so-called disjuncts). On the other hand, according to most of the references in the literature, the standard rule of logical deduction in this context, the so-called resolution rule, originally defined in 1965 in J. Robinson's paper [8] turned out to be "grupoidal" (it again produced disjuncts as logical consequences of the disjuncts on which it operated) and complete. Through its consecutive application, it is always possible to deduct an identical false or contradictory disjunct from a contradictory set of disjuncts).

iv. The resolution rule can be very successfully expanded from propositional logic calculi to predicate calculi, preferably of the first and second order.

v. Incorporating the resolution rule (often modified in accordance with certain ideas about reducing the number of generated resolvents, with the preservation of the completeness) into appropriate algorithmic "wrappers" (algorithms or heuristics) such as the level saturation method, the Davis-

Putnam method, the DPLL method (the generalized Davis-Putnam method), the recursive backtracking, proved to be extremely effective in solving the problem of automatic deduction.

D. Some basic types of automated deduction problem for the classical propositional calculus (and beyond)

The types of logic deduction problems for the classical propositional calculus (of refutation, as well as the satisfiability type) are now well-classified (see, for example, [9]). In addition to the classical SAT problem, by assigning weighted coefficients to propositional variables one at a time when it is true or false in a given interpretation (problem model), it is possible to define the cost of the solution of the SAT problem. The total cost of such a solution is measured by the total sum of the values of weighted coefficients of propositional variables. When an attempt is made to minimize this sum, the MINSAT problem occurs.

By making different additional requirements on the subsets of the clauses of a given (un)satisfiability problem and the very same propositional variables from which the clauses are constructed, a whole series of SAT or MINSAT problem variants arises, such as MAXCLS SAT, MINCLS UNSAT, MAXVAR SAT, MINVAR UNSAT. MINSAT type problems are dual problems of the MAXSAT type.

From a theoretical point of view, compared to the still unresolved problem (P = NP)? the so-called 3SAT problem is crucial. It is specific in that each of its clauses contains exactly three literals (a literal is a propositional variable or its negation). It turns out that the 3SAT problem is in NP, and since it is at the same time NP-complete, it is also NP-hard. For details see, for example, [10].

By allowing the action of the universal quantifier "for all" and existential quantifier "there exists" on the propositional variables of the CNF or DNF formula, the so-called quantified Boolean formula problem (QBF) arises [11].

There are at least two important logic calculi, which deserve special mention, that are actually fragments (in terms of being embedded) into the classical propositional calculus. These are the calculus of the functional and multivalent dependencies of the relational data model. These two logic calculi provide the relational data model with complete semantics, partially expressed through commonly known normal forms. For details, see, for example, [12].

E. Some non-classical (non-Hilbertian) propositional logic calculi.

Non-classical propositional calculi are generated by varying the different parameters of the definition of the classical propositional calculus. This also refers to the number of truth values, new logical operators (connectives), or the choice of axioms. In a situation where the propositional calculus knows more than two values of truth, we speak of multivalued or multiple-valued calculus. Such propositional calculi can be discrete or continuous. Today there is a multitude of such propositional calculi, amongst which the best known are the so-called Lukasiewizc logics (both variants exist, discrete, as well as continuous, and both are still being intensively developed). Another type of such propositional calculi are the so-called Post logics, with the characteristic (circular) definition of the connective "not".

Between the Lukasiewicz and the Post logics there is a somewhat strange (one could say even magical or mystical) connection which at the same time characterizes the very notion of the prime number: Number n is a prime number if, and only if, Lukasievicz logic F_{n+1} (meaning it supposes exactly n+1 truth values) is precomplete in Post's logic P_{n+1}. Being precomplete in this concrete case means that the set of valid formulae of Lukasiewicz logic F_{n+1}, being embedded (interpreted) in Post's logic P_{n+1}, needs to "borrow" just one propositional function from the logic P_{n+1}, which doesn't belong to it in order to be able to represent (via composition operation) every logic function from the logic P_{n+1}. For a general exposition of this result and Lukasiewicz logics see e.g. [13] - [15]. For tableaux based methods of automatic deduction in the context of multiple-valued logics see [16]. For an advanced exposition of the theory of multiple-valued algebras see [17].

In close connection with Lukasiewicz' propositional logics, to the extent that some are interpreted in others, there are so-called propositional fuzzy logics. Fuzzy logics are likely the most popular type of logics which from the very beginning of their development have found many practical applications on an industrial scale They are today managing smart household devices, robots and entire industrial facilities. Hundreds of thousands of papers and thousands of books have been written about them.

A recent query to the Google Scholar service of the keyphrase "fuzzy logic" resulted in almost a million links. So, what are then fuzzy logics and what makes them so applicable?

One could imagine fuzzy logic as a kind of a contextual domain logic. The context of a specific domain consists of objects with attributes (linguistic variables) which can assume values from some continuous numeric interval. The dynamics of the changes of values of those linguistic variables are "stable" at sufficiently large intervals of values where their behaviour can be, for example, in the case of the "level of movement" of an object, characterized as "fast" "slow", "too fast", "too slow", "not too fast", "could be a bit faster" etc. Those levels of membership are described with the so called membership functions, which are then used to interpret standard logical operators (connectives). A good introduction into fuzzy set theory and fuzzy logic is [18].

To a certain extent, fuzzy logic can be compared to the so-called discrete linear control systems theory whose behaviour is described by systems of so-called difference equations (see e.g. [19], or by the theory of continuous linear control systems whose behaviour is described by systems of linear differential (and integral) equations (see e.g. [20]).

Among the propositional logics that, in addition to the standard (Boolean) logical connectives, know additional connectives are the so-called modal propositional calculi

(logics). There are two additional logical connectives: "necessary" and "possible". If modal logic calculi are observed from the syntax point of view, they are, according to the axioms and inference rules that they "add" to the axioms of the classic propositional calculus, divided into a variety of specific systems, such as S1, S2, S3, S4, S4.2, S4.3, S5, K (an another label is Kr), D, M, T, ... A reader not specialised in modal logic will immediately think of how the notions of interpretation, truth and logical consequence are defined in that environment. Here, the so-called Kripke models that assume the object domain (set of worlds) and the so-called accessibility relation are of use. For details, see e.g. [21] – [24].

The propositional modal logics have become the theoretical basis of the so-called knowledge reasoning systems, populated by agents (most often software). Among the axioms of an agent's knowledge is the so-called axiom of positive introspection: *If an agent knows the knowledge (formula), then he knows that he knows that knowledge (formula)*; then the axiom of negative introspection: *If an agent does not know some knowledge, then he knows that he doesn't know that knowledge*; axiom of knowledge: *If an agent knows some knowledge, then this knowledge is valid ....* A very comprehensive view of reasoning on knowledge in the context of multi-agent systems is given in the monograph [25].

In addition to the axiomatic approach (most commonly of Hilbert's or Gentzen's type), the classical propositional calculi, as well as many non-classical, such as Lukasiewicz logics, are also considered from the so-called functional standpoint. As such, the logic formulae are represented through functions of the domain and co-domain of the identical set of truth values. Subclasses of such functions (recent terminology knows them as clones) are then studied with regard to different properties (monotonicity, symmetry, preservation of individual truth values ...) and their attributes. Furthermore, the problems of decomposition and synthesis of such functions are studied. Monographs [26] and [27] are very comprehensive and instructive in this regard.

Furthermore, logic calculi (not just the propositional ones) are often interpreted in other mathematical theories and structures. In this context, it is particularly worth mentioning linear algebra (see [28]) and semi-tensor logic (see [29]), polynomial algebra, as well as different types of algebraic structures such as rings and fields (see e.g. [30] - [33]). A special emphasis on the algorithmic efficiency of logical deduction is placed by the so-called positional (it is not a *lapsus calami*) logic of M. I. Telpiz (see [34] and [35]).

F. Some applications of propositional logic calculi

When talking about applications of propositional logic calculi, we should first mention their limitations in terms of problem modelling. This is especially in relation to the impossibility (due to limitations of their languages) of modelling "structural" relationships (of the type "to be a parent", "to be a child", "to be a relative"), reinterpreting discourse domains with functions or general mappings, as well as quantifying variables (except for quantified propositional calculi that are not "real" propositional calculi). Nevertheless, there are many applications of propositional logic calculi, ranging from, conditionally speaking, "academic" to industrial on a large scale.

A good part of the application of classic propositional logic calculi and fuzzy propositional calculi refers to so-called propositional expert systems (see [36] and [38]), solving various combinatorial problems of practical value that can be formulated as SAT type problems, such as sports scheduling problems (like the Round Robin problem), see [39], planning problems (see [40]), and combinatorial designs problems (see [41]). The functional approach to studying classical propositional calculi using methods of classical analysis (differentiation, integration, Fourier expansion...) has opened the way to a multitude of applications related to the decomposition and synthesis of logical circuits. More about this range of topics can be found in e.g. [42].

As far as the application of modal propositional calculi is concerned, it is particularly visible through its interpretation in so-called epistemic logics (logics of knowledge, see, for example, [43] and [44]). Epistemic logics (including the so-called logics of beliefs) are very applicable in modelling games in multi-agent systems, including living agents (humans) – see e.g. [25], modelling social games (card games – see e.g. [45] and [46]), solving the problem of retrograde chess analysis (see e.g. [47]), demonstrating the validity of strategies for playing chess endings (see e.g. [48] and [49]), modelling IT safety, reasoning about security-critical information flow among humans and computers, [51], modelling authentication, [52] and [53], etc.

G. Stälmarck's method

The applications of propositional logic calculi on an industrial scale aren't that many, but we shall indeed mention one that is very valuable. This is the so-called Stälmarck's proof procedure for propositional logic. It is widely known because it is patented (USPTO, *Patent number: 5276897*, January 4, 1994: *System for determining propositional logic theorems by applying values and rules to triplets that are generated from Boolean formula,*)[3]. At the same time, it is also extremely successful in solving the problem of verifying very large logic models of railway traffic management in marshalling yards and other types of railway infrastructure. Of course, the application domain of Stälmarck's method is not limited to this specific area of modelling.

In the case of Stälmarck's method, we are dealing with a kind of implicational propositional calculus in Gentzen's style, in conjunction with the specific execution of the tableaux method (which uses only the connectives $\neg$ (not) and $\rightarrow$ (implies) and logical constants $\bot$ (contradiction) and $\top$ (tautology)). The original proposition is decomposed into a sequence of so-called *triplets*, where in the triplet (b_i, c_i, d_i) b_i being the *name* of the implication $c_i \rightarrow d_i$ which

[3] The author himself considers the patenting of algorithms to be very problematic and this will be discussed later.

also represents some subformula of the original formula, while the triplet alone represents the formula $b_i \leftrightarrow (c_i \rightarrow d_i)$. The proof of a formula is performed by the proof of contradiction of its negation with the help of the corresponding deduction rules, such as

$$(r1)\ \frac{(0,y,z)}{y/1\ z/0},$$

actually meaning that the implication $y \rightarrow z$ is false, if and only if, y is true and z is false. A terminal triplet is one that is contradictory, for example (1,1,0). There is a sum total of seven deduction rules like rule (r1) and they are called *simple rules*. Since there are propositional formulae of Stälmarck's propositional calculus that cannot be proven by using only simple rules, a *rule of branching* is introduced which "cashes in on" the value of a given variable, branching the proof to the branch for which the value of that variable is 1 and the branch for which the value of that variable is 0. This rule is known as the *Dilemma rule*.

$$\frac{\begin{array}{c} T \\ \hline T[x/1] \quad T[x/0] \\ D_1 \quad D_2 \\ U[S_1] \quad V[S_2] \end{array}}{T[S]}$$

According to [54], on page 26, it writes formulas "D_1 and D_2 are derivations (or proofs). D_1 starts from the set of triplets T and the assumption that x is true. D_2 starts from T and the assumption that x is false. If one of these derivations gives a terminal triplet, then the result of applying this rule is the result of the other derivation. If neither D_1 nor D_2 lead to a contradiction, then the resulting substitution (or variable instantiation) S is the intersection of S_1 and S_2. Any information gained both from assuming that x is true and from assuming that it is false must hold independent of the value of x."

And further, on page 28, it says "The proof system M consisting of the simple rules r1 to r7 and the dilemma rule is sound and complete for formulas made from variables and implication. Any Boolean formula can be translated to such a formula in linear time by a procedure described by Stälmarck [34][4]."

So the system M is sound and complete for full propositional logic.

We turn the proof system into a proof method by making a sequence of increasingly more powerful subsystems of M. M_0 is M without the dilemma rule. M_{i+1} is M in which the derivations in the two branches of the dilemma rule are restricted to be M_i derivations. So, proofs in M_1 have, at most, one open assumption about the value of a variable, proofs in M_2 have at most two simultaneous assumptions, and so on.

Stälmarck's method can be seen as a family of algorithms that efficiently search for short proofs in M_i for a given i. One can find a proof in M_0 in linear time; this is just the closure of the simple rules. The time required to exhaustively search for a proof in M_k is $O(n^{2k+1})$ where n is the size of the formula.

We say that a valid formula is *i-hard* if it is provable in M_i, but not provable in M_j for any $j < i$. This notion of formula hardness is important, and we will return to it. For now, it is sufficient to note that many industrial verification problems give rise to formulas whose hardness degree is 0 or 1. The formulas may be large, but the method is much more sensitive to the hardness degree of a formula than to its size in terms of a number of variables or connectives.[5] This means that the method is applicable for industrial verification, even on a large scale."

One other very important notion related to Stälmarck's method is the notion of the k-saturated relation, [50], page 39:

"A relation R is *k-saturated* if and only if for every Dilemma derivation with it? holds that $R = S$. In other words, proofs of depth k or less add no new equivalences between subformulas. The k-saturation procedure exhaustively searches for a proof of depth k. If a relation R has a hardness degree k, then *saturate*(R,k) must be explicitly contradictory, and k-saturation finds a disproof of R. The procedure is defined recursively.

0-saturation applies the propagation rules to a relation until no more rules are applicable. It chooses a compound subformula, applies a related simple rule and then continues to apply simple rules on those triplets whose variables were affected by the result of the first rule.

The process continues until no further simple rules can be applied."

It refers to the notion of a *formula relation*, [54], page 34:

"The complement of a formula A, written A', is B if $A=\neg B$ and is A otherwise. Let $S(X)$ be the set containing all the subformulas of X (including $\top$) and their complements.

A *formula relation* $\sim$ on X is an equivalence relation with domain $S(X)$, with the constraint that if $A \sim B$ then $A' \sim B'$. If $A \sim B$, that means that A and B are in the same equivalence class and must have the same truth value. Working with $S(X)$, which includes the complements of subformulas of X, allows us to encode both equalities and inequalities between subformulas is encoded as $A' \sim B$."

H. To patent or not to patent?

The purpose of offering this short presentation of the Stälmarck's method is not to acquaint the reader with the very method itself, but to gain a certain perception of the subject of that particular patent.

There are plenty of methods of logic deduction comparable to Stälmark's. The SDLFN resolution method is an example and is lies in the foundations of logic programming language, such as Prolog or Warren's abstract machine. It represents a model of procedural realization of declarative logic programs, so-called deductive spreadsheet theory (see [56]), interpreting and implementing Excel like spreadsheets calculus in the so-called Datalog as a fragment

[4][55] in References

[5]Marked by the author

of the first order predicate calculus. Then there is the entire technology on which Knuth's TEX rests as a platform for writing mathematical texts, etc. None of these are patented, and in this author's opinion they shouldn't be, even though in his opinion there are more convincing reasons for patenting TEX or deductive spreadsheets, than for patenting Stälmarck's method. The authors of such methods and algorithms should be sufficiently compensated with profits from concrete implementations and appropriate software solutions. The exceptionally principled Professor Knuth relinquished even this. Furthermore, the original Stälmarck's method is still developing not only in the original propositional logic environment (see e.g. [57]), but also in the first order logic environment (see e.g. [58]). Connected to this, the question arises as to whether the original patent "covers" the new, modified and improved algorithms, as well as the question of who should be the holder of these "new" patent rights.

Unfortunately, Stälmarck's patent isn't the only one of its kind. Recently, we are witnessing a number of patents that patent some elementary set theory, dressed up in the "clothes" of relational algebra, for the needs of "big data management." Even worse, we have a patent that has not even patented the results of the scientific research of the patent owners themselves, but the results of the scientific research of completely different authors. The theory in question is known as "logic decision tables" theory and was recently patented for the purpose of modeling business rules. In concluding this short review of patenting logical deduction methods and algorithms, the author is compelled to state that the scientific community should, while it is still not too late (and even this may seem an illusory proposition to some), open a wide public debate on this subject in order to determine what can and what cannot be subjected to such patents.

III. First order predicate calculi

A. The first order predicate calculus, some of its fragments and extensions

Propositional logic calculi aren't very capable of fully modelling problems from the so-called real world due to the pretty limited language that they have, and even when they are, to a certain extent, capable of modelling somewhat more complex problems, this is achieved with great effort and a multitude of "tricks." This situation has changed fundamentally with the discovery of the so-called first-order predicate calculus (which, fortunately, isn't patented (yet)). The classical (I would call it Frege's) first order predicate calculus is the result of several thousands of years of development of symbolic logic that can be traced starting with Aristotle (silogistics), and continuing with W. Shyreshwood (the first half of the thirteenth century) and G.W. Leibnitz (seventeenth century), to its contemporary formulation (with the additional advance of the improvement of language syntax) in the works of G. Frege (the very end of the nineteenth century). It represents a far-reaching generalization of the classical propositional calculus, with a language that implements predicates as a generalization of relations to which it attributes the property of truth, variables and functions over object domains, as well as quantifiers. There is a large amount of literature on different presentation levels that deals with the first order predicate calculus (see e.g. [59] - [63]).

Numerous mathematicians and logicians have contributed to the development of the first order predicate calculus, among which prominent places belong to B. Russell, A. Tarski and K. Gödel. In 1931, K. Gödel proved the so-called incompleteness theorems (of arithmetic and related systems). Though they are not directly concerned with the logical methods used in AI, they most certainly have far-reaching consequences in understanding the scope of axiomatic modelling of "reality" and one should be well aware of them. According to [64]:

GÖDEL'S FIRST INCOMPLETENESS THEOREM

Any consistent[6] formal system F within which a certain amount of elementary arithmetic can be carried out is incomplete; i.e., there are statements of the language of F which can neither be proved nor disproved in F.

"The sentence in question is a relatively simple statement of number theory, a purely universal arithmetical sentence" (ibidem)

GÖDEL'S SECOND INCOMPLETENESS THEOREM

For any consistent system F within which a certain amount of elementary arithmetic can be carried out, the consistency of F cannot be proved in F itself.

"Gödel's second incompleteness theorem concerns the limits of consistency proofs (ibidem)."

There is a multitude of literature on Gödel's incompleteness theorems, from introductory and more technically oriented in character [65] to quite advanced and more philosophically oriented in character [66].

Like the classical propositional calculus, the classical first order predicate calculus also encompasses its fragments such as the already mentioned Datalog (see e.g. [67]), the calculus of positively constructed formulae (see e.g. [68]), the Horn clause calculus, etc. There are also predicate calculi of the second (and higher) order which, sometimes even without certain limitations, allow for each language term to play the role of a predicate or a function. Here, I would mention HiLog (see e.g. [69] and [70]), which is in terms of its syntax a higher order language, while its semantics is still first order semantics, also F-Logic (object oriented frame logic, see [71] and [72]) and the situation calculus (see e.g. [73]).

Of course, the first order predicate calculus interests us from the point of view of the possibility of automated (mechanical) deduction. For these purposes, it would be good to have an analogue of the propositional calculus disjuncts, as well as an analogous of a resolution rule as a logical deduction rule.

[6]A formal system is *consistent* if it contains no statement where the statement itself and its negation are both derivable in the system.

This deductive framework has been successfully developed with the efforts of mathematicians and logicians such as T. Skolem and J. Herbrand. Skolem's achievement is the theory and algorithm of elimination of existential quantifiers from the primitive normal form of a formula, whilst preserving its Skolem form being contradictory in a case when the starting formula was also a contradictory one. This is more than enough for the purposes of automatic deduction, and besides that it allows for the separation of the prefix (a series of universal quantifiers) from the matrix (an analogue of proposition) of a formula. However, it wouldn't be of much use if J. Herbrand had not proven that, in order to prove the contradiction of the original formula in general, and of the Skolem formula in particular, it was sufficient to prove it being false in all of the so-called Herbrand interpretations. A very good introduction of lasting value into this topic is [74].

B. Logic and related programming languages and development environments

R. Kowalski (at the theoretical level, see [75]) and A. Colmerauer and P. Roussel (around 1972 at the implementation level) have shown that a first-order predicate calculus fragment, known as Horn clause calculus (a special kind of disjunct with only one positive literal) can be interpreted and implemented as (logic) programming language. Somewhat later, more precisely in 1983, D. Warren has created a compiler model for Prolog, which is now known as WAM (Warren Abstract Machine, see e.g. [76]). One somewhat newer, but much less widely used alternative to WAM is the so-called Vienna Abstract Machine, [77]. The basis of the deductive mechanism of Prolog and the logic programming languages derived from it lies in the so-called SLDNF resolution, which treats the negation as the finite (ultimate) failure (in the so-called closed worlds model). It should be said that Prolog is a proven universal (Turing complete) programming language, see [78]. It is also the subject of ISO / IEC 13211-1, 1995. certificate

Today Prolog is implemented on all major computing platforms and operating systems, most often in synthesis with other programming paradigms (especially the functional and object-oriented ones), so it can be said that "clean" implementations of Prolog are less common today. Among modern designs one should mention the Visual Prolog (Borland Turbo Prolog's successor), which represents a combination of logical and object-oriented paradigms and has a visual interface of the Microsoft Visual Basic type; SWI Prolog that contains specially developed predicate libraries (command analogues) for the semantic Web, relational databases, constraint handling, ...; Extremely Advanced XSB Prolog + Flora−2 + Hilog programming development environment, which unifies the Prolog standard with a tabling mechanism, an implementation of F-logic (Frame Logic) of M. Kifer and G. Lausen (see eg [79]) and Higher Order Logic (which, roughly speaking, say

"every syntactically valid HOL language construct could be a predicate," see e.g. [80]), very suitable for many types of non-monotone reasoning, supported by corresponding "background" semantics; Amzi! Prolog + Logic ServerTM, logic programming environment embedded in Eclipse IDE, which includes full interfaces for both calling in and calling out from Prolog from a wide variety of development environments including C, C++, Java, Delphi, .NET, VB; SICStus Prolog, fully compliant with the International Standard ISO/IEC 13211−1 (PROLOG: Part 1General Core)7; Mercury, a purely declarative, strongly typed, modular programming language, which supports higher−order programming, including lambda expressions (thus implementing functional programming paradigm), WIN−PROLOG from Logic Programming Associates and numerous other implementations.

There is a large amount of literature about Prolog that also present the syntax and semantics of the language itself, as well as its application, among other things. to solving problems in the AI field. I would particularly mention [81] and [82].

The synthesis between logic programming and linear programming, developed for the optimization of linear functions with constraints expressed by sets of linear equations and inequations, resulted in the so-called constraint logical programming languages. These languages are especially intended for modelling and solving a wide range of combinatorial optimization problems on an industrial scale, including planning, scheduling, crew management, etc. Although most of the modern Prolog implementations incorporate some form of SAT and constraint solvers, there are programming languages and programming environments that have been developed for modelling and solving these specific types of problems, among which the most famous is the ECLiPSe Constraint Programming System (not to be confused with the Eclipse IDE system). The current version is ECLiPSe 7.0 from February of this year. Three very informative titles of monographic character on the subject of constraint logic programming in general and partially on the ECLiPSe system itself are [83] − [85]. Other systems worth mentioning are MiniZinc, FlatZinc and recently Picat CP/SAT.

C. Curry–Howard correspondence and its consequences

Declarative programming languages essentially differentiate their declarative semantics, that is, the contents of the logical program, most often described by some fixed point model, from its procedural semantics which deals with its procedural efficiency (for both see e. g. [86]), to the measure expressed by the syntagm:

PROGRAMMING = LOGIC + CONTROL

However, between the years 1934 and 1969 an idea gradually matured that has been attributed to H. Curry and W. A. Howard, and after them it was named the Curry-Howard correspondence or equivalence (see e.g. [87] and [88]). Nevertheless, L. E. J. Brouwer, A. Heyting and A. Kolmogorov are also credited for its development. The

[7]Information from 1458 pages SICStus Prolog User's Manual, December 2017.

Curry–Howard correspondence establishes a direct relationship between computer programs and mathematical proofs using syntagms *proofs-as-programs* and *propositions/formulae-as-types*.

To cite Wikipedia: "In other words, the Curry–Howard correspondence is the observation that two families of seemingly unrelated formalisms—namely, the proof systems on one hand, and the models of computation on the other—are in fact the same kind of mathematical objects."

Nowadays, there are several implementations of this correspondence, both at the theoretical and at the implementational level. One of the most successful is the so-called Calculus of Inductive Constructions (see example [87]) and its realisation Coq (see e.g. [90] and [91]). The program development environment Coq has been developed for over three decades by the famous French informatics institute, Inria. The latest version is 8.7.2. Coq can model almost all kinds of theories, and express, prove and verify their theorems. For some of the applications see e.g. [92] and [93].

D. *On the coming synthesis of machine learning methods and logic methods*

The last few years have indicated a new developmental wave of the "second half" of AI, which uses discrete mathematics, in particular the theory of graphs and combinatorics, probability theory, statistics and mathematical analysis, and studies disciplines such as pattern recognition, artificial neural net architectures, machine learning and most recently so-called deep learning. This new wave of interest in machine learning, with the emphasis on deep learning was initiated by Google when it opened up its TensorFlow tool for modelling neural network architecture with a focus on deep learning. (see e.g. [94] - [96]).

Shortly thereafter, F. Cholett has developed a library of functions / modul Keras (see e.g. [95]) that envelops Tensor Flow and allows the construction of artificial neural nets for deep learning purposes such as building (everything) with Lego bricks. In the words of F. Chollet himself, a great synthesis of classical methods of machine learning and formal logic methods is on the horizon. For initial examples of this synthesis see e.g. [98] and [99].

One possibility, which for now is a purely hypothetical application of this synthesis, and one the author sees could be called *theorem statement mining*, and would mean that a neural network, trained previously in a broad class of theorems of a given mathematical theory, "guesses" the evidence of new potential theorems. Whether the hit was valid or not could then be proven (or reasons could be found for the opposite) with tools like Coq. If he were alive, success would surely please the famous German mathematician B. Riemann, to whom the phrase "Just give me a theorem, I will prove it somehow!" was attributed.

E. *Some Problems with Accepting and Using Logic Formalisms*

Formal (symbolic, mathematical) logic today is to some extent studied at faculties of mathematics, electrical engineering and information technology. For example, there are two study programs in the Mathematics Department of the Faculty of Science at the University of Zagreb, Croatia, where it is possible to enrol in courses related to formal logic and computability theory. One of them is a study program in theoretical mathematics, and another is a computer science and mathematics program. The first offers two elective courses, mathematical logic and computability, both in the graduate part of the study program, as an obligatory one semester course. The second, also at the graduate level of studies and also obligatory, offers courses in mathematical logic, artificial intelligence, mathematical logic for computer science, and formal methods for computer science. For the purposes of an introduction to the field this is a solid offering (although it could be better structured in terms of content), but it remains very limited due to the Bologna model of studying. This model has abolished earlier postgraduate studies that offered extensions to the content of graduate studies and introduced doctoral studies. These studies are to a much greater extent specialized and oriented towards completing a doctoral dissertation, rather than expanding and deepening knowledge in the wider context of a particular scientific area.

A somewhat broader range of courses of the same "conceptual orientation" exists at the Computer Science Faculty of Electrical Engineering and Computing at the University of Zagreb, but without, for example, a course such as Logic Programming.

At the Faculty of Organization and Informatics of Varaždin, Zagreb University, Croatia, there is the study program of *Data and Knowledge Bases* with courses such as *Introduction to Formal Methods, Advanced Formal Methods, Logic Programming, Multi-agent Systems, Databases I, Databases II, Theory of Databases*, while the PhD studies encompass courses such as *Selected chapters of artificial intelligence, Selected chapters of the logic of conflict, Selected chapters of knowledge management* and *Pattern recognition*.

The author is of the opinion that there already exists a growing need for more comprehensive study programs that will cover both the "numerical" and "symbolic" approaches to AI, ranging from undergraduate to doctoral level.

IV. Scientific production

The production of scientific papers in the field of artificial intelligence is immense and the production of papers on the subject of symbolic logic and its applications, including applications in solving problems in the area of AI is no exception. A considerable list of books is given in the references, even though it is actually very short when one compares it to the total production.

Among the many journals, and not just those in the English language, I would mention the Journal of Symbolic Logic, Journal of Automated Reasoning, Journal of Symbolic Computation, Notre Dame Journal of Formal Logic, Studia Logica, Logical Methods of Computer Science, Journal of Logical and Algebraic Methods in Programming, Journal of Applied Non-Classical Logics,

Journal of Artificial Intelligence, Applied Artificial Intelligence Journal of Machine Learning Research,…

The list of conferences that cover the area of symbolic logic and its applications is also very long. A considerable number of them are held annually, such as NASA Formal Methods, Computer Science Logic, Logics in Artificial Intelligence, Logic Programming, Theorem Proving in Higher Order Logic, Logic Programming and Nonmonotonic Reasoning, Artificial Intelligence and Symbolic Computation, Formal Ontology in Information Systems, and many others.

V. Conclusion

The author is painfully aware of the fact that for a more complete, more structured and generally more convenient presentation of formal logic systems that are of interest to the field of artificial intelligence, ranging from their theoretical foundations through to their design and implementation in the form of programming languages and development environments as well as tools for specific needs, even a text hundred times more extensive would hardly be exhaustive.

Of course, such an exhaustive presentation was not what the author had in mind. Instead, the author's wish was to introduce engineers of different profiles to some of the achievements of contemporary formal logic systems and the possibilities of their application in solving problems in (but not only) the field of artificial intelligence. In his mind, there is no doubt that formal methods will very soon enter the pores of all scientific research and become irreplaceable research tools.

In particular, the author hopes that the choice of literature which intentionally emphasizes books, often monographic in character, as opposed to papers, will allow the reader to gain a broader insight into the entire subject matter.

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PAPERS

The Formal Logic Approach for Checking the Observability of a Specification Language on DES Functioning

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***Abstract*—Using the new approach to the formalization of controlled discrete-event systems (DES), based on positively constructed formulas (PCFs) calculus, the algorithm for testing the observability of the specification languages is presented in this paper. An information mapping in the form of a natural projection and an automata-based representation of a logical DES is considered. Sequences of events, causing changes in the state of the system, are generated as words of a formal language. A discrete-event model of an autonomous underwater vehicle (AUV) as a member of an AUV group is developed, which describe the main high-level functions of the AUV in surveillance missions. Its formalization in the form of PCF is presented.**

***Index Terms*—discrete-event system, supervisory control, observability, first-order logics, automata, planning**

I. Introduction

In continuation of [1], the paper presents a novel logical calculus, the calculus of positively constructed formulas (PCF calculus), application in the field of control of discrete-event systems (DES). In DES states change is a result of the occurrence of some discrete events. Some event sequences present unwanted behavior of the system, also called plant in the automation control theory. Automata representations of the plant and of the specification on plant's behavior as generators of formal languages are subject of so called supervisory control [2]. A supervisor presents a means to avoid unwanted words of the plant language thus satisfying the specification.

In spite of intensive study since 1980s, there are still a lot of open problems in the supervisory control theory (SCT) of DES, especially partially observed and decentralized ones, due to complexity issues of supervisor's construction algorithms. Therefore, new approaches and methods are needed to reduce this complexity. The PCF-calculus, due to its features, may be successfully used for solving some important problems of SCT.

The PCF calculus is developed by Russian scientists S.N. Vassilyev and A.K. Zherlov [3], [4] to formalize and solve some control theory problems. In [4] the proof of soundness and completeness of the PCF calculus as the first-order logical formalism is presented, and its further development may be found in [5]. Being both machine-oriented with interactive capabilities for a proof search, the PCF calculus is naturally aimed at solving problems of dynamic systems control due to its features, such as modifiability of semantics (constructive, nonmonotonic, temporal, etc.) and an ability to construct intuitionistic inferences of some non-Horn formulas while explicit usage of $\forall$– and $\exists$–quantifiers, since the skolemization procedure is not required. Constructive semantics allows one to extract some knowledge (for example, action plans) from the proofs, while non-monotonicity and a treat of time help to construct plans in dynamically changing subject areas. Interactive properties of the PCF calculus, its application for dynamic systems control and action planning are described in [4] with the examples of elevator group control, mobile robot action planning and telescope guidance. Problems of automatic theorem proving software, known as provers, design and implementation are briefly discussed in [6].

In the following an important property of the DES specification languages, called observability, is considered. It is well known that in the case of partial observations the observer automaton of the specification is needed to obtain and implement control actions by the supervisor [7]. Presented PCF-based approach intends to avoid using observers. Moreover, if the specification language is either not controllable or not observable, one may be interested in finding a controllable and observable sublanguage of the specification. While there are effective algorithms to construct the supremal controllable sublanguage of the given language [8], the supremal observable sublanguage does not always exist. Only maximal observable sublanguages may be found, which are not unique in general. To avoid disambiguation, normal specifications [9] are usually considered, which do not contain strings leading to conflict, i.e. violating the definition of observability. The notion of normality is stronger than observability so the set of possible specifications is narrowed by this condition. PCF-representation of specifications will be used to construct maximal observable sublanguages of unobservable specifications thus extending the set of languages used as DES's behavior restrictions.

The model of the autonomous underwater vehicle (AUV) behavior is chosen to demonstrate the presented approach, in particular, a model of the AUV's modes of operation changing while following the leader in the leader-follower formation [10]. DES are extensively exploited in mobile robots and robot group control [11], [12], [13], [14] as they allow formalizing

complex man-made technical systems.

II. The PCF-calculus

Let us consider the basic ideas behind PCFs and their calculus. The language of PCFs is a restricted variant of the language of first-order logic (FOL), which consists of first–order formulas (FOFs) built out of atomic formulas, or atoms, with the help of operators &, $\vee$, $\neg$, $\rightarrow$, $\leftrightarrow$, quantifier symbols $\forall$ and $\exists$, and constants **True** and **False**. The concepts of an *atom*, a *literal*, and a *term* are defined in the usual way.

Let $X = \{x_1, \ldots, x_k\}$ be a set of variables, $A = \{A_1, \ldots, A_m\}$ a set of atomic formulas, and $F = \{F_1, \ldots, F_n\}$ a set of subformulas. Then the formulas $((\forall x_1)\ldots(\forall x_k)(A_1\&\ldots\&A_m \rightarrow (F_1 \vee \ldots \vee F_n)))$ and $((\exists x_1)\ldots(\exists x_k)(A_1\& \ldots\&A_m\&(F_1\&\ldots\&F_n)))$ are denoted as $\forall_X A\colon F$ and $\exists_X A\colon F$, respectively, keeping in mind that the $\forall$–quantifier corresponds to the disjunction of all subformulas, and $\exists$–quantifier corresponds to their conjunction. If $F = \varnothing$ then above formulas turn to the form $\forall_X A\colon \varnothing \equiv \forall_X A \rightarrow$ **False** and $\exists_X A\colon \varnothing \equiv \exists_X A\&$**True**, since the empty disjunction is understood as **False**, whereas the empty conjunction is understood as **True**. Let $\forall_X A$ and $\exists_X A$ be abbreviations of such formulas. If $X = \varnothing$ then $\forall A\colon F$ and $\exists A\colon F$ are analogous abbreviations.

The set of atoms A is called a *conjunct*. Variables from X, bound by corresponding quantifiers, are called $\forall$*–variables* and $\exists$*–variables*, respectively. In $\forall_X A$, a variable from X that does not appear in the conjunct A is called an *unconfined* variable. Note that $\forall\varnothing \equiv \forall\varnothing\colon \varnothing \equiv \forall$**True** $\rightarrow$ **False** $\equiv$ **False**.

Constructions $\forall_X A$ and $\exists_X A$ are called *positive type quantifiers* (TQ), because A is a conjunction of positive atoms only and referred to as a *type condition* for X. In practice, these constructions denote phrases such as "for all X satisfying A there is...", "there exist X satisfying property A such that...", and so on; for example, "for all integer x, y, z and $n > 2$ there is $x^n + y^n \neq z^n$". Originally, the term "type quantifier" was introduced by N. Bourbaki [15] as a part of notation for formalization of mathematics.

A. PCF Language Explicit Definition

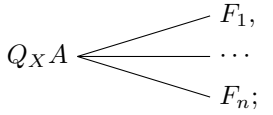
Definition 1 (Positively constructed formulas (PCF))**.** *Let X be a set of variables and A a conjunct. Then*

1) *$\exists_X A$ and $\forall_X A$ are $\exists$–PCF and $\forall$–PCF, respectively.*
2) *If $F = \{F_1, \ldots, F_n\}$ is a set of $\forall$–PCFs, then $\exists_X A\colon F$ is a $\exists$–PCF.*
3) *If $F = \{F_1, \ldots, F_n\}$ is a set of $\exists$–PCFs, then $\forall_X A\colon F$ is a $\forall$–PCF.*
4) *Any $\exists$–PCF or $\forall$–PCF is a PCF.*

This form of logical formulas is referred to as positively constructed formulas as they are written with positive type quantifiers only and do not contain logical negation sign explicitly. Without loss of generality only closed formulas will be considered. Any FOF can be represented as PCF [4].

A PCF starting with $\forall\varnothing$ is called a PCF in the *canonical form*. Any PCF can be represented in the canonical form. If F is a non–canonical $\exists$–PCF then $\forall\varnothing\colon F$ is the canonical PCF since $\forall\varnothing\colon F \equiv$ **True** $\rightarrow F \equiv F$. If F is a non–canonical $\forall$–PCF then the canonical PCF is $\forall\varnothing\colon \{\exists\varnothing\colon F\} \equiv$ **True** $\rightarrow$ **True**$\&F \equiv F$. Type quantifiers $\forall\varnothing$ and $\exists\varnothing$ are called *fictitious*, since they do not influence truth value of an original PCF and do not bind any variables. They are used to regularize PCFs, i.e. transform them to the canonical form.

PCFs are usually represented as trees for easier reading, i.e. $Q_X A\colon \{F_1, \ldots, F_n\}$ is represented as



where Q is a quantifier. Tree elements have conventional names: *node*, *root*, *leaf*, *branch*, etc. As the quantifier $\forall$ corresponds to a disjunction of formulas $\{F_1, \ldots, F_n\}$ (quantifier $\exists$ corresponds to conjunction), then each $\forall$–node is considered as *disjunctive branching*, and each $\exists$–node corresponds to *conjunctive branching*.

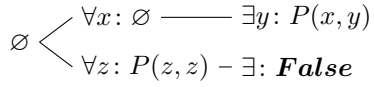
Parts of canonical PCF are named as follows:

1) The root of a PCF's tree-view $\forall\varnothing$ is called a *PCF root*.
2) Each PCF root child $\exists_X A$ is called a PCF *base*, the conjunct A is called a *base of facts*, and a PCF rooted from the base is called a *base subformula*.
3) PCF base children $\forall_Y B$ are called *questions* to the parent base. If the question is a leaf of the tree then it is called a *goal question*.
4) Subtrees of the questions are called *consequents*. If a question has no consequent then the question is referred to as *goal question*, and it is identical to **False**.

Example 1. *Consider a PCF representation of a FOF*

$$\mathcal{F} = \neg\big(\forall x \exists y P(x, y) \rightarrow \exists z P(z, z)\big).$$

An image $\mathcal{F}'$ of $\mathcal{F}$ in the PCF language is $\mathcal{F}' = \forall\colon \varnothing\{\exists\colon \varnothing\{\forall x\colon \varnothing\{\exists y\colon P(x, y)\}, \forall z\colon P(z, z)\{\exists\colon \boldsymbol{False}\}\}\}$. The tree–like form of the latter is as follows:



B. The Inference Rule

Definition 2 (Answer)**.** *A question $\forall_Y D : \Upsilon$ to a base $\exists_X A$ has an answer θ if and only if θ is a substitution $Y \rightarrow H^\infty \cup X$ and $D\theta \subseteq A$, where H^∞ is Herbrand universe based on constant and function symbols that occur in corresponding base subformula.*

Definition 3 (Splitting)**.** *Let $B = \exists_X A\colon \Psi$, and $Q = \forall_Y D\colon \Upsilon$, where $\Upsilon = \{\exists_{Z_1} C_1\colon \Gamma_1, \ldots, \exists_{Z_n} C_n\colon \Gamma_n\}$ then $split(B, Q) = \{\exists_{X \cup {Z_1}'} A \cup {C_1}'\colon \Psi \cup {\Gamma_1}', \ldots, \exists_{X \cup {Z_n}'} A \cup {C_n}'\colon \Psi \cup {\Gamma_n}'\}$, where $'$ is a variable renaming operator. We say that B is split by Q. Obviously, $split(B, \forall_Y D) = split(B, \forall_Y D\colon \varnothing) = \varnothing$.*

Definition 4 (Inference rule $\boldsymbol{\omega}$)**.** *Consider some canonical PCF* $F = \forall\varnothing\colon \Phi$. *Let there exists a question* Q *that has an answer* θ *to appropriate base* $B \in \Phi$*, then* $\omega F = \forall\varnothing\colon \Phi \setminus \{B\} \cup split(B, Q\theta)$.

In other words, if a question has an answer to its base, then the base subformula is split by this question. In the case of a goal question, we say that the basic subformula is refuted because $split(B, \forall_Y D) = \varnothing$. The refuted base subformula B removed from the set of base subformulas Φ, since $\Phi \setminus \{S\} \cup \varnothing = \Phi \setminus \{S\}$.

As soon as all the bases subformulas from Φ have been refuted, the formula F is also refuted, since $\forall\varnothing\colon \varnothing \equiv$ **False**. The PCF language and the inference rule $\boldsymbol{\omega}$ form the calculus oriented to refutation of a negation of an original formula. The only axiom of PCF calculus is $\forall\varnothing\colon \varnothing$, i.e., **False**.

III. Control of Partially Observed DES

Consider discrete-event system (DES) in the form of a generator of a formal language [2] $\mathcal{G} = (Q, \Sigma, \delta, q_0, Q_m)$, also called a *plant* in the automatic control theory. Here Q is the set of states q; Σ the set of events; $\delta\colon \Sigma \times Q \to Q$ the transition function; $q_0 \in Q$ the initial state; $Q_m \subset Q$ the set of marker states. As usual, Σ^* denote the set of all strings over Σ, including the empty string ε. δ is easily extended on strings from Σ^*. Language generated by $\mathcal{G}$ is $L(\mathcal{G}) = \{w : w \in \Sigma^*$ and $\delta(w, q_0)$ is defined$\}$, while language marked by $\mathcal{G}$ is $L_m(\mathcal{G}) = \{w : w \in L(\mathcal{G})$ and $\delta(w, q_0) \in Q_m\}$.

The Ramadge–Wonham supervisory control framework assumes the existence of a means of control $\mathcal{G}$ presented by a *supervisor* [2]. Let Σ_c be a controllable event set, $\Sigma_{uc} = \Sigma \setminus \Sigma_c$, $\Sigma_c \cap \Sigma_{uc} = \emptyset$. The supervisor switches control patterns so that the supervised discrete event systems achieve a control objective described by some regular language K. Let $\mathcal{G}$ be partially observable, i.e. a set Σ_o of observable events is distinguished from all events, $\Sigma_{uo} = \Sigma \setminus \Sigma_o$, $\Sigma_c \cap \Sigma_{uo} = \emptyset$. The observation function is usually defined as the natural projection $P : \Sigma^* \to \Sigma_o^*$ which erases unobservable events:

$$P(s\sigma) = \begin{cases} P(s)\sigma, & \text{if } \sigma \in \Sigma_o; \\ P(s), & \text{if } \sigma \in \Sigma_{uo}. \end{cases}$$

The supervisor observes only events from the Σ_o and, basing on this information, disables events in Σ_c. Formally, a supervisor is a pair $\mathcal{J} = (\mathcal{S}, \phi)$ where $\mathcal{S} = (X, \Sigma_o, \xi, x_0, X_m)$ is a deterministic automaton with input alphabet Σ_o. $\mathcal{S}$ is considered to be driven externally by the stream of observable event symbols (words) generated by $\mathcal{G}$ (i.e. words from $P(L(\mathcal{G}))$), while $\phi : X \to \Gamma$ is a function that maps supervisor states x into control patterns $\gamma \in \Gamma \subseteq 2^{\Sigma}$. If $\sigma \in \gamma = \phi(x)$, then σ is enabled, while if $\sigma \notin \phi(x)$ then σ is disabled (prohibited from occuring).

Extend the function δ to the function $\delta_c : \Gamma \times \Sigma \times Q \to Q$ accounting control patterns as

$$\delta_c(\gamma, \sigma, q) = \begin{cases} \delta(\sigma, q), & \text{if } \delta(\sigma, q) \text{ is defined and } \sigma \in \gamma; \\ \text{undefined}, & \text{otherwise.} \end{cases}$$

Construct the function $\xi \times \delta_c : \Sigma \times X \times Q \to X \times Q$, where $(\xi \times \delta_c)(\sigma, x, q) = (\xi(\sigma, x), \delta_c(\phi(x), \sigma, q))$ is defined iff $\delta(\sigma, q)$ is defined, $\sigma \in \phi(x)$ and $\xi(\sigma, x)$ is defined. Denote $L(\mathcal{J}/\mathcal{G})$ a language generated by the closed-looped behavior of the plant and the supervisor: $L(\mathcal{J}/\mathcal{G}) = \{s : s \in \Sigma^*$ and $(\xi \times \delta_c)(s, x, q)$ is defined$\}$. Let $L_m(\mathcal{J}/\mathcal{G})$ denote the language marked by the supervisor: $L_m(\mathcal{J}/\mathcal{G}) = \{s : s \in L(\mathcal{J}/\mathcal{G})$ and $(\xi \times \delta_c)(s, x_0, q_0) \in X_m \times Q_m\}$.

Supervisory control and observation problem. Given a plant $\mathcal{G}$ over an alphabet Σ, a language $L_A \subseteq L(\mathcal{G})$, a language $L_E \subseteq L(\mathcal{G})$, and sets Σ_o, $\Sigma_c \subseteq \Sigma$, construct a supervisor $\mathcal{J}$ for $\mathcal{G}$ such that $L_A \subseteq L(\mathcal{J}/\mathcal{G}) \subseteq L_E$.

Since the above problem face high computational complexity, it is often substituted by the less complex problem of finding such control patterns that the language marked by the supervisor is equal to some required language. Thus, the special case of the supervisory control and observation problem is to construct such supervisor that $L_m(\mathcal{J}/\mathcal{G}) = K$ where K is called a *a specification language*. The notions of controllable and observable languages are essential in solving this problem.

Let $L \subset \Sigma^*$. The *closure* of L is the set of all strings that are prefixes of words of L, i.e. $\overline{L} = \{s | s \in \Sigma^*$ and $\exists t \in \Sigma^* : s \cdot t \in L\}$. Symbol $\cdot$ denotes string concatenation and is often omitted.

Definition 5. K *is controllable (with respect to* $L(\mathcal{G})$ *and* Σ_{uc}*) if*

$$\overline{K}\Sigma_{uc} \cap L(\mathcal{G}) \subseteq \overline{K}.$$

If K represents the admissible behavior of the system, K is controllable if occurring of any uncontrolled event after prefix of the word from K leads to a word from K, i.e. still admissible. Only controllable languages may be exactly achieved by the joint behavior of the plant and supervisor.

Definition 6 ([16])**.** K *is observable (with respect to* $L(\mathcal{G})$ *and* P*) if*

$$\forall s, t \in \Sigma^* \, (P(s) = P(t) \to (\forall\sigma \in \Sigma)(s\sigma \in \overline{K} \,\&\, t\sigma \in L(\mathcal{G}) \,\&\, t \in \overline{K} \to t\sigma \in \overline{K})).$$

The definition of observability means that if two strings look the same, then they must be consistent in the sense that if an event is legal after one string, it must be legal after the other. *Supervisor existence criterion* sounds as follows: given $K \subseteq L(\mathcal{G})$, there exists supervisor $\mathcal{J}$ such that $K = L_m(\mathcal{J}/\mathcal{G})$ iff K is controllable and observable w.r.t. $L(\mathcal{G})$ and P. Note that it is also required K to be $L_m(\mathcal{G}) - closed$, i.e. $K = \overline{K} \cap L_m(\mathcal{G})$ [2].

IV. Observability Checking Using PCFs

Consider a simplified general DES model of an autonomous underwater vehicle (AUV) behavior as a follower in the leader–follower formation [10] during some mission implementation (Fig. 1). For this DES $Q = \{$G, LF, OA, LS$\}$, with G corresponding to the gathering mode, LF to the leader following mode, OA to the obstacle avoidance mode, and LS

to the leader search mode. $\Sigma = \{tr, gmr, od, flp, fll, lf\}$, where tr mean that a task is received by the AUV, gmr denote that a message containing the command for the group members to gather is received, od mean that an obstacle is detected, flp mean free space is detected and the leader is present, fll – free space is detected but the leader is lost, lf mean that the leader is found. q_0 = G, $Q_m = \{\text{G}\}$. Suppose $\Sigma_{uo} = \{flp, fll\}$.

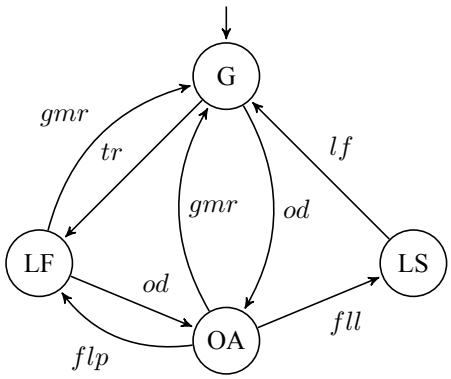


Fig. 1. Generator $\mathcal{G}$

Let a specification on the AUV-follower behavior prohibits the gathering attempt in the obstacle avoidance mode. The automaton generating this specification language K is shown on Fig. 2.

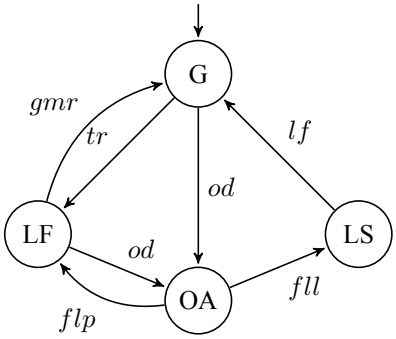


Fig. 2. Specification K

The goal is to check the observability of K using the approach to DES formalization as PCFs, developed in [1]. The following predicates will be used. $E(x)$ will be interpreted as "x is an event", $S(p(x_1, x_2), y, z)$ will denote "x_1 is a current z-length sequence of events in a state y, and x_2 is the projection of x_1". Note that we use the term p to simulate the observability of the current event. The function symbol "$\cdot$" denote the strings concatenation, and the "ϵ" symbol denote an empty string. The generator G (corresponding to Fig. 1) is described by the formula, name it F_G, consisted of the base $\mathcal{B}$ with the atoms $E(od)$, $E(tr)$, $E(gmr)$, $E(lf)$, $E(fll)$, $E(flp)$, $S(p(\epsilon, \epsilon), G, 0)$, and the following questions:

$$Q_1 : \forall_{\sigma,\sigma',l}\ E(tr), S(p(\sigma, \sigma'), G, l) - \\ - \exists\ S(p(\sigma \cdot tr, \sigma' \cdot tr), LF, l+1)$$
$$Q_2 : \forall_{\sigma,\sigma',l}\ E(od), S(p(\sigma, \sigma'), G, l) - \\ - \exists\ S(p(\sigma \cdot od, \sigma' \cdot od), OA, l+1$$
$$Q_3 : \forall_{\sigma,\sigma',l}\ E(od), S(p(\sigma, \sigma'), LF, l) - \\ - \exists\ S(p(\sigma \cdot od, \sigma' \cdot od), OA, l+1)$$
$$Q_4 : \forall_{\sigma,\sigma',l}\ E(gmr), S(p(\sigma, \sigma'), LF, l) - \\ - \exists\ S(p(\sigma \cdot gmr, \sigma' \cdot gmr), G, l+1)$$
$$Q_5 : \forall_{\sigma,\sigma',l}\ E(gmr), S(p(\sigma, \sigma'), OA, l) - \\ - \exists\ S(p(\sigma \cdot gmr, \sigma' \cdot gmr), G, l+1)$$
$$Q_6 : \forall_{\sigma,\sigma',l}\ E(flp), S(p(\sigma, \sigma'), OA, l) - \\ - \exists\ S(p(\sigma \cdot flp, \sigma'), LF, l+1)$$
$$Q_7 : \forall_{\sigma,\sigma',l}\ E(fll), S(p(\sigma, \sigma'), OA, l) - \\ - \exists\ S(p(\sigma \cdot fll, \sigma'), LS, l+1)$$
$$Q_8 : \forall_{\sigma,\sigma',l}\ E(lf), S(p(\sigma, \sigma'), LS, l) - \\ - \exists\ S(p(\sigma \cdot lf, \sigma' \cdot lf), G, l+1)$$

The PCF, constructing the specification language (Fig. 2), differ from the F_G only in the absence of the question Q_5, and will be referenced by F_K.

To check the observability of K we will parametrize the F_K. The base conjunct will be the same as in F_G, and the questions list will be as follows:

$$Q_1^K : \forall_{\sigma,\sigma',l'}\ E(tr), S(p(\sigma, \sigma'), G, l'), l' \leqslant l - \\ - \exists\ S(p(\sigma \cdot tr, \sigma' \cdot tr), LF, l'+1)$$
$$Q_2^K : \forall_{\sigma,\sigma',l'}\ E(od), S(p(\sigma, \sigma'), G, l'), l' \leqslant l - \\ - \exists\ S(p(\sigma \cdot od, \sigma' \cdot od), OA, l'+1$$
$$Q_3^K : \forall_{\sigma,\sigma',l'}\ E(od), S(p(\sigma, \sigma'), LF, l'), l' \leqslant l - \\ - \exists\ S(p(\sigma \cdot od, \sigma' \cdot od), OA, l'+1)$$
$$Q_4^K : \forall_{\sigma,\sigma',l'}\ E(gmr), S(p(\sigma, \sigma'), LF, l'), l' \leqslant l - \\ - \exists\ S(p(\sigma \cdot gmr, \sigma' \cdot gmr), G, l'+1)$$
$$Q_5^K : \forall_{\sigma,\sigma',l'}\ E(flp), S(p(\sigma, \sigma'), OA, l'), l' \leqslant l - \\ - \exists\ S(p(\sigma \cdot flp, \sigma'), LF, l'+1)$$
$$Q_6^K : \forall_{\sigma,\sigma',l'}\ E(fll), S(p(\sigma, \sigma'), OA, l', l' \leqslant l) - \\ - \exists\ S(p(\sigma \cdot fll, \sigma'), LS, l'+1)$$
$$Q_7^K : \forall_{\sigma,\sigma',l'}\ E(lf), S(p(\sigma, \sigma'), LS, l'), l' \leqslant l - \\ - \exists\ S(p(\sigma \cdot lf, \sigma' \cdot lf), G, l'+1)$$
$$Q_8^K : \forall_z\ \Phi$$

Here, l and Φ are parameters that are derived from the inference of the PCF for $\mathcal{G}$, which questions are changed by adding the atoms of the form $P(\#(\Phi = Q_i^r))$, where Q_i^r are the right sides of each question respectively, with variable z

replacing the second argument in the atoms S. For example, the question Q_1 has the form:

$$Q_1 : \forall_{\sigma,\sigma',l}\ E(tr), S(p(\sigma,\sigma'),G,l) - \\ - \exists\ S(p(\sigma\cdot tr,\sigma'\cdot tr),LF,l+1), \\ P(\#(\Phi = S(p(\sigma\cdot tr,\sigma'\cdot tr),z,l+1)))$$

The function # is the computable (actually, derivable in this case) function defined by the sub-inference of the latter PCF for K. # will return two values as two possible variants for sub-inference conclusion, the constant *ok*, if sub-inference ended with the answer to the goal-question $\forall_z\ \Phi$, and the constant value *stop* if that sub-inference is exhausted, proving the satisfiability of the formula which means that the language K is unobservable. Additional atoms $l' \leqslant l$ are there for the proof search constraint purpose, to make an inference machine to search no further than needed length of the current sequence of events. Also, we will add an additional question $Q_8 : \forall P(stop)$ to the base for $\mathcal{G}$, which will serve as a stop signal for the inference machine.

To clear that mess, let us show the inference steps proving that K is unobservable.

Step 1. We answer the question Q_1 with the $\{\sigma\to\epsilon, \sigma'\to\epsilon, l\to 0\}$, so the atom $S(p(\epsilon\cdot tr,\epsilon\cdot tr),LF,1)$ is added to the base of F_G. Then a sub-inference of F_K is started, where $Q_8^K : \forall_z\ \Phi = \forall_z\ S(p(\epsilon\cdot tr,\epsilon\cdot tr),z,1)$.

Step 1.1. In the sub-inference of F_K we answer the question Q_1^K with the $\{\sigma\to\epsilon,\sigma'\to\epsilon,l'\to 0\}$, so the atoms $S(p(\epsilon\cdot tr,\epsilon\cdot tr),LF,1)$ are added to the base of F_K.

Step 1.2. In the sub-inference of F_K we answer the question Q_8^K with $\{z\to LF\}$ and refute F_K. So the atom $P(ok)$ is added to the base of F_G and we continue the inference in F_G.

Step 2. We answer the question Q_3 with $\{\sigma\to\epsilon\cdot tr,\sigma'\to\epsilon\cdot tr, l\to 1\}$, so the atom $S(p(\epsilon\cdot tr\cdot od,\epsilon\cdot tr\cdot od),OA,2)$ is added to the base. Then a sub-inference of F_K is started, where $Q_8^K : \forall_z\ \Phi = \forall_z\ S(p(\epsilon\cdot tr\cdot od,\epsilon\cdot tr\cdot od),z,2)$.

Step 2.1. In the sub-inference of F_K we answer the question Q_1^K with $\{\sigma\to\epsilon,\sigma'\to\epsilon,l'\to 0\}$, so the atoms $S(p(\epsilon\cdot tr,\epsilon\cdot tr),LF,1)$ are added to the base of F_K.

Step 2.2. In the sub-inference of F_K we answer the question Q_3^K with $\{\sigma\to\epsilon\cdot tr,\sigma'\to\epsilon\cdot tr,l'\to 1\}$, so the atoms $S(p(\epsilon\cdot tr\cdot od,\epsilon\cdot tr\cdot od),OA,2)$ are added to the base of F_K.

Step 2.3. In the sub-inference of F_K we answer the question Q_8^K with $\{z\to OA\}$ and refute F_K. So the atom $P(ok)$ is added to the base of F_G and we continue the inference in F_G.

Step 3. We answer the question Q_5 with $\{\sigma\to\epsilon\cdot tr\cdot od,\sigma'\to\epsilon\cdot tr\cdot od, l\to 2\}$, so the atom $S(p(\epsilon\cdot tr\cdot od\cdot gmr,\epsilon\cdot tr\cdot od\cdot gmr),G,3)$ is added to the base. Then a sub-inference of F_K is started, where $Q_8^K : \forall_z\ \Phi = \forall_z\ S(p(\epsilon\cdot tr\cdot od\cdot gmr,\epsilon\cdot tr\cdot od\cdot gmr),z,3)$.

Step 3.1. In the sub-inference of F_K we answer the question Q_1^K with the $\{\sigma\to\epsilon,\sigma'\to\epsilon,l'\to 0\}$, so the atoms $S(p(\epsilon\cdot tr,\epsilon\cdot tr),LF,1)$ are added to the base of F_K.

Step 3.2. In the sub-inference of F_K we answer the question Q_3^K with the $\{\sigma\to\epsilon\cdot tr,\sigma'\to\epsilon\cdot tr,l'\to 1\}$, so the atoms $S(p(\epsilon\cdot tr\cdot od,\epsilon\cdot tr\cdot od),OA,2)$ are added to the base of F_K.

Step 3.3. In the sub-inference of F_K there is no any new answer with $l'\leq 3$. So the atom $P(stop)$ is added to the base of F_G and we continue the inference in F_G.

Step 4. We answer the question Q_8 with the $\{\}$ so the formula is refuted.

The unobservability of K means that this specification can not be satisfied by means of supervisory control. However, the same reasoning as above may be used to find an observable sublanguage of K, which may serve as a new specification. A special strategy may be used to provide directed and step-by-step inference search for the PCF corresponding to the plant. For each transition of the automata, producing the specification language, the strategy will produce a sub-inference to determine violation of the observability condition by the event, corresponding to this transition. If there is no violation, the inference is continued to check the rest of transitions until violation is found, i.e. the checked specification is rejected. The inference is restarted then for the specification, which automaton does not contain the verified transition.

A computational complexity of the inference search of PCFs is rely strongly on the complexity of the inference rule application. The application of the PCFs inference rule for the formulas presenting DES has the polynomial, close to linear complexity, since the obtained structures are quite simple and the answers search procedure (consuming the most of time) is also not so hard.

V. Conclusion

This paper is the ongoing work on developing a new way of formalizing and solving various control problems for the important class of dynamic systems known as DES. PCF-based algorithm for testing the observability of the specification language on DES behavior is proposed and demonstrated on the example of the discrete-event model of an autonomous underwater vehicle, which describe the high-level operation modes switching of the AUV, following the leader, in surveillance mission, performed by the AUV group. The algorithm presented may be modified for checking another important property of a specification language called co-observability. Co-observable languages serve as specifications for the decentralized supervisors, which are necessary to implement group control tasks. Indeed, AUV group members unable to observe and control all events of the whole system due to the water environment restrictions. An algorithm for constructing a decentralized supervisor is another objective of our research.

Another related problem is how to efficiently implement the supervisory control with partial observations in the case when system behavior is defined by a set of automata. Modular construction of the plant and the specification provides a possibility to modular design of the supervisor as well. However, checking the resulted supervisors for nonconflicting is a non-trivial task. Among other logical methods, for example [17], [18], PCF representation of DES will allow using the modularity in the efficient way, and this issue is the subject

of further research. Obtained results will be exploited in group control, for instance, to support AUV missions.

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A Genetic Algorithm for Group Steiner Tree Problem

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***Abstract*—In Group Steiner Tree Problem (GST) we are given a weighted undirected graph and family of subsets of vertices which are called groups. Our objective is to find a minimum-weight subgraph which contains at least one vertex from each group (groups do not have to be disjoint). GST is NP-hard combinatorial optimization problem that arises from many complex real-life problems such as finding substrate-reaction pathways in protein networks, progressive keyword search in relational databases, team formation in social networks, etc. Heuristic methods are extremely important for finding the good-enough solutions in short time. In this paper we present genetic algorithm for solving GST. We also give results of computational experiments with comparisons to optimal solutions.**

***Keywords* - genetic algorithm, group Steiner tree problem, minimum spanning tree, integer linear programming**

I. Introduction

The group Steiner tree problem (GST) is NP-hard combinatorial optimization problem that comes from wire routing problem in physical VLSI design [1]. During the last fifteen years this problem is applied in many areas such as keyword search in relational databases [2] , team formation in social networks [3], government formation problem [4], subnetwork extraction methods in bioinformatics [5], etc.

In GST, we are given an undirected graph $G = (V, E)$, $|V| = n$, $|E| = m$, with weight function $w : E \to \mathbb{R}_+$, and a family of subsets of V, $\mathcal{G} = \{G_1, \ldots, G_k\}$, $k \in \mathbb{N}$, $G_i \neq \emptyset$ which are called *groups*. The problem is to find a subtree T such that

$$\sum_{e \in E(T)} w(e)$$

is minimized and $V(T) \cap G_i \neq \emptyset$ for each $i \in [k]$, where $V(T)$ stands for set of vertices of T, and $E(T)$ for set of edges of T. Thus, GST generalizes two important combinatorial optimization problems: *Steiner tree problem* and *set cover problem*. A Steiner tree problem is one of the most important NP-hard problems in network design that admits an approximation algorithm with constant approximation ratio [6], [7]. Actually, it is NP-hard to approximate within ratio less then $96/95$ [8]. In the Steiner tree problem, we are given an undirected graph $G = (V, E)$, with edge-weight function $w : E \to \mathbb{R}_+$ and subset of vertices $\emptyset \neq R \subseteq V$ that are called *terminals*. Vertices in $V \setminus R$ are called *Steiner vertices*. The task is to find a minimum-weight subtree T that spans all terminals. It is easy to observe that the Steiner tree problem is reducible to a special case of GST problem where size of each group is at most one. A set cover problem is the second one, but not less important since it generalizes a dozen of other combinatorial problems. We are given a set of elements U and a family $\mathcal{U}$ of subsets of U such that $\bigcup_{S \in \mathcal{U}} = U$. We say that subfamily $\mathcal{R} \subseteq \mathcal{U}$ is a set cover with respect to the instance $(U,\mathcal{U})$ if every $u \in U$ is covered by at least one set from $\mathcal{R}$. The *set cover problem* introduced by Chvátal [9] is to find a subfamily $\mathcal{R}$ of minimum size. The more general version of the problem is typically called the *weighted set cover problem* where each set from family $\mathcal{U}$ has a nonnegative weight associated with it. It is known that the set cover problem cannot be approximated by approximation ratio better than $(1 - o(1)) \ln n$, unless NP contains slightly superpolynomial time algorithms [10]. For a given set cover instance $(U,\mathcal{U})$ we construct the star graph whose leaves are associated with sets in $\mathcal{U}$. Each element in U defines a group.

This paper is organized as follows: in section 2 a short overview of previous work regarding solving GST by various methods and solving variations of Steiner Tree Problem by using genetic algorithm is given. Also, in section 2 is given brief overview of our contribution. Definition of genetic algorithm and its adaptation for GST can be found in section 3. In section 4 integer linear programming (ILP) model is briefly explained. Experimental results together with implementation details of used methods are given in section 7. Finally, in section 8 a short conclusion is given.

II. Previous work

Garg et al. [11] give a polylogaritmic approximation for the GST problem based on novel randomized rounding scheme where the input graph is a tree. They also extended their results to general graphs by tree-metric embedding technique. Halperin and Krauthgamer [12] proved that it is NP-hard to approximate GST with the ratio better than $\Omega(\log^2 k)$, where k is the number of groups, even when the input graph is a tree. Approximation algorithms for GST that use (randomized) rounding of the solution of LP relaxation, motivate a research on approximation algorithms for fractional GST where integer variables are relaxed [13].

There are also some approaches that use heuristics for solving GST. Duin et al. [14] gave a set of heuristics for GST that use transformation to the undirected Steiner

problem in graphs. Nguyen et al. [15] used ant colony optimization to solve GST. Kapsalis et al. in [16] use genetic algorithm to solve graphical Steiner tree problem. Esbensen [17] uses genetic algorithm to solve the Steiner problem in a graph and compares obtained solutions with two deterministic heuristics. Haouari and Siala [18] use hybrid Lagrangian genetic algorithm to solve the prize collecting Steiner tree problem where the genetic algorithm fully exploits both primal and dual information produced by Lagrangian decomposition of a minimum spanning tree formulation of the problem. Haghighat et al. [19] proposed genetic algorithm in which genotype representation is based on Prüfer number for solving Steiner tree optimization with multiple constraints. Julstrom [20] uses genetic algorithm in order to solve rectilinear Steiner problem.

To the best of our knowledge, there are no papers that solve group Steiner tree problem by using genetic algorithm so this paper presents first heuristic approach for GST that is based on genetic algorithm. The flow-based integer linear programming formulation of GST is used to find an exact solution on relatively small instances. Heuristic approach, presented in this paper, is able to find an optimal solution in almost all standard instances. The most important contribution of this paper is a significant speed-up comparing to exact solver on large problem instances.

III. GA FOR GST

In this section, genetic algorithms (GAs) and how they usually work will be briefly explained. Also, implementation of GA and its application for solving GST problem will be explained. The general idea for GAs stems from the principles of natural selection and genetics. That is the reason why certain terms in GAs are equal to the terms that can be seen in genetics. Basic component of GA is an individual. Individuals are coded as finite dimensional vectors which come from an alphabet of some cardinality. Based on the selection of alphabet, individuals can be represented in various ways. Some of them are [21]: array of bits, permutation array, matrix representation, floating point vector, integer vector etc.

The strength of genetic algorithms is that they use a population of solutions, rather than only one solution, and that way one can explore broader set of possible solutions to a given problem. In order to obtain the best solution, one should determine some fitness function which can compare solutions and determine which solution is better. In GA, it is important to determine size of the population, choose individual representation and determine fitness function. After that, GA can be started and evolve solutions for a given problem by using the following steps [22]:

1) **initialization:** first, desired number of individuals for the initial population is generated randomly, or if some prior information about the problem is known, it is used for generating the individuals;
2) **evaluation:** every individual from current population is evaluated by given fitness function
3) **selection:** two or more individuals are selected from current population by some selection algorithm in order to reproduce; usually, better individuals have higher probability of being selected for reproduction in order to maintain better solutions in a population;
4) **crossover:** selected individuals are combined by some crossover operator in order to produce one or more children;
5) **mutation:** produced children are mutated with a given probability in order to maintain population diversity;
6) **replacement:** individuals obtained by selection, crossover and mutation replace (with some probability) worst or randomly selected individual from current population.

Aforementioned steps (except initialization) are repeated until some stopping criterion is met. Stopping criteria are usually: maximum number of generations, maximum number of evaluations, number of generations without improvement of solution fitness, achieving known optimal solution etc. GAs can be sequential and parallel [21]. Furthermore, sequential GAs can be steady-state GA or generational GA. Steady-state GA chooses two parents from population, makes one child, mutates it and evaluates it. With some probability, child can then be inserted in population (in that case some other solution candidate gets thrown out) or rejected. In generational GA in every step whole new population of children is created which replaces old parent generation. If in that process one does not want to lose best found solution, elitism can be introduced, i.e. the best current known solution is always put in child population.

For implementation of GA for solving GST, a sequential steady-state GA with elitism is used. There are not many papers which connect Steiner Tree Problem and genetic algorithms, but in almost all of them, bitstring representation is used for representing an individual. That is the reason why in this paper it is decided to use bitstring representation (vectors containing only ones and zeroes) for individuals as well. Lengths of individuals are defined by number of nodes in problem graph. Every bit in bitstring represents a node in a graph. If bit is equal to one, that means that corresponding node is selected for spanning tree and if the bit is equal to zero, corresponding node in not selected for spanning tree. In the process of evaluating each individual, first, algorithm checks if every group is visited by selected nodes. If that is not the case, simple procedure is used in order to complete individual to be feasible in that regard. For every selected node, its neighbours are put in a list and if some of those neighbours are from a group that is not yet visited, one of them is randomly chosen and included in graph. The procedure is repeated until all the groups are visited or if another node that will be put in a tree cannot be found. If the procedure finishes and not all groups are visited, an individual is assigned fitness value large enough for used set of problems in the sense that individuals with that value of fitness will probably not be selected to reproduce. After

that, each individual whose nodes make sure that every group is visited, is evaluated using Prim's algorithm. If the selected nodes are not connected, Prim's algorithm gives value of -1 and individual at hand is given large fitness value same as before.

IV. ILP MODEL

Since GA gives us a solution without guarantee on its optimality, we need an exact solution that serves us as a ground truth for our computational experiments. The usual approach tries to use general-purpose ILP solvers in order to find optimal solution. We present two straight-forward ILP formulations. In the natural cut-based ILP formulation we introduce binary decision variable $x_e \in \{0,1\}$, for each $e \in E$, that is 1 when e is a part of the solution tree, and 0 otherwise:

$$\begin{aligned} \min \quad & \textstyle\sum_{e\in E} w(e)x_e \\ s.t. \quad & \textstyle\sum_{e\in\delta(S)} x_e \;\geq\; 1, \quad S \in \mathcal{S}_r, \\ & x_e \;\in\; \{0,1\}, \quad e \in E. \end{aligned} \tag{1}$$

In order to give an interpretation of (1), we introduce a new dummy node g_i for each group G_i and directed edges from g_i to each vertex $v \in G_i$. A value of variable x_e is interpreted as a capacity of edge e (i.e. the maximum amount of flow that can pass in any direction trough edge e). Constraints ensure that the capacity of each (G_i, r)-cut is at least 1. Since this constraint is satisfied for all such cuts and all groups G_i, $i \in [k]$, it is also satisfied for cuts with minimum capacity. By max-flow-min-cut theorem [23] it follows that capacities x_e ensure that we are able to send at least one unit of flow from each group G_i to r. On the other hand, integer program minimizes a total weight of reserved capacities $\sum_{e\in E} w(e)x_e$ subject to previously mentioned constraints. In the case of integrality constraints, a total weight of selected edges is minimized subject to constraint that there is at least one path from each group G_i to r.

Unfortunately, cut-based formulation has exponentially many constraints[1] and it is intractable even in the case of moderately large instances. Fortunately, GST problem has a compact integer linear programming formulation with polynomially many variables and constraints.

Now, we describe a transformation of undirected graph G to digraph $\overline{G}$ with some artificial vertices and edges as it is described on Figure 1. For each group G_i we introduce one dummy vertex g_i and directed edge from g_i to each vertex in G_i. On the other hand, each undirected edge is replaced by two directed edges with opposite directions. A new set of dummy vertices is denoted by $V_{\mathcal{G}}$, while a new set of directed edges is denoted by $\mathcal{A}$. Here, we introduce binary decision variables $f_i^{st}, x_e \in \{0,1\}$ for each $i \in [k]$, $(s,t) \in \mathcal{A}$ and $e \in E$. Variable f_i^{st} represents an amount of flow that vertex g_i sends to r trough directed edge (s,t). As it is previously described, x_e can be interpreted as a capacity of two directed edges that are introduced for undirected edge e.

[1] a number of cuts separating groups form r is exponential function of input size

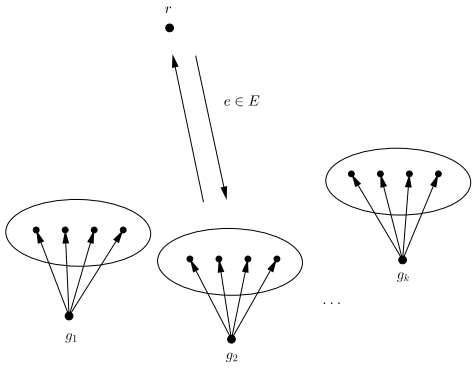

Fig. 1. A construction of the graph $\overline{G}$.

$$\begin{aligned} \min \quad & \textstyle\sum_{e\in E} w(e)x_e \\ s.t. \quad & \textstyle\sum_{vt\in\delta^+(v)} f_i^{vt} - \sum_{sv\in\delta^-(v)} f_i^{sv} = \\ & \begin{cases} 0 & , \quad v \neq r, g_1, \ldots, g_k \\ 1 & , \quad v = g_i \\ -1 & , \quad v = r \end{cases} \quad , \quad i \in [k], \\ & f_i^{st}, f_i^{ts} \leq x_e, \quad \{s,t\} \in E, i \in [k], \\ & f_i^{st}, x_e \in \{0,1\}, \quad (s,t) \in \mathcal{A}, e \in E, i \in [k]. \end{aligned} \tag{2}$$

Like in the case of cut-based formulation, we want to reserve capacities x_e such that from each vertex g_i the one unit of flow can be sent to r. These unit flows are not sent simultaneously. First constraint in (2) represents a law of flow conservation. In other words, a total amount of flow into a vertex $v \neq r, g_1, \ldots, g_k$ must be equal to the total flow out of that vertex. One unit flow enters the network at vertex g_i and exits from the network at r. Second constraint ensures that at most x_e units of flow can pass trough directed edges (s,t) and (t,s) that are introduced due to the undirected edge e.

Since flow-based formulation has polynomially many variables and constraints, we use (2) for finding optimal solutions (Section V).

V. COMPUTATIONAL EXPERIMENTS

The flow-based ILP model, described in section IV, is implemented in C++ using MILP solver Gurobi [24] and graph library Lemon [25]. GA is implemented by using ECF and Boost library [26]. Selection strategy used in this implementation is steady state tournament of size 3. For crossover, uniform crossover [27] operator was used and as for mutation, simple (single bit) mutation was used with probability of mutating a bit of 0.5%. After brief tuning phase, population size of 500 individuals and mutation rate of 0.7 (i.e. on average 7 out of 10 new individuals

will get mutated) is selected. As a stopping criterion, maximum number of 50 generations is determined. For every problem instance, the described GA is run 10 times. All tests are conducted on Linux machine with AMD Ryzen 7 2.2 GHz Eight-Core Processor, 31 GB of RAM, GCC 5.4.0. All experiments are run on only one core. We tested our algorithms on set of instances that is generated according to the procedure described in [14], [15]. Our set of instances contains three types of instances: RANDOM, EUCLIDEAN and GRID, with $n \in \{10, 40, 70, 100, 400, 700\}$. Random instances contain weighted graphs where weights are sampled from uniform distribution on segment $[0, 10]$. The weighted graphs in Euclidean and grid instances are derived from set of n points in plane where the weight of the edge, if such exists, is an Euclidean/Manhattan distance between its endpoints.

Although flow-based ILP formulation has polynomially many variables and constraints, the size of ILP grows fast enough such that branch and cut process cannot find optimal solution in reasonable time. Computational times for ILP solver in Figure 2 suggest that the number of groups k significantly affects running times since the number of flow variables grows linearly with k. It is the reason why some instances with larger number of k cannot be solved within time limit of 600 or 7200 seconds. The largest instance that we solved to optimality, with ILP solver in 2573.45 seconds, is the grid instance with $n = 100$, $m = 200$ and $k = 25$.

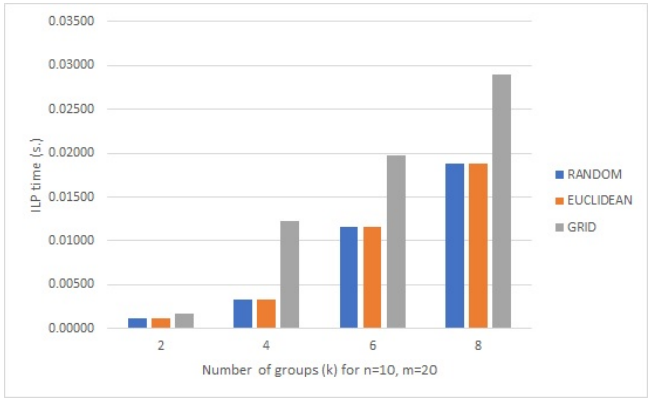

Fig. 2. Computational time for ILP solver with regard to k.

On the other hand, computational time of GA is slow increasing function with respect to the instance size. In table I we observe that GA is slower on smaller GRID instances, but the speed-up factor (calculated as ILP time over GA time) explodes when instance dimensions grow. Table I shows only those instances where ILP solver found a solution in under 600s and for all that instances GA found optimal solution too. Similar pattern can be observed on RANDOM and EUCLIDEAN instances as can be seen in tables II and III.

Interesting observations can be found on instances that are not solved to optimality, but the ILP solver returned the best found solution within the given time limit. GA returned better or equally good solution in about 82.85% instances of all tree types. There are several instances that are not solved by GA or it returned slightly worse solution than ILP solver. In Figure 3 improvements of objective function value are given for GA. Figure shows objective value obtained by GA (in blue) and improvement (difference between objective value obtained by ILP in 600 seconds and objective value obtained by GA) in orange. Also, the percentage of improvement is given for each of depicted instances which is calculated as value of improvement over objective value obtained by ILP in 600 seconds. Figure 4 gives improvements on large instances where GA found much better solutions. Similar behaviour can be observed in RANDOM and EUCLID instances, so figures for those cases are omitted.

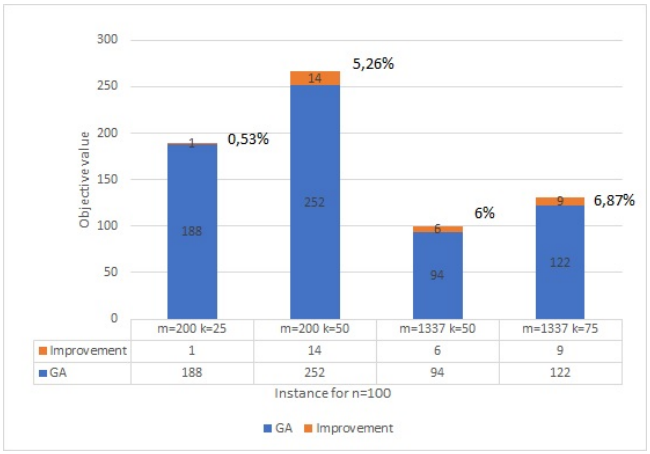

Fig. 3. Objective value improvement for GRID instances (n=100).

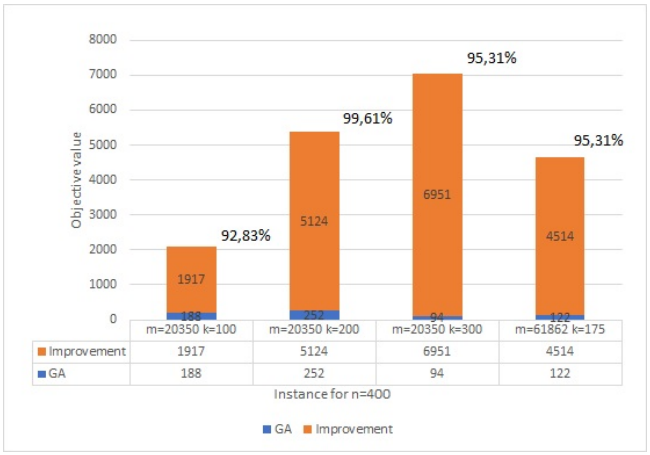

Fig. 4. Objective value improvement for GRID instances (n=400).

VI. Conclusion

Comparison of computational experiments confirmed that GA finds better solution than ILP solver in almost all benchmark instances, that are generated according to the procedures in [14], [15]. Improvements of solution quality, for instances where optimal solutions are not known, increases as the size of instances grows. ILP solver that uses flow-based model is computationally inefficient even in the case of moderately large instances. This motivates us to find another ILP formulation(s) for GST. In this paper

TABLE I
SPEEDUP ON GRID INSTANCES

n	m	k	Opt. sol.	GA time(s)	ILP time(s)	Speedup
10	20	2	0	0,416911	0,00175	0,004190343
10	20	4	14	0,445866	0,01232	0,027638349
10	20	6	21	0,465224	0,01978	0,042523602
10	20	8	24	0,477765	0,02898	0,060657436
10	21	2	0	0,416782	0,00049	0,001170876
10	21	4	8	0,436231	0,00655	0,015019565
10	21	6	14	0,451295	0,00941	0,020840027
10	21	8	23	0,470552	0,02936	0,062386304
40	80	10	41	0,542979	0,77733	**1,431600485**
40	80	20	72	0,633147	839,14208	**1325,351105**
40	80	30	93	0,715044	572,09693	**800,0863248**
40	235	10	20	0,555644	6,22750	**11,20771753**
70	140	17	55	0,723776	808,11554	**1116,527131**
100	200	25	94	0,850832	2573,45130	**3024,629182**

TABLE II
SPEEDUP ON RANDOM INSTANCES

n	m	k	Opt. sol.	GA time(s)	ILP time(s)	Speedup
10	20	2	0	0,415962	0,00117	0,002815161
10	20	4	7	0,453622	0,00328	0,00723069
10	20	6	17	0,470323	0,01155	0,024549086
10	20	8	13	0,469291	0,01876	0,039979458
10	21	2	2	0,427177	0,00078	0,001814236
10	21	4	17	0,442047	0,02677	0,060561434
10	21	6	18	0,448869	0,01916	0,042680604
10	21	8	16	0,475875	0,02320	0,048756501
40	80	10	24	0,523203	0,28057	0,536250748
40	80	20	65	0,599342	807,70074	**1347,645815**
40	80	30	99	0,702115	119,55635	**170,2803002**
40	235	10	13	0,608102	10,65462	**17,52110172**
70	140	17	40	0,677868	292,62090	**431,6782928**
70	673	17	16	0,9044	101,78776	**112,5472789**
70	1206	17	12	0,986232	3553,69938	**3603,309745**

TABLE III
SPEEDUP ON EUCLID INSTANCES

n	m	k	Opt. sol.	GA time(s)	ILP time(s)	Speedup
10	20	2	0	0,418271	0,00080	0,001907854
10	20	4	19	0,441973	0,00946	0,02140176
10	20	6	14	0,443973	0,01773	0,039934861
10	20	8	18	0,468536	0,03446	0,073539707
10	21	2	0	0,416872	0,00042	0,0010147
10	21	4	14	0,442232	0,00585	0,013219306
10	21	6	16	0,452036	0,01644	0,036368785
10	21	8	24	0,466493	0,03462	0,074211189
40	80	10	48	0,516337	0,52757	**1,021753235**
40	80	20	91	0,598032	279,75385	**467,7907737**
40	80	30	118	0,655126	591,39184	**902,7146579**
40	235	10	20	0,509099	273,46640	**537,157598**
70	140	17	98	0,704743	2561,66174	**3634,887803**

we tested our GA on generated instances. Since GST has interesting applications, future work should involve further tests on real-world instances.

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Predictive Analysis based Approach for Optimal Warehouse Product Positioning

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***Abstract*—Building a successful warehouse management system encompasses solving many problems of different nature to reshape the general workflow and ensure improvements in terms of resource management. In order for such a system to be accepted and used by a logistics company, those solutions need to be presented through a simple, adaptable and most importantly, a feasible software solution. One of the aspects that needs to be covered while building a warehouse management system is the optimal product placement in the warehouse. If the products are strategically placed, all the other improvement strategies like stock to picking zone item transfer and item picking order become more efficient and easier to implement. In this paper, tactics and issues regarding the optimal product placement in a warehouse are analyzed in detail through a real-world case study. Solutions of this problem largely differ for new, empty warehouses and for already operative warehouses not able to carry out a stocktaking process. Approaches for both possible situations are proposed and tested out on two different warehouses in a medium-to-large logistics company.**

***Keywords*—Warehouse Management System, Warehouse Optimization, Optimal Product Placement, Machine Learning**

I. Introduction

There are various factors that need to be analyzed in order for a warehouse management system to be successfully implemented. This is especially true for warehouses that didn't have an organized workflow beforehand and most of the operations and problems were handled *ad hoc*. In fact, introducing a warehouse management system to an existing warehouse requires a lot more attention than building a planned, structured warehouse from scratch with a detailed integrated and functioning workflow. This is due to different factors. The biggest issue is the opposition from the workers due to the significant paradigm shift in their every day routines which the introduction of any new system essentially means. It is of highest priority to properly introduce the new model to the workers since it can determine the final success of the system [1]. The next thing to have in mind is the current item placement in the warehouse which is the direct result of the previous workflow management. The heterogeneity of the resulting item placement can be a real issue for the whole system which will be further elaborated later in the paper. Other issues include invalid data inputs if any form of data collection is present at all, inefficient space utilization, warehouse racks repletion which means increased operational costs, inconsistent behavior from the workers etc.

Many diverse classifications of warehouse operations exist, but one of the most basic states that there are four main operations, namely [2]: receiving, storing, put-away, picking and shipping. The storing operations consist out of the distribution of goods to the storage areas, identification, assignment of the storage bin and put-away. The put-away is a process of determination of a storage bin concerning the physical dimensions and the weight of the goods which requires a strictly determined storage location. It is also stated in [2] that those two operations take up to 15% of all the operating costs. Because of that, these operations can be viewed as a niche to improve the efficiency of the system that has yet to be inducted. If the mentioned operations are observed strictly by definition, they represent hardly solvable mathematical problems in practice and need to be relaxed. For the purpose of this paper, storing and put-away operations will be viewed as the transition process of the items from the entrance area to the warehouse storage racks. After the items arrive at the entrance area of the warehouse, the action that can be influenced the most is the placement of the items from the entrance area to the warehouse racks. If the most frequent items are placed closer to the main transport passageways they can be later easier accessed and picked up to complete latter orders. Because of all that was mentioned, the focus of this paper will be on designing the optimal storing and put-away strategies in order to optimize the whole product placement process in a small to medium warehouse without any previously implemented optimization mechanisms. To fully comprehend the differences between the initial conditions, an analysis of a newly built warehouse with a detailed workflow will also be added and compared to the previously analyzed implementation.

This paper is organized as follows: In the first, introductory section the importance of item positioning in warehouses is briefly revised. Related work regarding various general approaches for optimal item positioning is revised in section two. In section three, detailed analysis of the current state of the warehouse in focus and various strategies for optimal item positioning are conducted and an appropriate predictive analysis algorithm is proposed and constructed. Also, the real-world implementation of the proposed method is described in detail. Discussion and analysis of the achieved results are also stated in section three. The paper is concluded in section four with appropriate remarks and guidelines for further research.

II. Related Work

There are various product placement and slotting strategies for different types of warehouse environments. They can be item based, depending on how frequently the item is picked without regard to picking sequences and they are often based on the Cube per Order Index (*abr. COI*) or they can be affinity based slotting strategies that place items that are frequently ordered together, closer to each other. Similarly, in [3] several order oriented stocking heuristics are combined together in a strategy that has the same goal. Their performance is compared through a set of Vertical Lift Module (*abr. VLM*) test problems with different order characteristics. One part of [4] focuses on the formalization of the novel Pick Frequency/Part Affinity score, which combines popularity and affinity measures. Product placement and slotting strategy approaches can largely differ in how many item relocations are needed to be executed in order to implement the strategy, which can be more applicable for new, empty warehouses than for already operative warehouses not able to pause the workflow and carry out a complete stocktaking process. Considering this aspect, the downside of the affinity based algorithms from [4] mentioned before was that implementing the generated assignments in a fully operational warehouse required extensive movements of items. Considering storage, relocation and picking efforts, the costs and benefits of extensive relocations versus iteratively moving a small number of items per period were analysed. It was shown that greedily selecting relocations has disadvantages, which were mitigated by switching to a "robust" selection strategy.

In industries with strong seasonality patterns and fluctuating demand regular re-locations of items might be necessary to ensure that the quality of the storage assignment does not deteriorate over time. In [5] it is analyzed how to generate more robust assignments that are suitable for volatile warehouse scenarios with correlated demand. The aim of [6] was to extend the classic storage location assignment problem (*abr. SLAP*) to a multi-period formulation (*abr. M-SLAP*) and to test and compare how various allocation rules and in particular an affinity based policy, perform in such dynamic scenarios. In [7], estimation of material handling time reduction for picking operations using optimal item allocation rather than a uniform distribution of picking and storage locations was analyzed. Results were calculated through simulations, based on a variable picking list size, with the aim of underlining the effect of different slot-code optimization levels on the reduction of average distances traveled. The comparison was carried out with and without the most commonly used heuristic. In [8] a multi-product slot allocation heuristic developed by taking cue from vertex coloring problems and its pragmatic evaluation on a real industrial case was presented. A benchmark with a randomized storage policy was presented to underline heuristic effectiveness and point out future research opportunities.

All the mentioned approaches represent good ideas to tackle the product placement problem but most of them define the problem too close to the warehouse structure and must rely on heuristics to solve the problems that arise. The next section will describe a different, more general, approach to the optimal product placement issue.

III. Predictive Analysis based Approach

As it was mentioned before in the introduction, if the storing and put-away operations are viewed strictly by definition, they represent hard to solve mathematical problems. If the volume and capacity of the warehouse racks and the capacity of the incoming items is taken into consideration a kind of knapsack problem [1] arises. Given the difficulty of the practical implementation of such a system and missing volume information, this problem needs to be relaxed and the capacities of items and storage space are no longer considered. This makes this problem a simple selling frequency based ordering problem if the warehouse is initially empty but it becomes more complicated if the warehouse is already working at full capacity and a new system needs to be implemented. This section will focus on finding a solution for the defined relaxed problem for both initial states. The whole process is split into different stages: analysis of the current state of the warehouse in focus, problem definition and construction of the predictive analysis based approach and result analysis.

A. Analysis of the Current State

The analysis of the current state of the warehouse has shown that, in the last 2 years, the warehouse stored about 2,360 different items. The average number of exported item units per day was 27,132 with a rather high standard deviation of 22,324 which indicates a large variety of differently demanded items present in the warehouse. The total number of orders for the last two years was 173,103. The appearance frequency of items in different orders is shown in Table I which further indicates the high differentiation in warehouse item demand.

TABLE I: Item Appearance Frequency on Different Orders.

Number of Order Items	Frequency
10,000 - 50,000	7
5,000 - 10,000	42
1,000 - 5,000	331
500 - 1,000	298
100 - 500	691
0 - 100	991

If this analysis is scaled down to the daily level, almost the same conclusion can be made. Table II shown below represents the average daily frequency of item units appearing on different orders analyzed in same periods of time.

TABLE II: Daily Appearance Frequency on Different Orders.

Number of Order Items	Frequency
30 - 40	7
20 - 30	17
10 - 20	77
5 - 10	216
2 - 5	618
0 - 2	1425

To further stress this fact, if the analysis of different products per order is shown in a graph like it is shown in Fig. 1, it indicates that 125,918 out of total 173,103 orders (around 72.75%) consisted out of 10 or less different products.

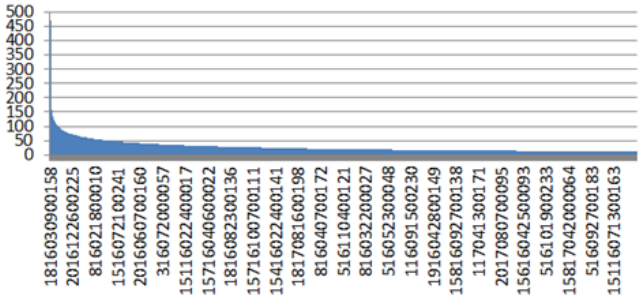

Fig. 1: Number of Different Products per Order.

Given the obvious importance of the items with the highest demand, the first idea was to target orders with 10 different products or less because they provide most space for optimization in terms of worker order collection travelling distance and time. The presumption was that the worker collecting the order with a large number of items will usually have to visit most parts of the warehouse anyway and in these scenarios there is not much room for optimization. Situations when a small number of items is collected on the other hand offers a lot of space for improvement if the items are placed strategically in the warehouse. Analysis of the orders with 10 or less different products in the period of one year have shown that they consisted out of 1,540 different products. Analysis of how many times products were ordered have shown that the number was 1 for least frequent and 2,512 for most frequent item. The graph presented in Fig. 2 shows how many times the top 100 products from small orders were ordered in the mentioned historical period of one year.

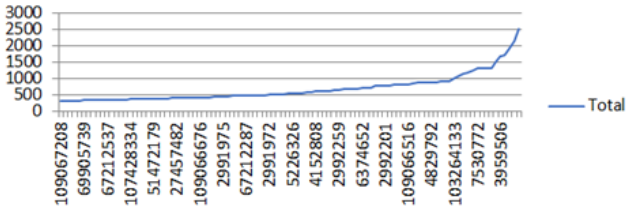

Fig. 2: Number of Orders per Product.

The warehouse in focus is divided in two logical parts or sectors for different item brands and additional separate rooms for items that must be stored in specific temperature ranges. Because they lacked a better solution, warehouse workers arranged products in warehouse *ad hoc*, according to their everyday experience and needs. Items were instinctively grouped so that they could find them easily find when they are collecting orders. Because of that and similar working habits, they needed more time later to accept new optimized working system that included new database, modules for order picking, pick zone capacity and content prediction which is described in [9] and [10] and product placement optimization which is described here.

B. Problem Definition and Introduction of the New Approach

After the relaxation, the easiest way to approach this problem is to view the whole warehouse as a sort of closed environment. The only communication with the outside are the items come in and leave the warehouse at a variable rate, day by day. Consequently, spots in the warehouse storage racks are freed and occupied according to the earlier mentioned *ad hoc* approach from the warehouse workers. As it is shown in Fig. 3, the warehouse in focus is organized as follows: the designated entrance area, the central hallway and the designated output area. Taking all the mentioned facts into consideration, the problem can be defined as a simple question: “How can the most frequent items be placed as near as possible to the central hallway but not get scattered too far away from the main accumulation point?”.

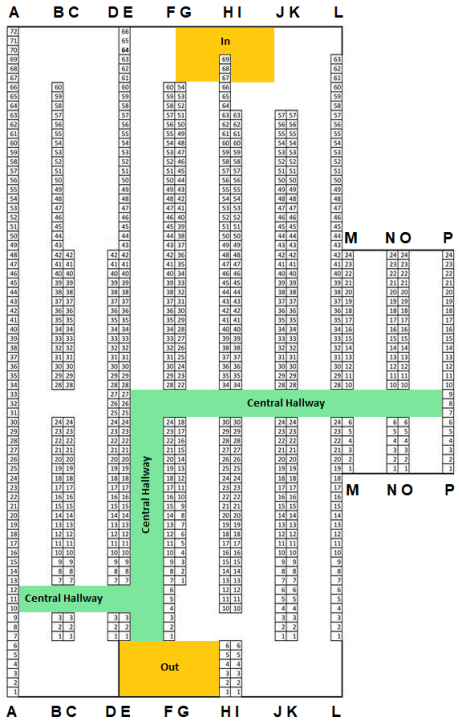

Fig. 3: Warehouse Layout with Designated Areas.

This brings up two main goals that can be set:

1) Move the most frequent items for the orders with 10 or less items as close as possible to the central hallway.
2) Restore and maintain the homogeneity of the placement of the warehouse items.

To achieve the first goal, the sales history needs to be thoroughly analyzed. The optimal period that was chosen was one year back from the current date because of the dynamic nature of the handling of warehouse items. Some items can stop being sold and become inactive, some items change their identification number, new items are introduced

etc. The second goal requires a kind of a sorting process to regroup the already scattered items. Since the company that owns the warehouse in focus could not allow itself a break in the workflow, the sorting of the items needed to be done dynamically and over a longer period of time. That required a smart approach in handling the occupation of free space in the warehouse racks. The new approach would dictate the position for each new item that enters the warehouse. This would require new calculation for each new item shipment that reaches the warehouse given the dynamic nature of the warehouse. The main steps of the approach are given in pseudo-code form in **Algorithm 1** shown below.

Algorithm 1 Position Grade Calculation Pseudo Code

```
function CALCULATEPRODUCTPOSITONGRADES
    Require:
    aid - Identification number of the entering article.
    sec - Sector of the entering article.

    ig = CalculateItemGrade(aid);
    positions = GetListOfFreePositions(sec);
    cwgb = CalculateCurrentWarehouseGradeBalance(sec);

    for p in positions
        result.Add(p.id, ig/p.grade, cwgb - ig/p.grade);
    end

    return result;
end
```

The approach consists out of multiple steps. The first, initial step is to calculate the grade of the item that needs to be positioned somewhere in the warehouse. This is done by considering the daily item picking frequency of the item acquired from a years worth of data. The second step is to get the list of all the available free positions in the sector of the corresponding item. The third and final step is to calculate the factor which reflects the current situation in the warehouse. This calculation relies heavy on the grades of the items and the positions of the warehouse. In this approach the grades of the items are calculated based on their daily picking frequency where the most frequently picked items get higher grades. On the other hand, the grades of the positions are calculated based on their distance from the central hallway where the positions closer to the hallway get the higher grades. In this case the grade and the distance are reversely proportional. Both grading scales need to be normalized to the same range in a way which will properly reflect the relations of the initial scale. Once the grades are put within the same range the current item/position grade balance can be calculated by dividing the item grades with their corresponding positions. Since the the grades need to be about equal to represent the ideal positioning, the average result needs to be closer to 1 as much as possible. This is a good parameter for monitoring the current state of the item placement in the warehouse. More about the calculation of the distance between the positions, picking frequency and item relocation can be found in previous work about this topic, [9] and [10]. After all these parameters are calculated, the list of all the available positions is expanded by the grade ratio of the corresponding item and the current position and the deviation of that grade from the current average grade ratio of the warehouse. This result is the complete list of available positions because it is not the best approach to limit the choices for the workers. Also, this list can be sorted by the best grade ratio or the deviation from the current situation in the warehouse which gives the workers room to maneuver if there are unforeseen impediments that can arise in such a dynamic environment like a logistics company warehouse.

C. Result Analysis for two Initial States

How long will it take to significantly improve the item placement situation in a warehouse largely depends on the initial state of the warehouse. The achieved results can be viewed from two different standpoints. First is how the reassigning of item positions simplified the item picking process and the second is how the homogeneity of the item placement has improved. This can be measured through the length of the picking route when an order is completed. Table III shows by how much percent the average length of the picking route was reduced one month after the approach was implemented.

TABLE III: Average Picking Route Length Reduction.

Number of Order Items	Average Length Reduction (%)
30 - 40	17.34%
20 - 30	12.5%
10 - 20	10%
5 - 10	7.1%
0 - 5	4.4%

What can also be measured are the changes in location homogeneity of the items in the warehouse before and after the implementation of this item assignment approach. This is represented in Fig. 4 where the red slots mark the positions of the ten most popular items in the warehouse before and one month after this approach was implemented in the warehouse.

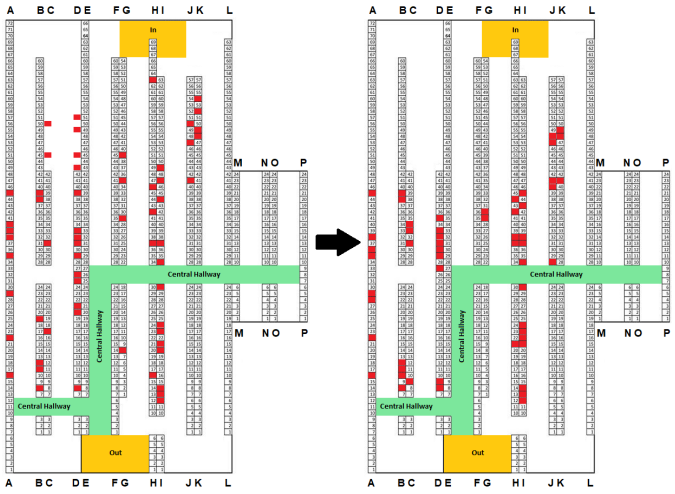

Fig. 4: Before and After Locations of the Top 10 Items.

It is clearly visible that the homogeneity of item grouping has increased since the items are not scattered all over the warehouse anymore. It is clear that they converge towards the central hallway of the warehouse since it has been selected as the reference point where the items should be placed as near as possible. There are still some unnaturally occupied item locations but it is important to keep in mind that this is only one month after the approach was implemented. This approach is meant to order and homogenize the item locations of the warehouse over a longer period of time and there is still room for further improvement than it is shown in the results. This is very important to note since it is a real constraint that can occur in many warehouses that can't allow a break in the workflow but a solution needs to be implemented nevertheless.

Like it was already mentioned, incorporating a new system that requires changes in the existing workflow is always more difficult than building a new system from scratch. The prime example is the implementation of such a system in a new warehouse branch that was being added by the logistics company in question. The layout of the new warehouse, as shown in Fig. 5, is more complicated than the layout of the previously described warehouse since it has more more sectors and differently temperature regulated rooms that are interconnected. Besides the structural complexity of the warehouse, given the fact that the functions for distance calculation are already implemented, the implementation of the approach was trivial since it came down to sa simple frequency ordering problem. Namely, for each sector which were given identification numbers, an appropriate reference point was calculated and the most frequent items were grouped and ordered as near as possible to that point for each sector. When an order is completed for an individual sector the worker moves on to the next one. The optimization is bound to each sector individually as the grouping of items is done locally.

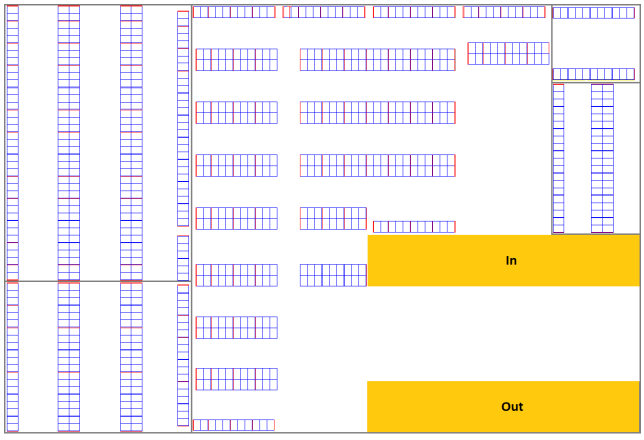

Fig. 5: Layout of the Initially Empty Warehouse.

Results of the optimization in both cases were satisfactory. Both described approaches represent optimization of the same operations but illustrate how much complications the initial state of a warehouse can cause when implementing those optimization modules of the warehouse management system.

IV. Conclusion and Future Research

In this paper, a solution for optimal warehouse item positioning was proposed. The described approach was the base of the optimization module that was incorporated in a medium-to-large logistics company warehouse in Bosnia and Herzegovina. Based on the results from this module an analysis of the achieved improvements was made and compared with the approach for an initially empty warehouse. The main assumption was that when items are strategically placed in the warehouse racks, all the other implemented optimization modules become more efficient. The thorough analysis conducted in subsection 2.A has shown that the previous workflow left a lot of space for improvement. How that improvement was accomplished and how the weak sides were fixed was explained in subsection 2.B. Product dimensions and weight are important aspects that were not taken into account when this solution was implemented because of the complexity of the resulting problem and absence of that kind of information in company databases. A future modification of the approach could include this information when it becomes available. Future improvements for the overall warehouse management system will be the transitions of the modules into deep learning based sales prediction which will, integrated with other implemented modules, lead to full coverage of the warehouse item workflow.

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Intelligent Analysis of Economic Parameters of European Countries

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***Abstract* - Engineers today are often bound to work with complex data, with valuable knowledge to be extracted and models to be built for predicting future behavior. With a given set of economic parameters for the European countries, the goal of this paper is to analyze if they can form meaningful community structure. To this end, we propose a network science approach to economic time series analysis. The first step is the creation of corresponding graphs as the most adequate data representation that can capture multiple relations and dependencies among entities of interest. The preprocessing steps for creating a graph include calculating correlation coefficients for the parameters, which are used for weighing the graph. The weighted graphs are then analyzed for their underlying structure using clustering algorithms which produce various communities depending on the settings employed. Experiments are performed using different correlation calculations for graph weighing and different settings for cluster extraction and the produced communities are analyzed in terms of their quality, both in view of modularity score and economic meaning. Results show that the proposed approach successfully captures meaningful economic relationships between European countries and can be a solid base on which future, more complex analysis can be build.**

Keywords - economic parameters; Europe; time-series; correlation; graph representation; community detection

I. INTRODUCTION

Time series data analysis is a crucial field of research in economy since many economic and financial parameters data are represented as time series. Financial institutions have long been leaning on intelligent systems and artificial intelligence for detecting outliers, with the intentions to analyze and process the newly-found suspicious data through a more detailed, meticulous approach. Moreover, time series are key to analyzing macroeconomic parameters and their effect and connectedness to overall economy growth [1]. There has been extensive research done in the field of clustering these data [2], however the literature is scarce in approaches viewing the data as a graph, thus exploiting the power that this representation has in capturing multiple relations and dependencies among the entities of interest.

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The topic of interest in this paper i.e. the economic parameters of countries, in terms of their significance for economy, has been analyzed in many different aspects. The authors of [3] study the uncertainty of inflation and use time series data to reproduce survey measures. Analyzing economic parameters in eight rapidly developing East and Southeast Asian economies has already been a topic of interest in a paper where time-series causality is compared to panel causality, albeit the results favor panel data as the superior choice since the implications there yield more logical conclusions [4]. More recent studies are focused on the relationship between economic parameters and the economy growth. In [5] the focus is on examining the relationship between financial and economic development by time series analysis of cointegration and causality between finance and growth for 22 advanced economies. Evidence of significant, asymmetric and positive dependence between tourism and GDP growth rates for United Kingdom, Spain, and Croatia is reported in [6].

According to [7] econometrics can benefit from clustering similar time series with application in: proper targeting of policy-making; improving economic forecasting through better discrimination of economic processes structure; and better risk and investment management using gained knowledge for stable dependencies. Novel developments in economy time series clustering [8,9] are mainly focused on finding the proper statistics and/or signal transformation in order to best distinguish different economic parameters. The understanding and validation of the produced results using these approaches requires the knowledge of the complicated underlying mathematical apparatus, thus deeper comprehension eludes majority of readers and practitioners interested in utilizing research results in real life scenarios as the ones stated above.

In this paper network science is applied in the field of econometry by representing economic parameter time series using graphs. Such representation is by far the most intuitive in terms of general understanding and has been used with the same purpose in many scientific fields, ranging from bioinformatics [10] to internet of things [11]. The methodological approach from [12] is adopted to test whether this kind of community detection in the economic parameters graphs would pinpoint to expected

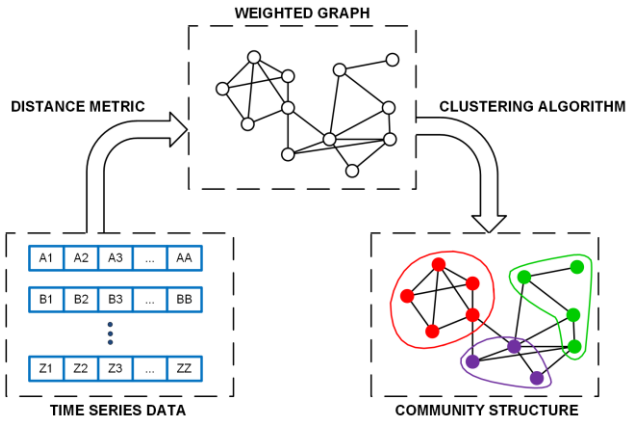

Figure 1. Architecture of the approach

groupings, which can lead to future use of the approach in more complex econometric projects having time series data as valid and verified underlying support.

The rest of this paper is organized as follows. Section II presents the steps in acquiring and building the data for the research and the technical details on the methods used. In the third section a detailed description of the performed experiments and the corresponding results is given. Discussion for the results and possible improvements are also provided. Finally, the paper is concluded in the fourth section.

II. Materials and Methods

The architecture of the adopted approach is depicted in Fig. 1. Firstly, we acquire the time series data for the economic parameters we use. Next, these data are transformed to a graph representation using corresponding distance metrics. Once the weighted graph is produced, clustering algorithms are employed to discover the underlying community structure.

A. Research data

The research data are collected via Quandl [13]. Quandl offers free, unlimited API for global economy data, including macroeconomics, demographics and social statistics. The website unifies data from the World Bank, UN, Eurostat, ADB, BEA, BLS, FRED and other publishers. Data available can be found for, but is not limited to: alcohol, tobacco products, demography, economic growth, economy, education, energy, health, inflation, mortality, population and unemployment.

The information is represented as time series data that correspond to data points registered in logged days, months or years in a consequential order. The dataset, however, is not fully logged from a definite point in history, the starting point might not always be the countries' year of forming, and the data last entry logs the last available date within the year of 2014. Certain cases exist when data from the 2014 is omitted as well.

Though there is data for variety of economic parameters, to showcase the validity of the approach proposed in this research, the following 4 parameters are in the focus, as the key factors that drive a country's economy:

- *GDP* (Gross Domestic Product) represents the total value of goods produced and services provided in a country for one year.
- *Per capita GDP* is a measure of the total output of a country that takes gross domestic product (GDP) and divides it by the total capita of the country.
- *Inflation* is the general increase in prices, and fall in the purchasing value of money.
- *Consumer Price Index* (CPI) is a measure that examines the weighted average of prices of a basket of consumer goods and services. It is calculated by averaging price changes for each item in a predetermined basket of goods.

For this research, the following 41 European countries are included, with their ISO codes given as follows: ALB (Albania), AUT (Austria), BLR (Belarus), BEL (Belgium), BIH (Bosnia and Herzegovina), BGR (Bulgaria), HRV (Croatia), CYP (Cyprus), CZE (Czech Republic), DNK (Denmark), EST (Estonia), FIN (Finland), FRA (France), DEU (Germany), GRC (Greece), HUN (Hungary), ISL (Iceland), IRL (Ireland), ITA (Italy), LVA (Latvia), LTU (Lithuania), LUX (Luxembourg), MKD (Macedonia), MLT (Malta), MDA (Moldova), MNE (Montenegro), NLD (Netherlands), NOR (Norway), POL (Poland), PRT (Portugal), ROU (Romania), RUS (Russia), SRB (Serbia), SVK (Slovakia), SVN (Slovenia), ESP (Spain), SWE (Sweden), CHE (Switzerland), TUR (Turkey), GBR (United Kingdom) and UKR (Ukraine).

B. Graph construction

The next step is to build a undirected weighted graph representation for the obtained time series data. The weighted graph representation for each economic parameter is defined as $G_{mn}(V,W)$. The index m corresponds to the economic parameter under analysis, where m=1,..,4, with the following mappings {1:GDP, 2:Per Capita GDP, 3:Inflation, 4:CPI}. The index n corresponds to the distance metric used. $|V|$=41 is the set of nodes with each node corresponding to a single country in the data. W is the weighted adjacency matrix, where w_{ij}=0 if i=j, for i,j=1..41; and w_{ij} for $i \neq j$ and i,j=1..41, is calculated using a distance metric between the time series of $Country_i$ and $Country_j$. In this paper the degree of correlation is chosen as the distance metric and the Pearson correlation [14] and Dynamic Time Warping [15] are both used to determine the most suitable choice, and these correspond to the two possible values of index n in the graph definition, 1 and 2, accordingly.

1) Pearson correlation

The most commonly used measure for data correlation has specific properties that need to be considered when analyzing the economic parameters. The correlation itself is independent of the unit measurement. As such, if a parameter (i.e. CPI) is given in a yearly percentage growth and a second parameter (GDP) is given in euros or dollars, currencies need to be converted for correct further analysis. The correlation is symmetric i.e. w_{ij}=w_{ji}, for i,j=1..41. There is no causality in the results. If correlation exists, it means two variables are correlated. A non-

existing correlation, however, only signifies that a linear relation does not exist between those two variables. Pearson correlation is sensitive to outliers. For example, an event that causes a disturbance in the economy within a given year, for a given country, may have a negative impact in producing an adequate correlation with other countries. When using the Pearson correlation, the cardinality of the time series needs be equal, and values normalized. To be able to obtain this requirement, the correlation coefficient in this research is measured for the intersection of the time series data for each country pair.

2) Dynamic Time Warping

As the Pearson correlation is limited to finding the linear correlation between time series data of same cardinality, dynamic time warping (DTW) was also used in the research so that the differences of the length of the data would not be omitted and at the same time non-linear correlations would be detected.

The DTW algorithm can be viewed as an optimal (minimal) traversal path in a matrix from its bottom left to its upper right corner, where matrix columns and rows correspond to times series being compared, and cells are the distances between corresponding time points in the series. There are two important properties of the DTW that need to be considered when applying the algorithm:

- *Window size*: The optimal window size does not allow the path to stray too far away from the matrix diagonal that spans from the left bottom corner to the upper right.
- *Slope constraint*: There is a limit of how many steps can be made in the x-axis or y-axis. This prevents connections of many short paths from one sequence with long paths from the other.

In this research the slope constraint was omitted, as results indicate that it is not crucial, and performance does not change significantly when the constraint is applied.

Considering the window size, results were compared for multiple countries and Fig. 2 shows a small example of how the results differed. The figure gives the correlation coefficients for the inflation parameter for the countries: Belgium, Belarus, Bosnia, Bulgaria and Croatia under different window sizes.

no window size constraint

Countries	Belarus	Belgium	Bosnia	Bulgaria	Croatia
Belarus	0	0.882994	0.895304	0.910308	0.910568
Belgium	0.882994	0	0.651846	0.679563	0.840521
Bosnia	0.895304	0.651846	0	0.843443	0.700198

window size = 3

Countries	Belarus	Belgium	Bosnia	Bulgaria	Croatia
Belarus	0	0.883025	0.895318	0.910314	0.910584
Belgium	0.883025	0	0.651835	0.68196	0.8505
Bosnia	0.895306	0.651846	0	0.847447	0.701842

Figure 2. Example of DTW correlation results for differernt window

As can be seen, with the rise in window size the correlation between countries increases. Similar behavior in correlation coefficients is registered for all parameters under analysis. However, setting a frame size as big as 30 could lead to false results in the sense that the algorithm follows only the matrix cell edges to get the smallest cost, thus producing results of no value.

Research on big economic events such as the "Global Financial Crisis" that triggered the "Great Recession", point to evidence that consequences can be felt abroad after only 2 years even amongst the countries of great distance [16]. This is an indicator that any two countries time-series window frames should not be set to be greater than 3 to at most 4 data points. Because of these findings and the small decimal difference when opting for bigger frame sizes, the window size is chosen to be 4.

C. Clustering of the economic parameters graphs

The understanding of complex systems has been greatly improved with the advancements in network science, especially with the development of algorithms that unravel the organization of the system's entities in communities as one of the most relevant features of their complexity. The community detection problem is very hard, and science still lacks highly satisfactory general solutions, as this problem is in the focus of a large interdisciplinary scientific community [17].

One of the biggest breakthroughs in the field was the Girvan and Newman modularity function [18]. They propose an equation that calculates the quality of a given clustering compared to a corresponding random graph. The randomization of the edges is done with preserving each node degree. The modularity function is defined as:

$$Q = \frac{1}{2m}\sum_{i,j}\left[A_{ij} - \frac{k_i k_j}{2m}\right]\delta(c_i, c_j)\,. \qquad (1)$$

where, $A_{ij} = w_{ij}$ for all the graphs used in this research, $k_i = \sum_j A_{ij}$, $m = (1/2)\sum_{ij} A_{ij}$, and $\delta(c_i, c_j)$ is the Kronecker delta symbol where $\delta(c_i, c_j) = 0$ if $c_i = c_j$, for c_i and c_j being the communities to which nodes *i* and *j* belong to.

The modularity function score is used as a performance metric for the algorithms used in this research. Two algorithms are used in the research as the representatives of two distinct families of clustering algorithms. The first refers to algorithms that iteratively partition the graph into clusters, while the algorithms in the second family employ different greedy strategies to optimize the modularity since the problem is NP hard. Both types of algorithms can produce a hierarchy of communities i.e. subcommunities within a community.

The partitioning algorithm of choice is the original Girvan and Newman Edge-Betweenness algorithm [18]. The concept of edge-betweenness is an extension of the concept of node-betweenness, which is an estimate of the centrality of a node in a network. Analogous to the definitions for node-betweenness, the betweenness of an edge is calculated as the number of shortest paths between any two nodes in the graph which pass through that edge. The inter-cluster edges, i.e. ones connecting two nodes of different clusters have higher betweenness then the edges which connect nodes that belong to the same cluster, thus by iteratively deleting edges with highest betweenness, the graph will be partitioned into several communities.

The Louvain algorithm [19] is the second algorithm used in the research since it is to date the best modularity optimization community detection algorithm. The greedy technique of Louvain is based on supervertices for representation of the communities and calculating the modularity. At start all nodes are in different clusters but as each node chooses a new cluster the clusters are replaced with supervertices. Two supervertices are connected if there exists an edge between any two nodes from the two supervertices. The "movement" of nodes between clusters is driven by the optimization of the modularity score.

Aside the different science behind the chosen algorithms there is an additional very important difference. Namely, for the Louvain algorithm we don't need to set any parameters (i.e. the algorithm finds the optimal community structure), while the Edge-Betweenness algorithm requires the number of clusters to be produced as input. To that aim the number of clusters obtained by Louvain are used as a median value for the number of clusters in the Edge-Betweenness experiments.

III. Results and Discussions

Data processing and experiments in the research was performed in Python, using the igraph module [20] for graph creation and clustering.

As stated in the graph building section the created graphs are fully connected. Since not all correlations are significant we perform experiments by defining an edge weight cut-off threshold θ. All edges with weight below this threshold are excluded from the graph, i.e. their weight is set to zero.

Given in Tables 1-4 are the results of the quality of clustering experiments when using different distance metrics, clustering algorithms and cut-off thresholds. The results show that DTW outperforms Pearson for all parameters, thus making it the better choice for distance metric. As expected, in most scenarios Louvain produces better clusters than the Edge-Betweenness algorithm. Regarding the threshold the best results are obtained for a cut-off value set at 0.9 which point to a conclusion that many of the edges in the fully connected graphs are noisy and bias the community detection in a false direction.

The graphs are further analyzed by identifying subcommunities within the initial clusters. The hypothesis that are tested in this step are: 1. The new community

TABLE I. Clustering performance for the GDP graph

		θ = 0.15		θ = 0.4		θ = 0.7		θ = 0.9	
Distance metric	**Clustering algorithm**	**No. of clusters**	**Modularity score**	**No. of clusters**	**Modularity score**	**No. of clusters**	**Modularity score**	**No. of clusters**	**Modularity score**
Pearson	Louvain	2	-0.0107	2	-0.0135	2	-0.0152	4	0.0062
	Edge-Betweenness	2	-0.0006	2	-0.0012	2	-0.0013	3	-0.0002
	Edge-Betweenness	3	-0.0027	3	-0.0025	3	-0.0025	4	0.0006
	Edge-Betweenness	4	-0.0061	4	-0.0037	4	-0.0047	5	-0.0019
DTW	Louvain	3	-0.0107	2	0.1321	2	0.2078	4	**0.4261**
	Edge-Betweenness	2	-0.0024	2	-0.0012	2	-0.0009	2	-0.0009
	Edge-Betweenness	3	-0.0036	3	-0.0013	3	-0.0032	3	-0.0013
	Edge-Betweenness	4	-0.0036	4	-0.0011	4	-0.0062	4	-0.0214

TABLE II. Clustering performance for the Per capita GDP graph

		θ = 0.15		θ = 0.4		θ = 0.7		θ = 0.9	
Distance metric	**Clustering algorithm**	**No. of clusters**	**Modularity score**	**No. of clusters**	**Modularity score**	**No. of clusters**	**Modularity score**	**No. of clusters**	**Modularity score**
Pearson	Louvain	2	-0.0095	2	-0.0077	2	-0.0067	3	0.0611
	Edge-Betweenness	2	-0.0024	2	-0.0024	2	0.0023	2	-5.7067
	Edge-Betweenness	3	-0.0036	3	-0.0036	3	0.001	3	-3.9947
	Edge-Betweenness	4	-0.0058	4	-0.0045	4	0.0005	4	-0.0007
DTW	Louvain	2	0.0011	3	0.0184	3	0.1399	4	**0.4023**
	Edge-Betweenness	2	-0.0005	2	-0.0005	2	-0.0013	2	-3.1745
	Edge-Betweenness	3	-0.0013	3	0.0002	3	-0.0017	3	0.0028
	Edge-Betweenness	4	-0.002	4	-0.0053	4	-0.0003	4	0.0019

TABLE III. CLUSTERING PERFORMANCE FOR THE INFLATION GRAPH

		θ = 0.15		θ = 0.4		θ = 0.7		θ = 0.9	
Distance metric	**Clustering algorithm**	**No. of clusters**	**Modularity score**	**No. of clusters**	**Modularity score**	**No. of clusters**	**Modularity score**	**No. of clusters**	**Modularity score**
Pearson	Louvain	2	-0.0094	2	-0.0094	2	-0.0077	3	0.0344
	Edge-Betweenness	2	-0.9783	2	-0.9783	2	0.0029	2	-2.5136
	Edge-Betweenness	3	-0.0014	3	-0.0014	3	0.0052	3	-7.5408
	Edge-Betweenness	4	-0.0029	4	-0.0029	4	0.0041	4	-0.0002
DTW	Louvain	3	0.1235	2	0.1349	3	0.2394	4	**0.4491**
	Edge-Betweenness	2	-0.0002	3	-0.0024	4	-0.0059	3	-0.0001
	Edge-Betweenness	3	0.0006	4	-0.0034	5	-0.0001	4	0.0204
	Edge-Betweenness	4	-0.0006	5	-0.0066	6	0.0076	5	0.0887

TABLE IV. CLUSTERING PERFORMANCE FOR THE CPI GRAPH

		θ = 0.15		θ = 0.4		θ = 0.7		θ = 0.9	
Distance metric	**Clustering algorithm**	**No. of clusters**	**Modularity score**	**No. of clusters**	**Modularity score**	**No. of clusters**	**Modularity score**	**No. of clusters**	**Modularity score**
Pearson	Louvain	2	-0.0126	2	-0.013	2	-0.0023	5	0.174
	Edge-Betweenness	2	-0.0035	2	-0.0032	2	-0.0015	4	0.003
	Edge-Betweenness	3	-0.0045	3	-0.0043	3	-0.0024	5	0.001
	Edge-Betweenness	4	-0.0056	4	-0.0064	4	-0.0029	6	0.0006
DTW	Louvain	3	-0.0125	2	-0.0125	3	0.0516	3	0.3758
	Edge-Betweenness	2	-0.007	2	-0.0011	2	0.0008	2	-8.4331
	Edge-Betweenness	3	-0.0074	3	-0.0023	3	0.0021	3	-0.0004
	Edge-Betweenness	4	-0.0084	4	-0.0035	4	-0.0015	4	-0.0964

structure yields improved modularity score, and 2. Subcommunities are composed of countries that have a common factor influencing their economic policies and as a result their economic parameters have similar dynamics. The discussion for the results is given for two experimental cases.

A. Experimental case 1

In this experimental case the parameter of interest is GDP, the clustering algorithm used is Louvain with DTW as distance metric and θ = 0.9. The obtained clusters are the following: ***Cluster 1:*** *{***1.0** {Belgium, Austria, Macedonia, Croatia}, **1.1** {Greece, Finland, Ireland, Portugal}}; ***Cluster 2:*** {**2.0** {Denmark, France, Italy}, **2.1** {Czech Republic, Serbia}, **2.2** {Norway, Germany, Sweden, Hungary}}; ***Cluster 3:*** {**3.0** {Spain, Ukraine, Poland, Turkey}, **3.1** {United Kingdom, Iceland, Netherlands, Switzerland}, **3.2** {Albania, Romania}}; ***Cluster 4:*** {**4.0** {Belarus, Russia}, **4.1** {Moldova, Slovenia, Slovakia, Bulgaria, Lithuania, Luxembourg}, **4.2** {Lithuania, Cyprus, Estonia, Malta, Bosnia and Herzegovina}}. The final modularity score is 0.8766.

As can be seen France and Italy are in the same cluster (2.0). Italy has its GDP varying between -2% and up to 8% of yearly GDP growth, whereas France has its range between -1% and 7%. One would expect that Spain would also be in this cluster (as opposed to cluster 4.1), because the countries are very close culturally [21], but also share most of their GDP variations within the last 50 years. In cluster 2.2 there are Norway and Sweden which are proclaimed two of the three (together with Switzerland as the third) winners in the European economy, and they have a higher growth than Germany that also pertains to the same cluster. The countries belonging in cluster 3.0 are Poland and Turkey that have had a continuous growth of their GDP in the last 10 years [22]. However, there is also Ukraine in the same cluster, although it economic growth has been stagnating due to it being a constant warzone territory.

B. Experimental case 2

In this experimental case the parameter of interest is Per capita GDP, the clustering algorithm used is Louvain with DTW as distance metric and θ = 0.9. The obtained clusters are the following: ***Cluster 1:*** *{***1.0** {Slovakia, Turkey, Croatia, Estonia, Latvia, Russia}, **1.1** {Macedonia, Serbia, Bulgaria, Romania, Montenegro}, **1.2** {Albania, Belarus, Bosnia and Herzegovina, Ukraine}, **1.3** {Lithuania, Poland, Hungary}; ***Cluster 2:*** {**2.0** {Belgium, France, Austria, Cyprus, Germany, Spain}, **2.1** {Sweden, Norway, Switzerland, Netherlands, Luxembourg}, **2.2** {United Kingdom, Ireland, Denmark, Finland, Italy, Iceland}; ***Cluster 3:*** {Greece, Czech Republic, Malta, Slovenia, Portugal}; ***Cluster 4:*** {Moldova}. The final modularity score is 0.8432.

One very "logical" and expected cluster is 3. Greece and Portugal are well known as the countries that have faced debts for a long time [23]. Moreover, if we want to

find out the momentarily situation of the GDPs per person in the world we can find Greece, Czech, Portugal, Malta and Slovenia in a consequential order among the European countries (48th, 49th, 51st, 53rd and 54th on global scale). Finally, all countries from this cluster are members of the EU.

The countries in the second cluster are mostly in EU, and one can see a regional division between north-west countries (Norway, Switzerland, Netherlands), central and south-west (Austria, Germany, Spain and France) belonging in different clusters. Cluster 2.1 additionally contains few of the richest countries with biggest GDP per person with Luxembourg (3rd place), Norway (4th place), Switzerland (7th), Sweden (13th) and Netherlands (14th). The cluster 2.2 is somewhat similar, although at first glance Italy may seem as an outlier. However, Italy, with Finland, Norway and Cyprus have the biggest drops of GDP per person between 2012 and 2014 recorded [24], which can be of importance as to why algorithms place them in same communities. Most southeastern European countries are in clusters 1.1 and 1.2 where we see 3 from 5 ex-Yugoslavia countries, together with Bulgaria that entered the EU in the 2007, but its GDP per person had only reached 30% of the average EU up until 2013 [24]. After the economic crisis, a very small economic progress has been noted in Moldova, but very soon after, the inflation had begun increasing steeply. This makes Moldova unique and drastically different, and that explains why it would be excluded from all other clusters.

IV. CONLUSION

In this paper network science is applied in the field of econometry by representing economic parameter time series using graphs. European countries are analyzed based on their GDP, Per capita GDP, Inflation, and CPI. The proposed approach uses correlation coefficient to derive weighted graphs, which are in turn explored for their underlying community structure. Results show that a coefficient that can capture non-linear correlations (Dynamic Time Warping) combined with a modularity optimizing clustering algorithm (Louvain) yield the best performance. A more in-depth analysis shows that the produced community structures in part reflect the countries' common factors, such as geo-political, cultural and historical similarities, influencing their economic policies. The approach is a solid base for future research which should include external influence on the European economy, but also consider co-dependencies of the economic parameters.

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The Domain-Specific Editor for Rule-Based Knowledge Bases

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***Abstract* – The aim of the paper is to describe a domain-specific editor for the design of rule-based knowledge bases in the field of the prognosis of technical conditions and remaining operation time of petrochemical equipments. The architecture, main functions and a structure of files for configuration of the editor are presented. The feature of the editor is a semantic layer in the form of a platform-independent model. This layer provides to configure the editor with the account of features of a subjects domain. The semantic layer is implemented as a set of domain specific templates describing facts and rules (cause-and-effect relationships). These templates help to abstract from the syntax of certain knowledge representation languages (programming languages for knowledge bases, in particular, CLIPS - C Language Integrated Production System) and generate the graphic user interface elements.**

Keywords - knowledge base, domain-specific editor, platform-independent model, CLIPS, code generation, assessment of technical conditions and operation life

I. INTRODUCTION

The design of knowledge bases (KB) is the main stage of intelligent systems engineering. The results of the stage are represented in the form of formalized and codified knowledge that contains information about the processes, phenomena and objects of the subject domain under consideration.

Several main trends to improve the efficiency of the knowledge bases design are existing, in particular:

- Using the software for ontological and cognitive modeling, CASE-tools (Protégé, OntoStudio, IHMC CmapTools, XMind, FreeMind, TheBrain, IBM Rational Rose, StarUML and etc.), which create graphic models that correspond to the key software abstractions. However, most of these systems do not cover the KBs creation stage and do not provide the completeness of the development process: from the subject domain model to the program codes. In some cases, they can only help obtain graphic images of KB structures. Perhaps, only Protégé is capable of generating a limited set of KB elements, in particular, for CLIPS/COOL.

- Using KBs editors and expert systems shells (Expert System Designer, Expert System Creator, ARITY Expert Development Package, CxPERT, Exsys Developer, DDTRES and etc.), which are programmer-oriented and allow implementation of a formalized description of the domain concepts and KB structures in a certain programming language (PL), but have a low integration capacity with visual modeling systems and knowledge interpretation modules, in most cases supporting one specific PL.

- Using integrated frameworks and unified approaches that provide the coverage of all phases of the life cycle of knowledge-based systems and the integration of the first two trends. It should be noted that this area offers such solutions as AT-TECHNOLOGY [1] and such special methodologies as HeKatE [2] and CommonKADS [3], however, there is a general tendency to target non-programmers [4] and employ conceptual models, including ontologies and semantic nets, when creating KBs.

So, we propose to improve the effectiveness of this stage is the use of specialized software to design knowledge bases directly by the subject domain experts, [5-6] in particular, in the form of domain-specific editors.

This paper describes the domain-specific editor (DSE) for the creation of rule-based knowledge bases in the field of the assessment of technical conditions and remaining operation time of technical objects in petrochemical industry. The DSE is developed with the use of the Personal Knowledge Base Designer (PKBD) platform [7].

The PKBD platform provides the ability to create rule-based expert systems and knowledge bases in accordance with the main principles of a model-driven approach (Model Driven Development) [8].

II. THE MODEL DRIVEN DEVELOPMENT APPROACH

The Model Driven Development (MDD) is an area in the software engineering that considers information models as the central artifacts in the software development providing the automatic synthesis of software codes.

The main MDD concepts are the following:

1. A model is an abstract description of a system (a process) in a formal language. As a rule, the models are

visualized with the aid of certain graphic notations and serialized (represented) in XML.

2. A metamodel is a model of the formal language used to create models (a model of models).

3. A meta-metamodel is a language that describes metamodels. The most common languages for metamodeling are: MOF (Meta-Object Facility), Ecore, KM3 (Kernel Meta Meta Model), etc.

4. A four-layer metamodeling architecture is the concept that defines the different layers of abstraction (M0-M3), where the objects of reality are represented at the lowest level (M0), then the level of models (M1), the level of metamodels (M2) and the level of the meta-metamodel (M3).

5. A model transformation is the automatic generation of a target model from a source model with the accordance of a set of transformation rules [9]. In this case, each transformation rule describes the correspondence between the elements of a source and a target metamodels.

A more detailed description of these concepts can be found in [10].

Currently, there are some ways to implement the model transformation:

- using graph grammars (graph rewriting) (e.g., VIsual Automated model TRAnsformations (VIATRA2) [11], Graph REwriting And Transformation (GReAT) [12], etc.);
- using visual design of transformation rules and category theory (e.g., Henshin [13]);
- using transformation standards (e.g., Query/View/Transformation [14]);
- using hybrid (declarative-imperative) approach for specifying and constructing transformation rules (e.g., ATLAS Transformation Language [15]);
- using declarative and procedural programming languages [16];
- using languages for transforming XML documents (e.g., eXtensible Stylesheet Language Transformations [17], etc.).

However, programmers who use the special model transformation languages should:

- know the specific syntax of the model transformation language;
- be able to describe transformation rules with the aid of the model transformation language;
- know the additional languages, such as an Object Constraint Language [18] that can be used to construct the transformation rules;
- be able to describe metamodels for the source and target languages (to support the transformation process).

It should be noted that all model transformation languages are supported by specific software tools, which, in turn don't provide an opportunity to visualize the development process, i.e. the transformation rules are defined in special text editors focused on programmers. The combination of these factors complicates the use of these languages and tools in a practical way by end-users (e.g., domain experts, knowledge engineers, analysts, etc.), in particular, when developing KBs and ESs on the basis of conceptual models. So, in practice developers prefer 'ad-hoc' solutions for particular tasks with the use of declarative and procedural programming languages.

The following MDD initiatives are best known today:

- The Eclipse Modeling Framework (EMF) is an Eclipse-based modeling framework and a code generation facility for building tools and other applications based on a structured data model. EMF provides the foundation for interoperability with other EMF-based tools and applications. The heart of EMF is Ecore. Ecore is a special language for description of meta-models (implementation of an OMG's Essential Meta-Object Facility, EMOF). The basic tools to work with meta-models and a skeletal code generation of software (programming skeletons) are EMF.Core, EMF.Edit, EMF.Codegen.
- The Model-Integrated Computing (MIC) has been developed over two decades at ISIS, Vanderbilt University for building a wide range of software systems. MIC focuses on the formal representation, composition, analysis, and manipulation of models during the design process. It places some models in the center of the entire system life-cycle, including specification, design, development, verification, integration, and maintenance. MIC provides three core elements: the technology for the specification and use of the domain-specific modeling languages (DSML); a fully integrated metaprogrammable MIC tool suite, and an open integration framework to support formal analysis tools, verification techniques and model transformations in the development process; the three-level representation of the system development process (Application Level, Model-Integrated Program Synthesis Level, Meta-Level).
- The Model-Driven Architecture (MDA) is a registered trademark of the Object Management Group (OMG). The main idea of this approach is to build an abstract meta-model for the management and exchange of metadata (models) and setting the ways of their transformation into a software-supported technology (Java, CORBA, XML, etc.). MDA specifies three default viewpoints on software: computation independent, platform independent and platform specific. The viewpoint is an abstraction technique for focusing on a particular set of concerns within a system while dismissing all irrelevant

details. The viewpoint can be represented via one or more models.

In the context of the development of rule-based KBs, the MDA as the most standardized version (initiative) of the MDD was selected in the form of the primary approach.

III. The Personal Knowledge Base Designer

The PKBD is a research platform based on the universal rule-based knowledge base editor designed for the end-users.

This platform provides the creation of domain-specific editors for knowledge bases by means of an implementation of the main principles of the Model Driven-Architecture (MDA) [19] (a separate direction within the MDD). The MDA assumes a clear definition of three levels (viewpoints) of the software representation:

- a computation-independent level that describes the basic concepts and relationships of the subject domain expressed in the form of ontologies. Models of this level can be form automatically on the basis of the analysis of XML-like formats [20], in particular: XMI (XML Metadata Interchange) for UML class diagrams, CXL (Concept Mapping Extensible Language) for concept maps, ETXL (Event Tree Mapping Extensible Language) for event trees;

- a platform-independent level that represents the subject domain model in the context of the knowledge representation formalism used, in particular, a logical rules formalism. The PKBD provides a mean for visual modeling – the Rule Visual Modeling Language (RVML) based on the UML [21];

- a platform-dependent level that represents a formalized description of knowledge bases taking into account the features of a certain software platform. The PKBD currently supports CLIPS.

The architecture of the PKBD includes the main modules for: knowledge base management, for knowledge representation languages support, dictionaries management, integration with CASE-tools, interpretation of models and the graphical user interface (GUI) generation.

The interface is generated both in the form of pop-up windows and wizards.

Wizards represent sequences of GUI forms, which segment and order the processes of entering and editing elements of the knowledge base. In particular, the user is consistently asked to specify: the name of the template (used for display in the editor), the short name (used in the process of inference), the description and the properties (slots) of the template when entering it; the property name, its short name, description, a type (string, symbol or number), a possible default value and a constrain for this value (more, less, equal, unequal) when entering a slot.

The similar wizards are used when entering and editing facts and rules.

Let's consider the process of configuring the PKBD for designing rule-based knowledge bases in the field of a prognosis of technical conditions and an operation life for technical objects in petrochemical industry.

IV. The Domain-Specific Editor

The main difference between the DSE and the universal one (based on the PKBD platform) is the use of a semantic layer in the form of a structure of a platform-independent model (a set of templates for facts and rules). In this case, each fact template describes a certain concept of the subject domain and is considered as an analog of the concepts of the "prototype frame" or "sample frame" from the knowledge representation frame model [5].

The rule template describes the cause-effect relationship between the concepts in the following form:

```
IF template_1 AND template_2 AND … AND template_N THEN template_M.
```

The specialized configuration files are used to represent and store templates (Tables 1 and 2). The special PKBD module interprets these files and generates the elements of the knowledge acquisition system and the graphical user interface (GUI), which provide the interaction of experts with the DSE in terms of a subject domain. The configuration files are created by a knowledge engineer (an administrator) once before the DSE is transferred to the end-user who can add new fact and rules (concrete instances of concepts and relationships), but can't change templates (the concepts).

So, the DSE has the role-based mechanism to control the access to functions. There are two main user roles:

- A knowledge engineer (an administrator) configures the editor and changes templates. This role requires in-deep knowledge of the problem area.
- An expert (a subject domain specialist) inputs of rules and facts without the possibility of making changes to the templates.

The DSE provides following main functions:

- managing knowledge bases, including:
  - open, load and save the knowledge bases;
  - create, delete and edit the elements of knowledge bases (facts and rules);
  - import and export information from conceptual models (XMI, CXL and ETXL formats);
  - preview of the knowledge base elements using the RVML [21];
  - generate knowledge bases codes for the target programming language, in particular, CLIPS, including description of slots, templates, facts and rules.
- managing dictionaries (add and remove the concepts to directories with the purpose to improve the efficiency of entering facts and rules);

TABLE I. THE STRUCTURE OF A CONFIGURATION FILE FOR FACT TEMPLATES

File element	*Description*	*Example*
[**Metadata**]	The file title.	**[Metadata]**
;description	The template description.	;Exist damage
tempale_name=<template name>	The template name, this field is used for the generation of GUI and peogramm codes.	tempale_name=Damage
edited_by_user=<No|Yes>	The instruction for the GUI generator. This field determines the ability to edit the generated forms by the end-user.	edited_by_user=No
[**Fields**]	The section title for the template slots description.	**[Fields]**
<slot_name>=<datatype>	Each line is a slot description, where <slot_name> is the internal name used to generate the GUI forms and CLIPS codes; <datatype> = string | integer | float | <name_of_the_variable_from_the_values_list>, where < name_of_ the_variable_from_the_values_list > = <value>; ...; <value> - is defined in the "**Values**" section.	dam-type=string dam-orientation=val3:1
[**Captions**]	The section title for the template slots captions. These captions are displayed on the GUI forms and used for the multilanguage support.	**[Captions]**
<slot_name> = <name>	Each line is a slot description.	form=Exist damage dam-type=Type of the damage
[**Values**]	The section title for the passible values of slots.	[**Values**]
<value_name> = <value_1>,…,<value_N>	Each line is a description of the passible values of slots.	Val3:1=LONGITUDINAL, CROSS-SECTION

TABLE II. THE STRUCTURE OF A CONFIGURATION FILE FOR RULE TEMPLATES

File element	*Description*	*Example*
[Generalized rules]	The file title.	**[Generalized rules]**
#<Name of the process>	The name of the degradation or the dangerouse process that is described by the the rules. This name will be displayed on the screen.	#Corrosion cracking
##<Name of the process modification>	The name of the process modification (the sub-process). This name will be displayed on the screen.	##1
<rule_name> = <title> : <template names from the rule conditions> : <template names from the rule actions>	<rule_name> - the name of the rule for GUI and CLIPS codes generators, <title> - the name of the rule that will be displaed on the GUI forms, <template names from the rule conditions> = <template_name>, …, <template_name>.	fail-mechanism-fail-ky=Rule_for defenition_of_the_failure_mechanism: exist-meh-des,exist-des:exist-meh-fail

- testing the knowledge bases:
  - select the inference machines in the form of dynamic link libraries;
  - logical inference with the aid of libraries selected;
  - description of the decision making process in the form of a chain of activated rules;
- building reports for:
  - description of the knowledge bases;
  - description of the logical inference results.

The process of DSE configuring includes the following steps:

1. Creation of the semantic layer in the form of the platform-independent model, including:

- conceptualization and formalization of the main concepts and relationships;
- designing templates for describing logical rules.

2. Testing and verification of the knowledge base designed and the DSE obtained.

The DES supports the knowledge base engineering for the end-users in accordance with the features of the problem of the prognosis of technical conditions and an remaining operation time. Thus, we analyze failure cases of the equipment in petrochemistry [22] and industry expertise [23]. The main results of this step are the concepts (for fact templates) and relationships between concepts (for rule templates).

In particular, it is defined that the basic concept of the subject domain is the "undesirable process" concept [24] (fig. 1).

The undesirable process [24] is a set of physical-chemical processes resulted from various technological processes, imperfections and infringements of a constructive, industrial and operational origin.

The following fact templates are defined on the basis of the structure of the "undesirable process" concept (fig. 1): the "material" template includes the material name and it's technological (e.g., residual stresses, constructive heredity, etc.) and metallurgical (e.g., manufacturing defects, etc.) heredity; the "mechanical loadings" template includes description of the static, variable, dynamic and temperature loadings, etc. Next, the template configuration files are generated on the basis of templates obtained.

The dynamics of the undesirable process can be represented in the form of a cause-effect chain of classes of technical conditions: initial defectiveness, damage, destruction, failure. The cause-effect chain of classes defines of the sequence of the steps of degradation process description, which, in turn, stored in configuration files.

So, the platform-independent model consists on such and similar templates and describes the sequence of the

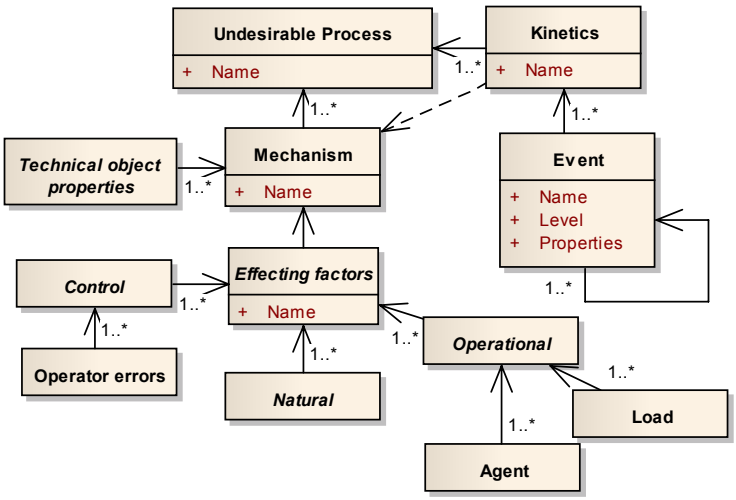

Figure 2. The "undesirable process" concept

technical condition classes or steps of the certain process, where each class/step are defined by a mechanism and kinetics. The mechanism is a set of the effecting factors and properties of the technical object. The technical object is an owner of the process. Kinetics is a set of sequences of events of the process.

Let's present some examples of the sequence of the steps for the description of the "corrosion cracking" degradation process (fig. 2), a rule template configuration file and GUI forms of the DSE (fig. 3) [20]:

```
[Generalized rules]
#Corrosion cracking
##1
dam-mechanism-dam-ky= Rule_for defenition_
of_the_damage_ mechanism:material,structural-
heredity,making-defects,mechanical-stress-
const,thermal-stress,technological-
environment,heat-exchange-technological-
environment,flow-technological-
environment,surface-damage-from-corrosive-
environment:exist-meh-dam
dam-damage-
ky=Rule_for_defenition_of_damages:exist-meh-
dam:exist-dam
des-mechanism-des-
ky=Rule_for_defenition_of_the_desctruction_mecha
nism:exist-meh-dam,exist-dam:exist-meh-des
des-destruction-ky=
Rule_for_defenition_of_the_desctructions:exist-
meh-des:exist-des
…
```

The user can preview the knowledge-base elements in the form of RVML schemes (fig. 4) [20], which are corresponded to CLIPS codes. The CLIPS codes obtained may be used further in external systems.

V. CONLUSION

The effective knowledge base engineering requires the development and the use of the specialized software, in particular, in the form of domain-specific editors (DSE).

In this paper we describe the configuration and application of the DSE on the basis of the PKBD platform. The DSE developed uses the main principles of the MDD, in particular, it provides creating and interpreting the platform-independent models for the certain subject

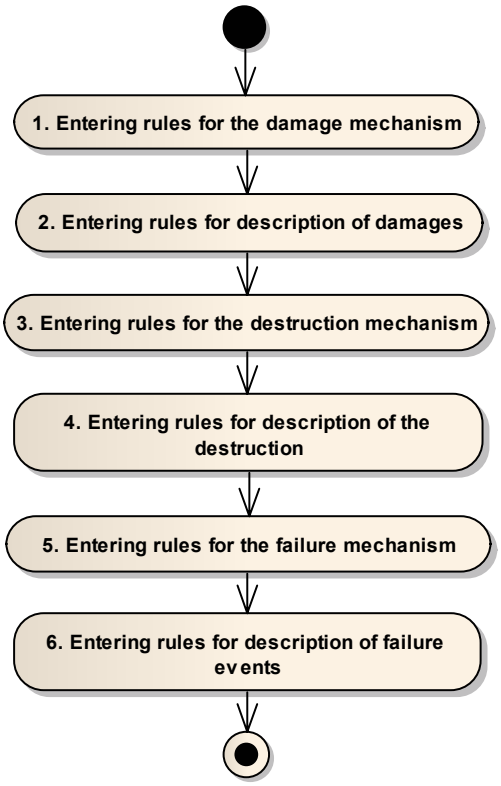

Figure 1. The sequence of the steps for the description of the "corrosion cracking" degradation process

domain. The problem of prognosis of technical conditions and the remaining operation time of petrochemical equipments is used as a case study.

The DSE was used for the development of the knowledge base for defining the causes of damage and destruction of construction materials [23], and they were also used in the educational process at the Irkutsk National Research Technical University (IrNRTU).

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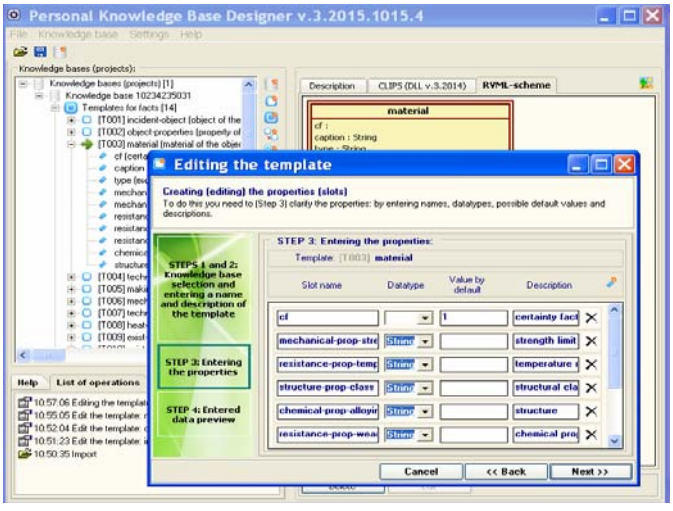

Figure 3. The example of DSE GUI forms

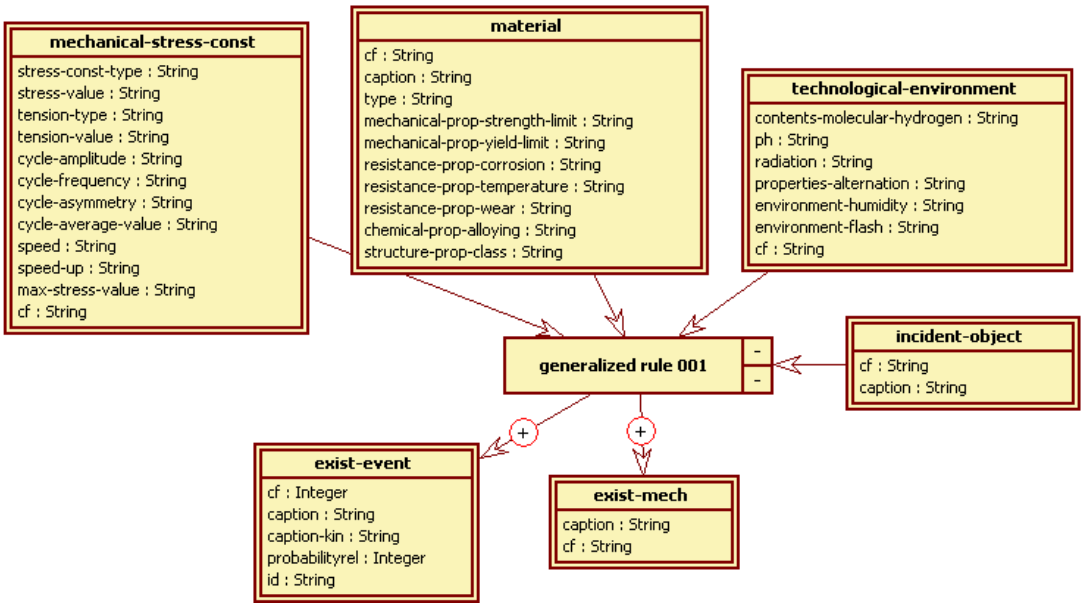

Figure 4. An example of the RVML scheme for a rule

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Fishbone Diagrams for the Development of Knowledge Bases

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***Abstract* - The paper describes an approach for the automated development of rule-based knowledge bases by transforming fishbone diagrams. The approach is based on the identification and extraction of structural cause-effect elements of fishbone diagrams and their transformation into the elements of a target knowledge representation language, in particular, C Language Integrated Production System (CLIPS). The source metamodel of fishbone diagrams, the target metamodel for a unified representation of rules (a model for representation logical rules), transformation operators and a transformation technique are presented. An illustrative example describes the development of a rule-based knowledge base for diagnosing and forecasting the states of complex technical systems based on the approach proposed.**

Keywords – knowledge acquisition; knowledge base; rules; fishbone diagrams; model transformation, code generation; CLIPS

I. INTRODUCTION

Currently, the development of new approaches and tools for the automated creation of domain-specific intelligent systems remains a relevant topic of scientific research [1-5]. It should be noted that such domain-specific systems use heterogeneous structural information that requires the application of adequate processing methods, in particular, expert systems designed to process a poorly- and semi-structured knowledge.

The main element of expert systems is a knowledge base (KB). The KB development process includes the stages of acquisition, structuring, formalization and codification of expert knowledge, which traditionally are considered as a "bottleneck" of the intelligent systems engineering [6, 7]. In recent years there is a trend to automate these stages by the means of visual (cognitive) modeling. The main results of this modeling are visual conceptual models (e.g., concept maps or mind maps, etc.), which have a high cognitive power and ability to describe the regularities of a subject domain. This trend is confirmed by examples [8-10].

Today, there are many different languages and standards for representing the conceptual models. For example, UML, IDEF, DFD and others are widely used for information systems designing. There are also domain-specific means addressing the features of knowledge representation models (e.g., RVML [11], XTT2 [12], etc.). However, domain experts prefer to use models that take into account the features of the subject domain problems and have a system-wide focus. It should be noted that most of the tools for designing such models considering these models only as graphic artifacts (primitives) ie. there is no possibility to generate program codes, specifications or software components.

In this paper we propose the approach for the automated development of rule-based knowledge bases by transforming fishbone diagrams [13]. These models describe the dynamics of degradation processes (DP) and processes of violation of technogenic safety (fire, explosion and other dangerous processes) in petrochemistry. In this case, the transformation is the process of an automatic generation of a target KB from a source model according to a set of transformation rules. Transformation rules describe how one or more constructs of the source language can be transformed into one or more constructs in a target knowledge representation language (KRL).

The C Language Integrated Production System (CLIPS) [14] is selected as the target KRL. CLIPS is one of the most widely used means for rule-based expert systems developing.

II. THE PROBLEM STATEMENT

The approach proposed provides to automate the stages of knowledge formalization and codification by the generation the rule-based KB codes in the CLIPS format on the basis of the fishbone diagram analysis. In turn, the fishbone diagrams analyzed are the results of the stages of acquisition and structuring (conceptualization).

Let's formalize the problem statement as follows:

$$T : CM^{FD} \rightarrow KB, \quad (1)$$

where CM^{FD} is a source conceptual model in the form of a fishbone diagram; KB is a target KB in the form of CLIPS codes, $KB = \left\langle Code^{CLIPS} \right\rangle$.

Thus, it is necessary to define a set of transformation rules (T) in the context of designing rule-based KBs and implement them in the form of a special tool (transformation module).

The previously developed technology [15] that was implemented in the form of a web-based program system – Knowledge Base Development System (KBDS) [16] was used. This technology supports the creation of software components (transformation modules) designed for converting the source conceptual models (represented in XML-like formats) into the KB codes of the target KRL (in particular, CLIPS).

III. FISHBONE DIAGRAMS

The fishbone diagrams (also called Ishikawa diagrams or "fish skeletons") are cause-and-effect diagrams that represent the graphical ordering of factors effecting the object. These diagrams are useful for extracting and visualizing knowledge about the mechanisms of different processes. Figure 1 shows the meta-model of the fishbone diagrams.

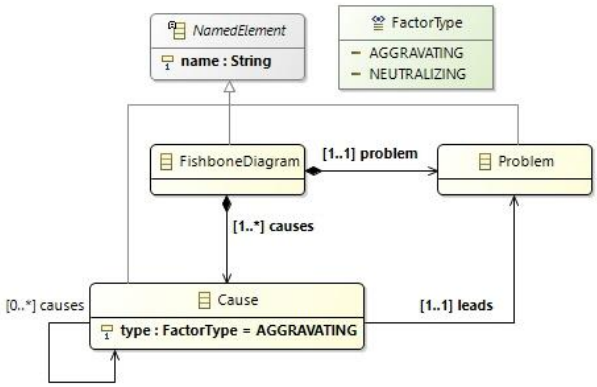

Figure 1. The meta-model of fishbone diagrams

The "fishbone head" of the diagram is the problem under investigation. The "fishbone spine" is depicted as a direct horizontal arrow. The "bones" represent causes and factors directly and indirectly effecting the considered problem and they are depicted by inclined arrows. The arrows of the effecting factors of the second on other levels can be added to the main arrows of cause categories. At the same time, different factors can both aggravate and neutralize the problem. Traditionally the "brainstorming" method is used to identify and form the possible main cause categories and their details (offshoots of "bones"). In fact, this method provides the generation of creative ideas by a group (team) of experts.

In the case of the problem of the definition of mechanisms of degradation or dangerous process we propose to specialize the fishbone diagram and develop a specific diagram template that includes the main cause categories (the first level of "bones"). This fishbone diagram template is shown in Figure 2. Only three levels of "bones" are sufficient to determine the mechanism of different DP types. So, the subject domain experts need to specify this diagram template. After that, it is possible to generate automatically a rule draft that describes the mechanism. If necessary this draft can be completed with the corresponding logical relationships (e.g., "AND" or "OR"):

IF (Technical_object_property$_1$ **AND** … **AND** Technical_object_property$_n$) $\circ$ (Operational_factor$_1$ **AND** … **AND** Operational_factor$_n$)

THEN Mechanism **AND** (Event$_1$ $\circ$ Even$_n$), where $\circ$ is a logical operation $\circ \in \{\wedge, \vee, \oplus\}$.

Also it is suggested to associate a certainty factor (CF) with each possible specific cause (the second level of "bones"). The CF value reflects the subjective degree of the expert's confidence about the effect of this specific cause on the problem occurrence. The calculated CF value depends on the corresponding aggravating and/or neutralizing factors (the third level of "bones"). At the same time, aggravating and neutralizing factors can be expressed by a concrete value (a "name-value" bundle).

The abstract syntax of the fishbone diagram for describing the DP mechanism is shown in Figure 4. The metamodel proposed corresponds to the meta-metamodel Ecore and it is further used as the initial metamodel for the development of transformation rules (transformation models), which are describe the correspondence between the elements of the initial metamodel and the target metamodel of the rule-based KB.

IV. KNOWLEDGE BASE DEVELOPMENT SYSTEM

The KBDS implements the approach to the development of software components (modules) for the program code generation for KBs based on conceptual models presented in the XML format (the most common format for the exchange and storage of the different conceptual models).

The main purposes of the developed software are:

- the support of the development of software components for the program code generation for KBs based on different conceptual models;
- the support of the development of KBs (with the use of the developed software components).

Further we present the main functions and the architecture of KBDS in detail.

The main functions of KBDS in the context of the development of the software components are the following:

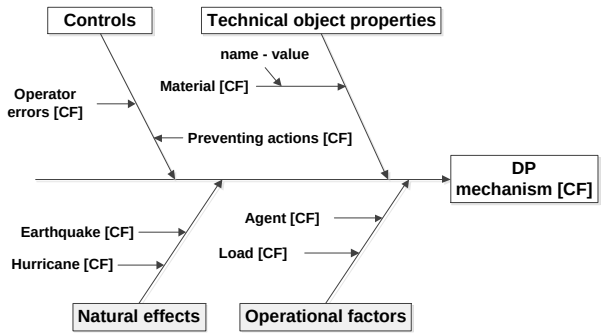

Figure 2. The fishbone diagram template with main cause categories of degradation processes

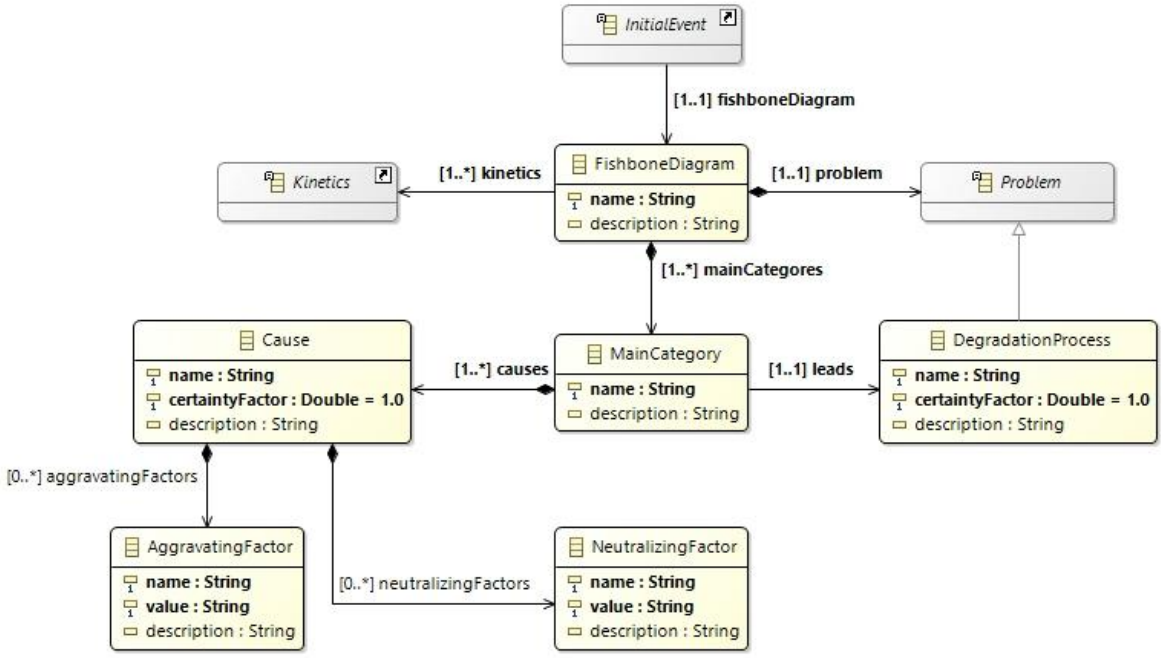

Figure 3. A metamodel of the fishbone diagram for determining the mechanism of the DP

- the creation (import) of a meta-model of the source conceptual model on the basis on the XML schema (XSD) of this model, or by analyzing the model (Reverse Engineering);
- the visual representation and modification of the obtained meta-models;
- the visual design of a transformation model (in the form of a set of rules for transforming the elements of the source model to the elements of the target model) and the automatic TMRL (Transformation Model Representation Language) [15] code generation;
- the generation (assembling) of the software component based on the developed transformation model and the analyzer and generator units selected (depends on the type of the software component).

The KBDS provides the following main functions for the design of the KBs:

- the code generation for KBs on the targeted knowledge base programming language (CLIPS or OWL) using the software components developed;
- the automated synthesis of an ontological and a rule-based model (the internal representation of knowledge in the KBDS) based on the analysis of conceptual models;
- the storage and representation of obtained knowledge with the use of these models;
- the use of the special graphic notation - Rule Visual Modeling Language (RVML) [11] for the representation and modeling the logical rules;
- the visual representation and modeling knowledge in the form of ontological model.

The KBDS has the client-server architecture that implements the main factions.

The client part of the KBDS includes the following main modules:

- the RVML editor that provides a visual representation and editing the logical rules with the aid of RVML;
- the ontology editor that provides a visual representation and editing knowledge in the form of a graph (ontological model);
- the meta-model editor that provides a visual representation and editing the meta-model elements;
- the transformation model editor that provides a visual representation and editing the transformation rules.

The server part of the KBDS includes the following main modules:

- the administration module that provides an user interaction with the KBDS (the limitation of user rights, the collection and analysis of various statistical information, etc.);
- the knowledge bases management module that provides a creation and managing KB projects;
- the meta-level management module that provides an internal representation of knowledge in the KBDS in the form of the rule-based and ontological models. These models allow us to abstract form the features in elements descriptions of various knowledge representation languages which are used in the implementation of KBs (for example, CLIPS, Jess, Drools, RuleML, OWL,

SWRL, etc.) and to store knowledge in own independent format;

- the software components development module that provides the creation and managing software component projects, as well as code generation of the software components based on the developed transformation model and the analyzer and generator units selected;
- software components that provide a synthesis of the KB model (ontological or rule-based models) based on the analysis of conceptual models and a program code generation for a KB (CLIPS or OWL) based on the analysis of the KB model or the source conceptual model.

The prototype is implemented using: PHP, Yii2 Framework and JQuery, jsPlumb libraries. The PostgreSQL was used as the data base management system.

V. Transformation Model Representation Language (TMRL)

The TMRL [15] grammar belongs to the class of context-free grammars (CF-grammars, for example - LL (1)). The TMRL constructs allow one to describe the elements of the transformation model in a declarative form, in particular, the rules for the correspondence of metamodel elements, as well as the mechanism of interaction with previously developed (external) software components for the transformations. TMRL specifications meet the requirements of accuracy, clarity and completeness, ie. the specifications for TMRL contain all the necessary information (for the considered transformations) to solve the task, all objects of the model are well formalized, while the specifications are compact enough and at the same time understandable (readable). TMRL contains 15 special elements (lexemes), which are used to describe the source and target meta-models.

The main difference between TMRL and existing models transformation languages is its ease of use, achieved through a limited set of elements. TMRL is not an extension of other languages and does not use the constructions of other languages, as other transformation languages very often do, in particular, ATL uses the OCL

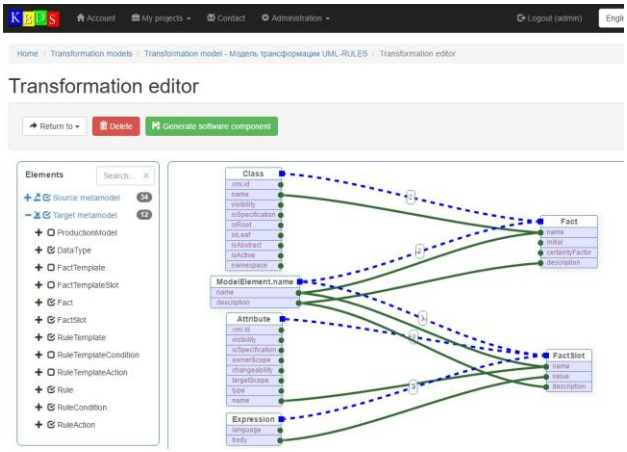

Figure 4. The editor for TMRL visual programming

[17]. In addition, TMRL has human-readable syntax for the purpose of making the necessary modifications to the model of the transformation manually, if necessary. An additional feature of TMRL is the ability to describe interaction with previously developed software components of the transformation in support of the import of different formats of conceptual models.

The TMRL programs are created in the special editor for visual programming (it is a subsystem of the KBDS) (Fig. 4).

VI. The Transformation Model

Let's define the transformation operator (T) from (1):

$$T = \langle T_{CM-RM}, T_{RM-KB} \rangle, \quad (2)$$

$$T_{CM-RM} : M^{FD}_{XML} \rightarrow M^{PR},$$
$$T_{RM-KB} : M^{PR} \rightarrow Code^{CLIPS},$$

where T_{CM-RM} is a set of rules for transformation of the source fishbone diagram into the model of logical rules; T_{RM-KB} is a set of rules fro transformation of the model of logical rules into the KB code in CLIPS; M^{FD}_{XML} is a model of fishbone diagrams in the XML-like format (in our case the Fishbone Diagram Mapping Extensible Language (FDXL) is used); M^{PR} is a model for the representation of gained knowledge in the form of logical rules. This model doesn't depend on the used KRL (e.g., CLIPS, Jess, Drools, RuleML, etc.) and contains only general constructions inherent in all rule-based KRL; $Code^{CLIPS}$ is a target KB code in CLIPS.

The transformations from (2) are carried out at the abstract level of metamodels. For this purpose it is necessary to define:

- the transformation rules for T_{CM-RM} ie. between the elements of the metamodels of the fishbone diagram and the model of logical rules;

- the transformation rules for T_{RM-KB} ie. between the

TABLE I. The Elements Correspondences

Fishbone diagrams (FDXL)	Logical rules	CLIPS
FishboneDiagram	FactRule (шаблон правила)	defrule
Effect	FactTemplate / Action	deftemplate
Effect (certaintyFactor)	Fact / Action(certaintyFactor)	-
Cause (certaintyFactor)	Rule(certaintyFactor)	-
AggravatingFactor	FactTemplate / Condition	deftemplate / defrule
AggravatingFactor (name)	Slot	Slot
NeutralizingFactor	FactTemplate / Condition	deftemplate / defrule

elements of the metamodel of logical rules and CLIPS constructions.

The transformation rules for T_{CM-RM} and T_{RM-KB} form a transformation model (scenario) in terms of the domain-specific declarative language – Transformation Model Representation Language (TMRL) [15].

Examples of compliance between the main elements of the fishbone diagrams, a logical rules model and CLIPS are presented in Table 1.

VII. TRANSFORMATIONS OF FISHBONE DIAGRAMS

The technique for transformations of fishbone diagrams into the KB code with the use of the KBDS consists of the following main steps:

Step 1: specifying the fishbone diagram templates by means of various software (domain-specific editors or general editors, for example, Microsoft Visio and etc.). At this step the subject domain expert defines the cause-and-effect information about mechanisms of degradation or dangerous process.

Step 2: storing the designed diagrams in the XML-like format, for example, FDXL.

Step 3: analysis of the obtained XML documents of fishbone diagrams with the KBDS [16]. The results of this step are the model elements and their relationships corresponding to the transformation model.

Step 4: generating the model for the logical rules representation based on the extracted diagram elements. This model is stored in the KBDS.

Step 5: visualization, modification and verification of rules obtained with a special graphical editor that is a part of the KBDS. The original author's notation – Rule Visual Modeling Language (RVML) is used to improve the visibility of represented rules. RVML provides:

- to use special graphic primitives to represent the elements of logical rules;
- to assign the subjective probabilities in the form of the CFs for facts and rules;
- to show the type of actions for a logical rule (assert, modify, retract).
- to show the logical operators in the rule conditions (e.g., "AND", "OR" and "NOT").

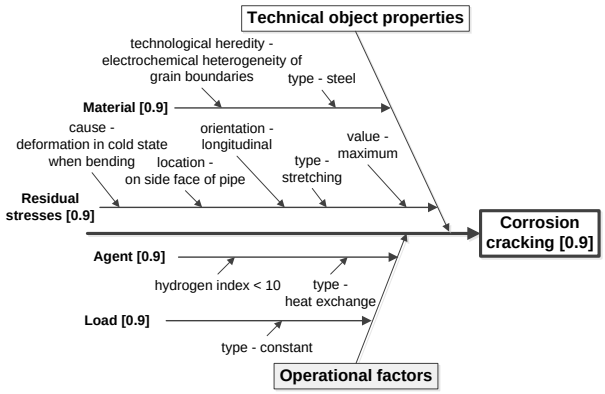

Figure 5. The fishbone diagram fragment of "corrosion cracking" at the damage stage

Step 6: automatic generation of KB codes in the CLIPS format based on the model modified.

VIII. AN ILLUSTRATIVE EXAMPLE

Let's consider an illustrative example of application of the approach proposed for the automated development of a rule-based KB by transforming the fishbone diagrams. These diagrams describe the "corrosion cracking" DP mechanism at the damage stage (Fig. 5).

The following FDXL fragment corresponds to the fishbone diagram (Fig. 5):

```
<FishboneDiagram name="Mechanism of a degradation process" description="Fishbone diagram for description of a mechanism of a degradation process ">
<MainCategory id="MC-1" name="Operational factors" description="Main category of causes">
<Cause id="C-1" name="Load" certainty-factor="0,9" description="Root factor">
<AggravatingFactor id="AF-1" name="type" value="constant" description=""/>
</Cause>
<Cause id="C-2" name="Agent" certainty-factor="0,9" description="Root factor">
<AggravatingFactor id="AF-2" name="type" value="heat exchange" description=""/>
<AggravatingFactor id="AF-3" name="hydrogen index" value="< 10" description=""/>
</Cause>
</MainCategory>
<MainCategory id="MC-2" name="Technical object properties" description="Main category of causes">
<Cause id="C-3" name="Material" certainty-factor="0,9" description="Root factor">
<AggravatingFactor id="AF-4" name="type" value="steel" description=""/>
<AggravatingFactor id="AF-5" name="technological heredity" value="electrochemical heterogeneity of grain boundaries" description=""/>
</Cause>
<Cause id="C-4" name="Residual stresses" certainty-factor="0,9" description="Root factor">
<AggravatingFactor id="AF-6" name="value" value="maximum" description=""/>
<AggravatingFactor id="AF-7" name="type" value="stretching" description=""/>
<AggravatingFactor id="AF-8" name="orientation" value="longitudinal" description=""/>
<AggravatingFactor id="AF-9" name="location" value="on side face of pipe" description=""/>
<AggravatingFactor id="AF-10" name="cause" value="deformation in cold state when bending" description=""/>
</Cause>
</MainCategory>
<Effect id="DP-1" name="Corrosion cracking" certainty-factor="0,9" description="Degradation process is a corrosion cracking (a damage stage)"/>
</FishboneDiagram>
```

The extracted fishbone diagram elements are used to generate rules templates, which can be represented in the RVML notation (Fig. 6). Further, the templates are modified and used to create specific rules.

The following CLIPS code corresponds to the analyzed FDXL document:

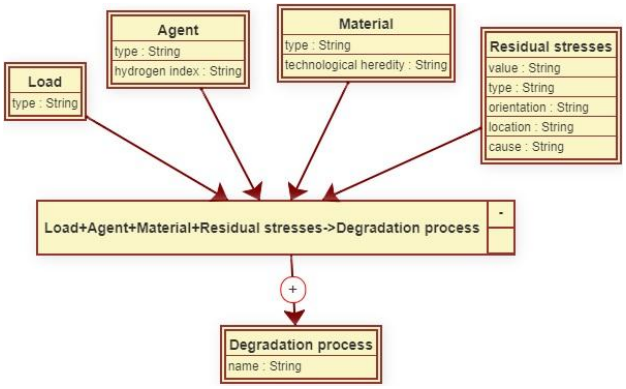

Figure 6. An example of a rule template in RVML

```
   (defrule Material+Load+Residual_stresses+Agent -
>Degradation_process
        (declare (salience 1))
        (Material (type "steel")
                  (technological_heredity
   "electrochemical heterogeneity of grain
   boundaries") )
        (Load (type "constant") )
        (Residual_stresses (value "maximum")
           (type "stretching")
           (orientation "longitudinal")
           (location "on side face of pipe")
           (cause "deformation in cold state when
bending")  )
        (Agent (type "heat exchange")
               (hydrogen_index "<10") )
        =>
        (assert (Degradation_process
                  (name "Corrosion cracking") )
        ) )
```

IX. Conclusion

The paper describes the approach for the automated development of rule-based KBs for diagnosing and forecasting the states of complex technical systems, in particular, for definition of the mechanisms of degradation and dangerous processes.

The approach is based on the analysis of structural cause-effect elements of fishbone diagrams describing the mechanism of DPs and their transformations into the target KRL elements (CLIPS). This approach helps to reduce the time for the KB development and to avoid programming errors at the stage of knowledge formalization due to the automatic KB code generation. The approach also provides the ability for the subject domain experts to be involved in the development of domain-specific intelligent systems at the codification stage by means of the generation of program codes on the basis of subject domain models.

The proposed approach implements the technology [15] and the KBDS platform [16], and is used to prototype the KBs for the industrial safety review support [18].

Acknowledgment

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An approach to route underwater mobile robots under continuous squad rotation

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Abstract - Multiple cooperative vehicle systems hold great promise for use in large-scale oceanographic operations due to ability of high-resolution surveying in both time and space. Multi-objective missions of long-duration require underwater robots to recharge their batteries periodically by docking to the specialized underwater bases (resurfacing in case of solar batteries). Furthermore, it should be taken into account, that the real world underwater vehicle systems are partially self-contained and could be subjected to any malfunctions and unforeseen events. Thus, it is a problem of considerable practical interest to effectively route the group of vehicles under continuous rotation. We propose a dynamic rendezvous point-selection scheme based on pre-estimated vehicle rotation cycle and an evolutionary path planner to route the group of robots ensuring well-timed accomplishment of all tasks and simultaneous arrival of vehicles at their selected rendezvous destination.

I. INTRODUCTION

Autonomous Underwater Vehicles (AUVs) have proven their efficiency in implementing such underwater works as seabed mapping, inspection and survey, sampling and monitoring, searching and deactivating mines, etc. These underwater mobile robots are capable of carrying out large-scale underwater missions of long duration at lower costs comparing manned vessels. Currently, the state of the art in mission planning is dominated by single AUV operations using preplanned trajectories [1]. Obviously, a single AUV is not able to meet all specified tasks in a single mission with limited time and energy. In this regard, multiple cooperative vehicle systems hold great promise for use in large-scale oceanographic operations due to ability of high-resolution surveying in both time and space.

Autonomous cooperative operation of AUVs in a vast and dynamic underwater environment is a complicated process: a number of different underwater works should be collaboratively and efficiently accomplished under specific requirements and environmental changes. Thus, the effective coordination of AUVs network is crucial for the likelihood of the mission success. As a result, the middle level of the group control system that is responsible for the allocating tasks between robots and both route- and path- planning is coming to the fore. Development of such self-controlled systems tightly depends on the design of robust mission-motion planning and task allocation scheme [2].

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In general, the problem of task allocation and path planning is vehicle routing problem (VRP) under specific spatio-temporal constraints imposed by the uncertain dynamic nature of water environment and by inaccuracy of the measuring devices. In many real cases, like patrolling and guarding, taking samples and measurements, etc., certain underwater tasks require not the single but the series of periodic attendances by AUVs. In this context, multi-objective underwater operations could be classified as either exploration or monitoring missions. Exploration missions relate to a wide range of different tasks, each of which demands single accomplishment. Monitoring missions, inversely, include underwater tasks that require continuous and regular inspections by AUVs at scheduled intervals. In both cases, different tasks may involve additional conditions and requirements (temporal, equipment, quantitative, etc.). Between two suggested mission types, the latter is of greater scientific interest since it combines both complex temporal and spatial constraints.

In addition to all constraints, it should be taken into account, that the real world underwater vehicle systems are partially self-contained and could be subjected to any malfunctions, environmental changes and unforeseen events. Necessity for AUVs battery recharging during the long-term missions make routing problem even more challenging: firstly, it causes periodic changes in the group compositions resulting in necessity of regular strategy adjustments; secondly, it causes necessity of regular rendezvous of all currently working vehicles at a specified location for the purpose of data exchange and vehicle recharging, maintenance, or collection [3]. Despite the fact, that frequent rendezvous allow AUVs keeping up with all essential changes, they also significantly distract vehicles from well-timed accomplishment of mission tasks. Inter-vehicle communication is also a critical aspect of effective cooperation and must not be trivialized [4].

In this paper, we propose two-level approach to solve the AUVs group routing problem under the high dynamic conditions for the multi-objective monitoring missions of long duration. The first level employ simple genetic algorithm to dynamically select AUVs rendezvous points according to expected vehicle rotation cycle. With consideration of group composition changes after each rendezvous point, second level utilizes evolutionary route planner to find trajectories for currently working squad ensuring maximal efficiency of the group work and simultaneous arrival of all vehicles at the selected rendezvous destination.

II. PROBLEM FORMULATION

In general, multi-objective monitoring missions require group of AUVs to visit and inspect (perform some underwater works) the set of tasks at scheduled intervals [4]. The routing problem here is to find a feasible group route ensuring, as far as possible, the well-timed inspection of the majority of tasks under continuous change of currently working squad due to the AUVs battery limitations and recharging needs. The problem is formally defined as follows.

Assume there is a set of tasks $N = \{1,...,n\}$ distributed over a specific operation area. These tasks are defined not only by their location in space, but also with the demanded periodicity of inspections $p_i, i \in N$ and the single-inspection accomplishment time $s_i, i \in N$, which are known in advance by AUVs. The periodicity value p_i means that the duration of the time interval between two successive inspections of i -th task must not exceed p_i . In other words, it is an upper bound on time allowed between leaving task and coming back to it. We denote by T the whole mission length and suppose that it is a big value.

The group of robots performing the mission consists of m functionally equivalent vehicles, which however may differ by their cruising speed v^k and battery capacity $b^k, k = 1,...,m$. Here we rate AUV's batteries not in energy units but as average run-time on cruising speed.

Battery limitations force vehicles to recharge at intervals by docking to the specialized underwater bases or resurfacing (in case of solar batteries). Concrete locations of the charging bases, if any, are not essential, since we only need the estimated traveling time for each vehicle to resurface/get to the nearest free recharging dock from the operation area. We assume that the number of bases/docking spaces is not limited so that there is always a free dock for a vehicle in need. We denote the average charging speed for all batteries by constant parameter $0 < c < 1$. In that case, charging time of fully empty battery with capacity of b hours will be $c \cdot b$ hours.

Assuming that different tasks are distributed over a specific water area, they can be mapped by a network in which each task is presented by a waypoint. In this way, the complication of vehicle routing in a graph-like terrain can be addressed straightforwardly [2]. Additionally, we define the waypoint V_0 for the specified rendezvous location. Let $V = N \cup V_0$ denote the set of all waypoints. Let the $\varepsilon = \{(i, j) : i, j \in V, i \neq j\}$ define the set of edges. Each edge represents the shortest traveling path between each pair of tasks. It is assumed that all paths for the initial set of tasks are pre-computed and paths for all new tasks, if any, are calculated by AUVs on-board via specialized path planner. The path length is assigned as edge weight as it can be easily translated into traveling time cost for all AUVs relying on their cruising speed. Thus, the undirected fully connected weighted network $G = (V, \varepsilon)$ represents the "roadmap" for the current mission of the group.

Before proceeding with our model development, we should note that the process of mission implementation is self-contained, i.e. all calculations are performed exclusively on AUVs board computer systems. It is obvious, that all parallelizable calculations should be distributed among accessible vehicles to achieve maximal cumulative processing power and allow fully decentralized group control. In order to achieve proper decentralization, all vehicles should possess identical data about current conditions and environment. To fulfill this requirement, robots in the squad should coordinate in a such way to periodically establish common information space when possible. Group coordination here is provided by transferring data between robots through hydro-acoustic channel. Hence, complete synchronization of actual data within the group could be achieved only if each vehicle of the group would be able to transfer data directly to each other vehicle co-instantaneously. As underwater communication is slow and limited in range, we assume that the common information space and following full data synchronization could be completed only during so-called rendezvous, when current squad simultaneously arrives at a specified location. In what follows the group routes are called *communicatively stable*, if they guarantee the ability to synchronize data regularly.

Communication stability requirement primarily arises due to the dynamic nature of real underwater missions: firstly, the inspections results alone may require modifying the current task set; secondly, the uncertainty of external environment and possibility of delays and malfunctions may lead to unexpected changes in the status of the working group. All these changes may occur in real time, making it necessary to adjust the current route (re-plan) in order to maximize the group efficiency in new conditions. Among the events that require route re-planning are:

- Adding new tasks or withdrawing the old ones;
- Changing task's required periodicity;
- Unexpected AUV loss or malfunction;
- Collecting previously lost AUVs or new ones;
- AUVs leaving the group for recharging;
- Collecting recently recharged AUVs.

It is worth noting individually, that the two latter cases should not be initially included to the list above as these events can be accurately pre-estimated according to the vehicle rotation cycle. However, since occurrence time of these events may shift due to the dynamic nature of the mission, we consider them also as the key points for mission-planning procedure alongside with other more unpredictable cases.

The effectiveness of the group as a whole is defined by maintaining the regularity of well-timed inspections of all tasks. Situations of AUVs arriving too late and delaying the inspection are undesirable and should be excluded, if possible. Thus, our objective is to develop a synchronous control architecture able to construct communicatively stable group routes providing minimum delays during continuous and regular task's inspections up to the moment of the mission's end under continuous squad rotation and high dynamic conditions.

III. TWO-LEVEL CONTROL SYSTEM

Effective mission planning for real underwater operations of AUVs group is a complicated and challenging problem, especially when it is required to respond to environmental changes and unexpected disturbances. Since, even in ideal (static and fully known) environment, high dimensional routing alone is a problem of high computational complexity, given dynamic conditions make it meaningless to build optimal solution straight for the whole mission. In this regard, we propose the following two-level control system that allows performing complex monitoring of long duration. Two levels of the proposed approach utilize dynamic mission planning strategy and task assignment (routing), correspondingly.

As long as finding new global optimal solutions with each change of conditions is impractical, prompt and accurate local planning with consideration of nearest expected changes is more essential. Therefore, the suggested upper-level mission planner is designed to the purpose of simple on-line mission decomposition that provides both communication stability and computational load reduction, while lower-level route planner is required to handle graph search constraints and carry out the task assignment.

It is obvious that, ideally, decomposition points should be associated with essential condition changes. In this case, the routing problem for each operating period (period between two consecutive decomposition points) could be regarded as static. Nevertheless, as we can predict reliably only those events among previously mentioned that relate to AUVs recharging needs, we propose following mission decomposition scheme based on the expected vehicle rotation cycle (Fig. 1).

According to this scheme, each decomposition point involves rendezvous of the currently working squad at a specified location for a purpose of sending AUVs to and receiving from the charging bases, continued by full data synchronization within the group and mission conditions adjustment if any changes has occurred. Following that, as the newly formed squad continues task's inspections until the next point of rendezvous, each vehicle in the squad computes to find the best group route for the next operating period. While doing so, the expected upcoming squad rearrangement should be taken into account: which AUVs would leave the group for recharging during next rendezvous and which would re-join. Such pre-planning would allow for a saving time and shortening the rendezvous length alongside with decentralization and distribution of calculation among vehicles. In this regard, full data alignment at the end of operating period should include exchange of the AUV's best-found solutions.

To this end, upper-level mission planner strategy is to manage mission time by scheduling AUVs group rotation cycle. As vehicles are not obliged neither to leave the squad only being completely discharged nor to always recharge up to entirely full battery (although it is preferable), we can adjust charging periods for each vehicle in order to obtain reasonable group rotation cycle. Firstly, we want to exclude as far as possible simultaneous mass charging of several vehicles since it reduces performance capability of the remaining squad. If it is found impossible, we want at least to achieve equal distribution of number of simultaneously charging vehicles (cumulative speed of simultaneously charging vehicles, to be specific) during the course of the mission. Secondly, since each rendezvous distracts vehicles from task's inspection, as it requires squad spending a significant portion of time to make it to the rendezvous location, perform all required actions and travel back, we want to minimize the rendezvous' frequency. In order to do this, we want to conjoin closely-spaced events together where possible by shifting them to the common timepoints. For example, in Fig. 1 two short-timed operating periods #4 and #6 (#5 successor) could be avoided by sending AUVs "C" and "D" to the charging bases a period earlier. Still, even with all requests considered the main requirement here is maintaining AUVs group in good working order by organizing well-timed recharging for all vehicles in need.

Upper-level mission planner should be simple, reliable and fast, as quick and effective re-planning is required each time an unexpected event occurs. Unlike to mission planning strategies, the lower-level route planner is not designed to react on environmental dynamic changes. However, as the operating field is split to smaller spaces, routing system should be capable of high-performance local group motion planning under spatiotemporal constraints. The main goal of routing here is not only to achieve punctual task's inspection for group of vehicles with different speeds, but also to ensure simultaneous group arrival at the rendezvous location by the end of operating period. It should be also considered, that task allocation problem on a single operating period should not be treated separately from the global objective, as mission timer does not pause when squad interrupts inspection in the interest of rendezvous and task's inspection would be continued immediately at the next operating period.

As both mission planning and local task allocation are essential for well-timed monitoring over operating periods, providing cooperation and synchronization between both level planners would allow ultimate control system to deal with complex requirements and restrictions, which are aimed to a more accurate simulation of real-world problems [2].

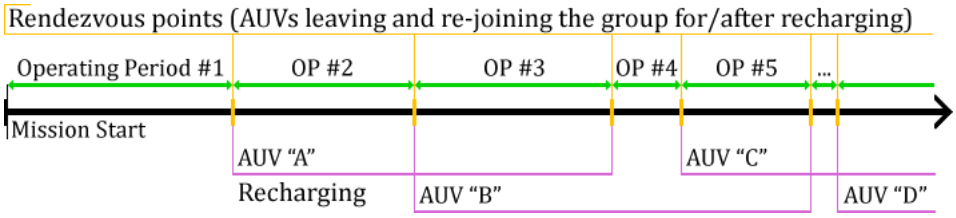

Figure 1. Mission decomposition on the basis of vehicle squad rotation

IV. MISSION PLANNER

Summarizing the above, mission planner's goal is to construct a reasonable group rotation schedule coming from AUVs recharging needs to provide maximal performance capabilities of the working squad alongside with its high condition-change responsiveness.

As mission length T is supposed to be a considerable big value, we see no rational for building schedule for the entire mission at once, since it would require periodic re-planning due to unexpected events. Hence, we define T_M as planning period that should be long enough to include at least several recharging cycles of each AUV. For the large-size planning problems, the search space discretization proves itself to be rational and efficient way to speed up both encoding of and finding the solutions. For that reason, we will consider planning period as a sequence of equal time intervals $T_M = \langle T_1, ..., T_e \rangle$, $e = T_M / T_0$, where T_0 is the duration of each interval.

In this case, single AUV schedule can be represented by e-dimensional binary vector, where x-th attribute is 0 if the vehicle is within the working squad during corresponding time interval T_x and 1 otherwise (vehicle is traveling to the base, charging, or traveling back). A single vehicle schedule is considered as feasible if none working period (continuous sequence of 0-attributes) lasts longer than vehicle's battery level at the beginning of that period. The group schedule at this point can be represented as e-by-m binary matrix $H = \{h_{ij}\}$ (Fig. 2). The objective function for the group schedule H is as follows:

$$f(H) = \sum_{i=1}^{e} \left(\left(\sum_{j=1}^{m} h_{ij} \right) \left(\sum_{j=1}^{m} h_{ij} \cdot v^j \right) \right) \qquad (1)$$

Loss function (1) evaluates the performance capability of currently charging AUVs on each interval T_i of the planning period. With the use of (1), we are trying to exclude simultaneous charging of both big number of vehicles and fastest vehicles in the group. The planning problem here is to minimize loss function $f(H) \to \min$.

A series of computational experiments has shown that even under severe constraints a large number of different solutions are able to deliver the same minimum value of the objective function (1). Because of that, we define an additional criterion which purpose is estimating the number of expected rendezvous (time intervals, where at least one vehicle is changing its status):

$$f_T(H) = \sum_{i=2}^{e} \left(1 - \prod_{j=1}^{m} (1 - |h_{ij} - h_{i-1\,j}|) \right) \qquad (2)$$

Tiebreaker-function (2) is used to determine a preferable solution among equally efficient according to (1).

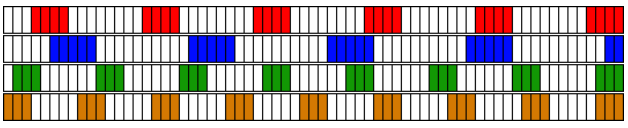

Figure 2. Rotation schedule for the group of four vehicles with different battery capacites. Colored sell represents charging periods.

V. TASK ALLOCATION AND PATH PLANNING

Operating field decomposition made by the mission planner leads to problem space reduction and reducing the computational burden, which is another reason for fast operation of the proposed approach. Limited duration of operating periods allows us to define the routing problem as follows.

The input to the group routing problem includes AUV's and task's characteristics proposed above in the "Problem Formulation" section, task's initial status inherited from the previous period, and duration of the current operating period T_p. Then, we define the route of single vehicle $r = \langle V_0, V_1(r), V_2(r), ..., V_h(r), V_0 \rangle$ as a list of task numbers in the consecutive order of their planned visits, where h is the route length. As can be seen, vehicles start each period from the rendezvous point and travels back there at the end of the period. It also should be noted that any task could be included more than once into the route of a single vehicle. The group route $R = \{r_1, ..., r_k\}$ is a set of all single AUVs routes. Thus, the routing problem is to generate the group route providing:

- Minimum delays during regular inspection of all mission tasks within the current operating period;
- Simultaneous arrival of all vehicles at the rendezvous location;
- Favorable mission conditions to be inherited by the routing problem for the next operating period.

The proposed routing problem on a single operating period has many similarities with the cyclic routing problem for the unmanned aerial vehicles (CR-UAV) [5]. The main difference is that we are trying not to find the minimal number of vehicles in order to guarantee the total absence of delays, but instead to find the optimal group route for the given heterogeneous squad. For another thing, although cyclic routes are indeed easier to handle [5], they still represent a very restricted class of solutions; hence we are not considering cyclic-type routes only and keep ours options open to generate any type of routes.

To evaluate and compare the effectiveness of different group routes under given requirements, we propose using scenario-based scheme that relies on the list of *desirable* and *undesirable* modes of group behavior that should be pre-organized beforehand by the human operators. Each scenario includes a priority-order value, set of triggering events, scoring type (penalty or reward) and scoring conditions. All scenarios are checked during virtual simulation of the group work with the output being a sum of penalty and reward points weighted according to given priorities. For the proposed routing problem, we suggest using the following list of three scenarios:

#1. Each time an AUV arrives to inspect a task / Penalty / If inspection is already delayed;
#2. Group collection at the rendezvous point / Penalty / For the time gap between arrivals of first and last AUVs;
#3. Group collection at the rendezvous point / Penalty / For each task with currently delayed or almost delayed inspection.

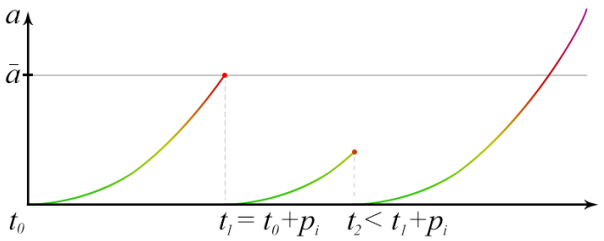

Figure 3. Graphical representation of the "hotness" function

To normalize penalty points we use the scoring technique presented in our earlier works [6,7]. This technique is based on the additionally defined "hotness" function $a_i(t)$ corresponding to each task $i \in N$ of the mission and following two rules: the inspection of the i-th task by any AUV resets its hotness to a zero value; the hotness exponentially grows from zero value up to the constant threshold value $\bar{a}$ (common for all tasks) in a period of p_i (Fig. 3). Now we define the penalty-charging function for the first scenario proposed above:

$$\varphi(i,\mathrm{t}) = \begin{cases} a_i(\mathrm{t}) - \bar{a}, a_i(\mathrm{t}) > \bar{a} \\ 0, \quad a_i(\mathrm{t}) \le \bar{a} \end{cases}. \tag{3}$$

In the similar manner, we define the penalty function for the third scenario:

$$\phi(i, t_0 + T_P) = a_i(t_0 + T_P), \tag{4}$$

where t_0 stands for the start moment of current operating period. In effect, using penalty function (4) not only encourages group to inspect regularly each task of the mission, but it also allows us to provide favorable mission conditions for the next operating period, and, what's even more important, it indirectly normalizes route's durations of all vehicles in the group. Thus, we do not really need a specified penalty function for the second scenario, as it is already included in (4).

It is also should be noted that the function (3) is constructed in such way, that "hotness" of tasks with lesser periodicity grows faster. In that way, inspections delays, if any, would happen preferably with tasks of the biggest periodicity, which are likely to be less prioritized.

Turning to the planning procedure, it should be reminded, that the group route for the current operating period is always calculated at the previous operating period with consideration of the expected group changes during the nearest rendezvous. If any unexpected event occurs up to the rendezvous point, all previously calculated routes usually become less of an issue, but still they could be utilized as being in some sort of knowledge base for more intelligent plan re-adjustment.

Besides, we can negate impact of some unpredictable events in advance by constructing additional back-up plans if the computational capacity allows. For example, an additional group route could be constructed for the group of one less vehicle (in the event of a single AUV's malfunction or delaying from the charging base). It would be reasonable to consider the fastest vehicle in that role as it could replace any other missing vehicle with hardly any trouble at all.

VI. Control System Implementation

In this study, two different modifications of genetic algorithms (GA) are developed and applied in the context of group mission planning.

For the upper-level mission planner we propose using a simple genetic algorithm with some modifications since GA offer near-optimal solutions in faster time with better scalability in number of tasks at average than other heuristic- and meta-heuristic approaches. GA are appropriate for large-sized high-dimensional problems, but may converge to local optima in a finite time.

We use the matrix $H = \{h_{ij}\}, i = 1,2,...,e,\ j = 1,2,...,\mathrm{m}$ representation in the form of a one-dimensional binary array as the chromosome, function (1) as the objective function with (2) as the tiebreaker during tournament selection. The feasibility of all chromosomes is checked additionally with specialized algorithmic procedure considering AUV's cruising speed, battery capacity, traveling time to reach the charging base and, finally, charging speed. For the genetic operators, we suggest using "1+1"-point crossover of our own design [7] instead of or in addition to standard one- or two-point versions.

Lower-level routing problem is much more complicated and computationally intensive problem as it is known to be NP-hard. Thus, there are no algorithms solving it in polynomial time, which leads us to the class of approximation algorithms allowing to obtain rational sub-optimal solutions in low computational time.

Evolutionary methods have proven to be efficient on the standard vehicle routing problems and on a number of other variants like periodic routing and routing with time windows [8], that shares very similar and restrictions and constrains with our regular routing problem. Their main advantage of evolutionary algorithms (EA) is ability to find solutions for poorly structured problems and problems with complex constraints, as EA require a relatively small amount of information about the nature of the problem. Essential drawback of evolutionary methods is in very strong speed and efficiency dependence on the construction and improvement heuristics being used.

Another layer of complexity is implied by a "bad" neighborhood structure of the described multi-objective routing problem, making it difficult to allocate and to find qualitative and feasible solutions, as they may not be in the neighborhood of other feasible high-quality solutions in the search space.

We propose a hybrid evolutionary approach featuring specialized genetic operators, advanced local search heuristics and solution improvement techniques to address both the expectable large-size of the problem and complex spatio-temporal constraints. Both algorithm's structure and original heuristics are in-depth studied in our previous works [6,7] devoted solely to the low-level routing problems, so we omit the details here.

Both mission- and route- planning algorithms were integrated with offline hierarchical pathfinding (HPA*) [9] and implemented in our simulation framework "AUV Multiobjective Mission Planner" to run a series of simulation studies.

VII. CONCLUSION

This paper presents a two-level approach to the AUVs dynamic routing problem that incorporates rendezvous point-selection scheme providing advantageous mission decomposition and local task allocation scheme to maximally utilize currently available vehicles during the course of the mission.

Simulation tests have been performed to route the heterogeneous group of vehicles with inconstant lineup under the complex constraints coming from the regular nature of mission tasks. The high efficiency of the suggested approach is shown through these tests. Upper-level mission planner is proved to be fast, accurate and reliable for the purpose of dynamic scheduling. It allows fast construction of reasonable group schedules and their prompt re-building, if needed. Lower-level routing system, in return, offers efficient near-optimal task allocation procedure even under strict constraints and large-sized search field. The proposed cooperation scheme between both planners allows group to maintain its efficiency in ever changing environment and under continuous squad rotation.

The next stage in this work is to introduce the heterogeneity in functional capabilities of vehicles with each AUV being able to inspect only those tasks that require the available type of equipment. In this case, upper-level mission planner should construct schedules specifically taking care of full equipment availability at each operating period. Another extension of this work is to develop an advanced three-dimensional online path planning system to deal with collision avoidance, ocean currents, dynamic and uncertain obstacles.

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Logic Level of Control for Robot Groups Using the Method of Positively Constructed Formulas

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***Abstract*—The use of the logic calculus of positively-constructed formulas (PCF) for generating plans of actions for groups of underwater robots is considered in this paper. These actions are supposed to be managed by the high level of some control system and plans can be generated in automatic or interactive mode. An example of high-level control implementation for a group of autonomous underwater robots on the basis of formalization of the subject area using the PCFs is presented.**

I. Introduction

The advancement of intellectual capabilities of control systems is increasingly based on the application of various logic formalisms [1], [2], [3]. This paper presents an approach based on the application of automated first-order logics theorem proving and software system (prover) to the upper level of the robot group control system. A number of significant difficulties do not allow to achieve the necessary efficiency of provers for their application in real time tasks: a) the proving program makes too many conclusions, most of which are redundant or irrelevant; b) the program has to store too much information in the database; c) inference rules and the steps of deduction are not coincide in size; d) inadequate focusing, the program easily stumbles on a false search path. The proposed approach is based on the original logical calculus of positively-constructed formulas (PCFs). The PCF calculus was developed in [4], [5] for formal description and synthesis of the theorems in the Vector-Lyapunov Functions method and further developed as a complete method for automated theorem proving with functional symbols in [6] and [7]. Due to its features, the PCF calculus allows one to combine the automatic search for logic inferences with special domain based heuristics which are customizable for each task being solved, making above-mentioned difficulties less significant.

The approach to the implementation of the high-level control of a groups of autonomous underwater vehicles based on the formalization of the domain via PCF calculus is considered. The logical deductions of PCF fragments formalizing the process of functioning of the groups of AUVs controlled by some supervised control system showed as the example.

II. The Language of Positively Constructed Formulas

Let's consider a language of first-order logic that consist of first-order formulas (FOFs) built out of atomic formulas with $\&, \vee, \neg, \rightarrow, \leftrightarrow$ operators, $\forall$ and $\exists$ quantifier symbols and constants $true$ and $false$. The concepts of term, atom, literal we define in the usual way. Further, non-atomic formulas and subformulas will be denoted by capital calligraphic letters ($\mathcal{F}, \mathcal{P}, \mathcal{Q}$, etc.), possibly with indices. Sets of formulas will be denoted by capital Greek letters (Φ, Ψ, etc.), possibly with indices.

Let $X = \{x_1, \ldots, x_k\}$ be a set of variables, $A = \{A_1, \ldots, A_m\}$ be a set of atomic formulas called *conjunct*, and $\Phi = \{\mathcal{F}_1, \ldots, \mathcal{F}_n\}$ be a set of FOFs. The following formulas $\forall x_1 \ldots \forall x_k (A_1 \& \ldots \& A_m) \rightarrow (\mathcal{F}_1 \vee \ldots \vee \mathcal{F}_n)$ and $\exists x_1 \ldots \exists x_k (A_1 \& \ldots \& A_m) \& (\mathcal{F}_1 \& \ldots \& \mathcal{F}_n)$ are denoted as $\forall x_1, \ldots, x_k A_1, \ldots, A_m \{\mathcal{F}_1, \ldots, \mathcal{F}_n\}$ and $\exists x_1, \ldots, x_k A_1, \ldots, A_m \{\mathcal{F}_1, \ldots, \mathcal{F}_n\}$. They can be abbreviated as $\forall_X A\ \Phi$ and $\exists_X A\ \Phi$ respectively, keeping in mind that the $\forall$-quantifier corresponds to $\rightarrow \Phi^{\vee}$, where $\Phi^{\vee}$ means disjunction of all the formulas from Φ, and $\exists$-quantifier corresponds to $\& \Phi^{\&}$, where $\Phi^{\&}$ means conjunction of all the formulas from Φ. Any of sets X, A, Φ may be empty, and in this case they could be omitted in formula formalization. Thus, if $Q \in \{\forall, \exists\}$ then $Q_X A \varnothing \equiv Q_X A$, $Q_X \varnothing\ \Phi \equiv Q_X\ \Phi$ and $Q_{\varnothing} A\ \Phi \equiv Q A\ \Phi$. Since empty disjunction is identical to $false$, whereas empty conjunction is identical to $true$, the following equivalences are correct: $\forall_X A\ \varnothing \equiv \forall_X A \rightarrow false \equiv \forall_X A$ and $\exists_X A\ \varnothing \equiv \exists_X A \& true \equiv \exists_X A$ and $\forall \varnothing\ \Phi \equiv true \rightarrow \Phi \equiv \forall\ \Phi$ and $\exists \varnothing\ \Phi \equiv true \& \Phi \equiv \exists\ \Phi$.

At first glance, it seems quite strange that in some formulas abbreviations there is no any variable occurrence in a some quantifiers $\forall$ and $\exists$. Such quantifiers are called *fictitious* and we do not omit them from a formula structure since it allow us to correctly interpret set of FOFs Φ. If $\mathcal{P} = \forall A\ \Phi$ then we know that in this case we interpret formula $\mathcal{P}$ as $A \rightarrow \Phi^{\vee}$. And if $\mathcal{P} = \exists A\ \Phi$ then we interpret $\mathcal{P}$ as $A \& \Phi^{\&}$.

In practice, phrases of form $\forall_X A\ \Phi$ and $\exists_X A\ \Phi$ denote the following natural language statements: "for all X satisfying A there is Φ"; "there exists X satisfying property A such that Φ"; "for all integer x, y, z and $n > 2$ there is $x^n + y^n \neq z^n$". Originally, constructions $\forall_X A$ and $\exists_X A$ are called *type quantifiers*, they were introduced by N. Bourbaki [8] as a part of a notation for formalization of mathematics.

Definition 1. *Let X be a set of variables, and A be a conjunct, both can be empty.*

1) *$\exists_X A$ is an $\exists$-PCF,*
2) *$\forall_X A$ is a $\forall$-PCF,*

3) *If $\Phi = \{\mathcal{F}_1, \ldots, \mathcal{F}_n\}$ is a set of $\forall$-PCFs, then $\exists_X A\ \Phi$ is an $\exists$-PCF,*
4) *If $\Phi = \{\mathcal{F}_1, \ldots, \mathcal{F}_n\}$ is a set of $\exists$-PCFs, then $\forall_X A\ \Phi$ is a $\forall$-PCF,*
5) *Any $\exists$-PCF or $\forall$-PCF is a PCF,*
6) *There is only PCFs of form $\exists$-PCF and $\forall$-PCF.*

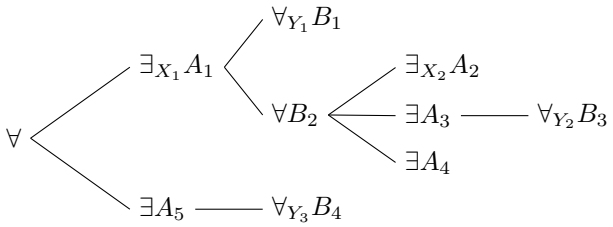
The term "positively" comes from the fact, that according to the definition 1 PCFs contain no negation operator ($\neg$).

If a PCF has form $\forall\ \Phi$, then this PCF is called *canonical PCF*. Obviously, any PCF can be converted to a canonical form. If $\mathcal{P}$ is a non-canonical $\exists$-PCF, then $\mathcal{P} \equiv \forall\ \mathcal{P}$, since $\forall\ \mathcal{P} \equiv true \to \mathcal{P} \equiv \mathcal{P}$. If $\mathcal{P}$ is a non-canonical $\forall$-PCF then $\mathcal{P} \equiv \forall\ \{\exists\ \mathcal{P}\}$, since $\forall\ \{\exists\ \mathcal{P}\} \equiv true \to (true \& \mathcal{P}) \equiv \mathcal{P}$.

For the sake of readability we represent PCFs as trees, whose nodes are type quantifiers, and we use corresponding names: *node, root, leaf, branch*. For example, a PCF

$$\forall\ \{\exists_{X_1} A_1\ \{\forall_{Y_1} B_1,\ \forall B_2\ \{\exists_{X_2} A_2,\ \exists A_3\ \{\forall_{Y_2} B_3\},\ \exists A_4\}\},\ \exists A_5\ \{\forall_{Y_3} B_4\}\}$$

is represented as a tree as follows:



Given PCFs $\mathcal{P} = \forall\{\mathcal{F}_1, \ldots, \mathcal{F}_n\}$ and $\mathcal{F}_i = \exists_{X_i} B_i\{\mathcal{Q}_{i1}, \ldots, \mathcal{Q}_{im}\}$, $i = \overline{1,n}$, then $\mathcal{F}_i$ is called *base subformula* of $\mathcal{P}$, B_i is called *base of facts* or just *base*, $\mathcal{Q}_{ij}$ are called *question subformulas*, and roots of question subformulas are called *questions* to the base B_i, $i = \overline{1,n}$. A question of a form $\forall_X A$ (without any children) is called *goal question*.

Inside each of the base subformulas, any variable cannot be free and bound simultaneously, furthermore, it cannot be bound by different quantifiers simultaneously.

III. The ATP Method based on Positively Constructed Formulas

In the process of reasoning, one often proves a statement $\mathcal{F}$ by refuting its negation. We intend to proceed similarly. The method deals with canonical PCFs only.

Definition 2 (Answer)**.** *Consider some base subformula $\exists_X A\ \Psi$ of a PCF. A question of the subformula $\mathcal{Q} = \forall_Y B\ \Phi$, $Q \in \Psi$ has an answer θ if and only if θ is a substitution $Y \to H^\infty \cup X$ and $B\theta \subseteq A$, where H^∞ is Herbrand universe based on constant and function symbols that occur in the corresponding base subformula.*

Definition 3. *Let $\mathcal{P}_1 = \exists_X A\ \Psi$ and $\mathcal{P}_2 = \exists_Y B\ \Phi$, then $merge(\mathcal{P}_1, \mathcal{P}_2) = \exists_{X \cup Y} A \cup B\ \Psi \cup \Phi$*

Definition 4. *Consider some base subformula $\mathcal{B} = \exists_X A\ \Psi$. A question subformula $\mathcal{Q} \in \Psi$ has the form $\forall_Y D\ \{\mathcal{P}_1, \ldots, \mathcal{P}_n\}$, where $\mathcal{P}_i = \exists_{Z_i} C_i\ \Gamma_i, i = \overline{1,n}$, then $split(B, Q) = \{merge(B, \mathcal{P}'_1), \ldots, merge(B, \mathcal{P}'_n)\}$, where $'$ is a variable renaming operator. We say that $\mathcal{B}$ is split by $\mathcal{Q}$, and $split(\mathcal{B}, \mathcal{Q})$ is the result of the split of $\mathcal{B}$. Obviously, $split(\mathcal{B}, \forall_Y D) = \varnothing$.*

Definition 5 (The inference rule ω)**.** *Consider some canonical PCF $\mathcal{F} = \forall\ \Phi$. If there exists a base subformula $\mathcal{B} = \exists_X A\ \Psi$, $\mathcal{B} \in \Phi$ and there exists a question subformula $\mathcal{Q} \in \Psi$, and the question of $\mathcal{Q}$ has an answer θ to $\mathcal{B}$, then $\omega(\mathcal{F}) = \forall\ \Phi \setminus \{\mathcal{B}\} \cup split(\mathcal{B}, \mathcal{Q}\theta)$.*

Note, that when the set Φ becomes empty after applying an ω rule and the PCF becomes just $\forall$, then it can be concluded that the negation of an original formula is unsatisfiable.

Any finite sequence of PCFs $\mathcal{F}, \omega\mathcal{F}, \omega^2\mathcal{F}, \ldots, \omega^n\mathcal{F}$, where $\omega^s\mathcal{F} = \omega(\omega^{s-1}\mathcal{F}), \omega^1 = \omega, \omega^n\mathcal{F} = \forall$, is called *a deduction* of $\mathcal{F}$ in PCF calculus (with the axiom $\forall$).

Suppose that a search strategy verifies the questions in consecutive order, without omissions (while repeating the verification only when the whole cycle of questions is over), and it does not use repeated application of ω to a question with the same θ (question-answering method of automated deduction).

Example 1 (A refutation in PCFs)**.** *Consider the PCF F_1 :*

$$\forall\text{ - }\exists S(e) \begin{cases} \forall x\ S(x) \text{ — } \exists A(x) \\ \forall x, y\ C(x, y) \\ \forall x\ A(x) \begin{cases} \exists y\ C(y, f(x)) \\ \exists \text{ — } \forall x\ S(x), A(x) \text{ - } \exists C(x, f(x)) \end{cases} \end{cases}$$

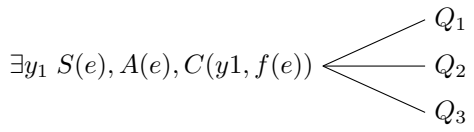
At the first step there is only one answer $\{x \to e\}$ to the first question (top to bottom numbering, name it Q_1). After applying rule $\boldsymbol{\omega}$ with this answer to the only base of F_1, the formula will be converted to the following form, F_2:

$$\forall - \exists S(e), A(e) \begin{cases} Q_1 \\ Q_2 \\ Q_3 \end{cases}$$

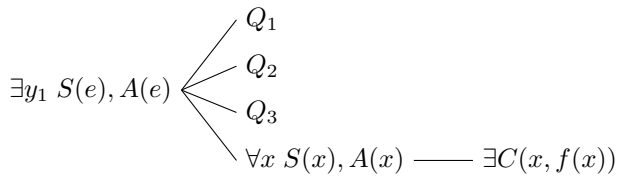
At the second step there is also only one answer $\{x \to e\}$ to question Q_3. After applying $\boldsymbol{\omega}$ with this answer, formula is split, because Q_3 has disjunctive branching. The formula will have the following form, F_3:

$$\forall \begin{cases} F_3^1 \\ F_3^2 \end{cases}$$

where F_3^1 is:



and F_3^2 is:



At the third step the first base can be refuted by answering on Q_2 (goal question) with $\{x \to y_1; y \to f(e)\}$. The refuted base (and its whole base subformula) is to be deleted from the list of base subformulas.

At the fourth step there is the answer $\{x \to e, y \to e\}$ to fourth new question of the base F_3^2 which adds the atom $C(e, f(e))$ to it.

At the fifth step the only base can be refuted by answering on Q_2 (goal question) with answer $\{x \to e; y \to f(e)\}$, finishing refutation because all the bases were refuted.

A. Features of PCF Calculus

1) Any PCF has a *large-block structure* and only *positive quantifiers* $\exists$ and $\forall$.
2) PCF contains both $\exists$ and $\forall$ quantifiers, but structure of PCF is *simple*, *regular* and *predictable* due to predictable quantifiers alternation $\exists$ and $\forall$ in all the branches.
3) There is no need to preprocess (Skolemization) the original formulas by elimination of all existential quantifiers. The Skolemization related to this elimination leads to elevating the complexity of terms. Also, this feature makes PCF calculus more human-oriented.
4) "Theoretical" quantifiers $\forall x$ and $\exists x$ usually not used in the formalization of human knowledge, typical quantifiers $\forall x(A \to \sqcup)$ and $\exists x(A\&\sqcup)$ are used instead.
5) The PCF calculus inference rule is unique and this property make PCF calculus more machine-oriented. In addition, inference rule has a large-block structure that make PCF calculus more human-oriented.
6) The proof procedure focuses on the root surroundings of the PCF. This is possible due to features 1, 2.
7) The proof procedure can be represented in terms of the *question-answering* procedure instead of technical terms of formal deducibility (i.e., in terms of logic connectives, atoms, etc.). Base conjunct can be interpreted as *base of facts*.
8) There is natural *OR-parallelism*, because the refutation of base subformulas are executed independently of one another.
9) Due to 1, 2, 6, 7 the proof procedure is *well compatible with heuristics*, as well as to a general proof control heuristics. Due to feature 5 proof consist of large-block steps, and it is well *observable* and *controllable*.
10) Due to features 7, 9 the proof obtained are quite interpretable by human. This interpretability of proof is quite important from the viewpoint of human-machine applications. Thus, as mentioned above, PCF calculus are not only machine-oriented, but also human-oriented.
11) Semantic of PCF calculus can be changed without any modifications of axioms and inference rule ω. Such modifications are implemented merely by some restrictions to application ω and allow us to transform classical semantics of PCF calculus in non-monotonic, intuitionistic, etc. Examples of using such semantics are provided in [5].

IV. Planning and control of AUVs groups

The PCFs method question-answering procedure of inference search can be utilized in the area of problem solving. Indeed, in this way of searching for deductions, it is easy to pick out the events that can be used to tune up strategies of deduction search in an automatic mode. Also, by means of these events, the inference machine can be run in an interactive mode so that it will be possible to communicate with a human operator of the control system. The most natural way to implement such a connection is the use of the following events:

- a successful answer to the question;
- updating the database with new atoms;
- refutation of a base.

Let's consider the example of PCFs method application to describe and solve the following problem. Imagine a fragment of a centralized control system of groups of autonomous underwater vehicles that are continuously monitoring certain underwater area. Let's consider that there are two groups of autonomous robots (a_1 and a_2) in the area. Groups are composed of robots with different functionalities united in the likeness of tasks it can handle (for example, identification, sampling and manipulation, etc.). The groups control is maintained by the means of acoustic communication network with some central server (CS), that is allocated on the support ship. The CS operates automatically under the supervision of a human operator who can change group tasks and goals. Next, consider PCF language specifications of robots and CS as a possible parts of a larger system specification, focusing here on achieving a common goal of the two groups that will be reached in stages. It is required to achieve sub-goals to complete each stage. The completing or the inability to complete sub-goals is defined by events in the deductions search of formulas that specify the functionality of robot groups. If there is no way to complete a sub-goal, then a communication with CS is taking place to request re-planning.

Sub-goals that are possible in the our problem statement:

- object identification;
- carrying out additional actions with the object (sampling, communication);
- conducting defensive operations;
- loading of an object;
- docking with the object.

Groups of robots specifications in some initial moment of abstract time is described by the following base subformula:

$$\exists s_1, s_2, a_1, a_2 S(s_1), A(a_1), S(s_2), A(a_2), T(0)$$

Here $S(s_i)$ denote the set of atoms defining the state of groups $A(a_i)$.

The current functioning and tasks for groups are described by following questions to the base subformula:

$$\forall t\ T^*(t) - \exists\ T(t+1)$$
$$\forall x, t\ Patrol(t, s_i, a_i), T(t), See^{\#}(x) - \exists\ Find(t, x)$$
$$\forall x, t\ Find(t, x) - \exists\ \boxed{Task(t, x, a_i)}$$

The first formula in the list of questions is the our method of the time moment counting in PCFs. It uses the atom with the symbol $*$, which means that if there is a successful answer to a question, then the corresponding atom must be removed from the base of facts. Thus, from the initial moment of time, in the cycle of the questions answering procedure, T(1) is added to the base instead of T(0). Further, if the base is not refuted, T(2) will be added, and so on.

The second question, assume that one of the groups has the capability to detect objects. This option is checked with the help of the computational predicate $See(x)$ denoted hereinafter in formulas by the symbol #. Truth values of the computational predicates are not established by the logical inference but by the actual state of environment. Thus, if detection sensors trigger successfully, the fact $See(Obj)$ – a symbolized definition of the detected object – is added to the base. Then, for example, at time moment n, the second question has the answer, and the fact $Find(n, Obj)$ will be added to the base.

Framed atom in the third question indicates the achievement of one of the sub-goals and the end of the deduction search. The communication with the CS is taking place. In our case, there is a request to the CS for further instructions after the object detection. The atom $Task(n, Obj, a_i)$ is sent to the base of facts of the CS.

This behavior is handled by the following question that might present in the list of questions on the CS.

$$\forall t, x\ Task(t, x, a_i) - \exists\ \boxed{Identify(x, a_i)}$$

After this question is answered, the fact $Identify(Obj, a_i)$ will be sent to the coordinator of the group which sent the request.

The system's further work is related with the study of the detected object. The first step is to determine whether the found object can present any danger. Suppose that the given task can be handled by group a_1. If there is no danger, the group a_2 can proceed to the task by robots with the ability to capture photos and videos.

Any object found in the area can be considered hazardous if it is moving and is not a local fauna representative, or if it contains any hazardous materials (pollution, underwater mines). For this task, there must be the following question subformulas in the list of questions of the a_1 group coordinator:

$$\forall x\ Identify(x, a_1) \begin{cases} \exists\ Move^{\#}(x), Answ^{\#}(x), Fish^{\#}(x) \\ \exists\ Contamination^{\#}(x) \\ \exists\ Mine^{\#}(x) \end{cases}$$

$$\forall x\ Move(x), Answ(x), Fish(x) - \exists\ \boxed{Danger_1(x, a_1)}$$
$$\forall x\ Contamination(x) - \exists\ \boxed{Danger_2(x, a_1)}$$
$$\forall x\ Mine(x) - \exists\ \boxed{Danger_3(x, a_1)}$$

The first question in this list splits the base, each new base subtree will correspond to the type of danger. Atoms with the symbol # request the corresponding sensors. In case of the negative analysis of the object, corresponding atoms in the base are removed (replaced by the constant $true$). According to the problem statement, only the one of the last three questions in the list can be answered, if it did, the deduction search stops and the type of danger - $Danger_j(Obj, a_1)$ - is sent to the CS. If the deduction search fails, the group a_1 returns to the normal functioning, and the CS sends the task for the photo and video shooting to the group coordinator of a_2, which processes it with questions:

$$\forall x, t\ PhotoVideo(x, a_1), T(t) \begin{cases} \exists\ Photo(x, t) \\ \exists\ Video(x, t+1) \end{cases}$$

$$\forall x, t\ Photo^{\#}(x, t), T(t)$$
$$\forall x, t\ Video(x, t+1), T(t)$$

The deduction search of two new bases will be successful, one after another. The first, at some moment T(n), there will be a photo shoot as a result corresponding question application in the bottom list. After that, the second base's time will change to T (n + 1) and it will be possible to answer the last question, refuting the base and thereby completing the deduction search. The end of the deduction search means the achieving another sub-goal.

The presented statements describe some "life cycle" of two groups of robots. Further, by analogy, we can describe all possible situations and circumstances of the area's environment in the system. The plans of actions of the system are built and performed in automatic or interactive mode during the inference search. This example demonstrates a common approach to the planning problem using the method of PCFs.

V. Conclusion

The extended logic calculus of positively-constructed formulas, with functional symbols, and its features are considered. The approach to the implementation of the high-level control of a groups of autonomous underwater vehicles based on the formalization of the domain via PCF calculus is considered. The logical deductions of PCF fragments formalizing

the process of functioning of the groups of AUVs controlled by some supervised control system showed as the example.

Acknowledgment

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Agent Behavior Model for Distributed Computing Management in the Environment with Virtualized Resources

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Abstract – We address the management of jobs generated by scalable applications in an environment that integrates Grid system and cloud infrastructure. The complexity of the management is high due to the differences of the cloud and Grid computing models. There exist conflicts between the preferences of owners and quality criteria defined by users. Multi-agent systems achieve a significant success in solving this problem. The agents are intelligent software entities endowed with rights and responsibilities for servicing computational processes. They interact to achieve their goals. A representation of the needed knowledge and designing agent functions taking into account specifics of applications is a non-trivial problem for the known multi-agent systems used for managing distributed computing in practice. We propose a multi-agent system to manage jobs in a heterogeneous distributed computing environment that integrates Grid and cloud computing. To this end, we implement new specialized models and tools for the agent designing and operation. The model is based on the integrated use of conceptual and finite state machine programming paradigms. We demonstrate the advantages of our system on an example of the job management of a scalable application to solve optimization problems of warehouse logistics.

I. INTRODUCTION

Solving large-scale scientific and applied problems in an environment that integrates the Grid and cloud infrastructures causes new challenges for management systems of user application jobs [1]. These challenges are owing to differences in the cloud and Grid computing models, as well as conflicts between resource owner preferences and quality criteria of solving problems that are determined by end users.

The agent approach enables to significantly mitigate the aforementioned differences and conflicts through the interaction and coordination of agents representing cloud and Grid resources, their owners and users. Moreover, the cooperation of agents in the problem-solving processes significantly improves the quality of management. Examples of successful applying multi-agent systems (MASs) for managing problem-solving processes in distributed computing environments that include cloud infrastructure elements are given in [2, 3, 4].

However, the efficiency of multi-agent management largely depends on the completeness of knowledge about problems of end users, environment resources, applications and their jobs. When agents operate, they have to receive and use such knowledge [5, 6]. Moreover, an agent behavioral model and its capabilities are determined by knowledge reflecting the agent subject domain specifics. Thus, special tools are required in order to create an agent with the necessary knowledge and abilities for distributed computing management.

There is currently a large set of tools for the MASs development. Some of them are successfully applied in practice [7]. However, an agent creation automation and knowledge representation about the subject domains and system infrastructure (software and hardware of the environment) in MASs are important challenges.

The purpose of our study is the development of agent functioning model in the distributed computing management process and tools for its design.

The rest of the paper is organized as follows. In the next Section, we give a brief overview of the known MASs and comparative analysis of their characteristics. Section 3 proposes a new agent behavior model for the MAS developed for distributed computing management in a heterogeneous distributed environment with virtualized resources. Section 4 describes aspects of the agent development automation process. Section 5 provides experimental analysis. Section 6 concludes with a summary of our study.

II. RELATED WORK

The known MASs are successfully applied to manage distributed computing [8, 9]. Among them are Condor-G (s_1) [10], GridSolve (s_2) [11], AppLes (s_3) [12], MAGE (s_4) [13] and MAAG (s_5) [14], and tool for planning jobs of distributed computational system (s_6) [15]. Nowadays, the special attention is on the multi-agent management of cloud computing. Singh [16] presents an agent framework (s_7) for supporting scalability in cloud computing environments by finding a cloud that fully satisfied user requests when the used cloud is overloaded. Kalyaev A. and Kalyaev I. [17] propose the system (s_8) for multi-

agent scheduling in cloud computing environments taking into account job completion deadlines.

In this regard, we developed the system (s_9) to manage distributed computing in a heterogeneous environment with virtualized resources. Architecture, algorithms of functioning and capabilities of this multi-agent system are described in detail in [6, 18, 19].

The listed-above systems differ in their capabilities for distributed computing management. In the column named **c**, Table 1 shows the following 18 characteristics c_1-c_{18} of the systems s_1-s_9 that significantly affect on the job management efficiency:

- Existence of build-in agents (c_1),
- Ability to develop agents by users (c_2),
- Supporting the management of interrelated jobs (c_3),
- Creating a problem-solving scheme (workflow) on the basis of its formulation in a procedural form (c_4),
- Creating a problem-solving scheme (workflow) on the basis of its formulation in a non-procedural form (c_5),
- Resource allocation (c_6),
- Environment monitoring (c_7),
- Ability to model an agent behavior by other agents (c_8),
- Resource allocation optimization in the interest of the environment (c_9),
- Resource allocation optimization in the interest of applications (c_{10}),
- Matching resource owner preferences and quality criteria of solving problems (c_{11}),
- Centralized algorithm of agent interactions (c_{12}),
- Decentralized algorithm of agent interactions (c_{13}),
- Using a logical time system in the process of sending messages from agents (c_{14}),
- Applying by agents of economic mechanisms for regulation of resources demand and supply (c_{15}),
- Ability to play multiple roles by one agent (c_{16}),
- Agent behavior model adjustment (c_{17}),
- Learning of agents (c_{18}).

The symbol '+' ('–') means the possibility (impossibility) of supporting a characteristic in systems.

TABLE I. CHARACTERISTICS OF MULTI-AGENT SYSTEMS

c	s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8	s_9
c_1	+	+	+	+	+	+	+	+	+
c_2	–	–	–	+	–	–	–	–	+
c_3	+	+	+	+	+	–	+	+	+
c_4	+	+	+	+	+	–	+	+	+
c_5	–	–	–	–	–	–	–	–	+
c_6	+	+	+	+	+	+	+	+	+
c_7	+	+	+	+	+	+	+	+	+
c_8	–	–	–	+	–	–	–	–	+
c_9	+	+	+	+	+	+	–	+	–
c_{10}	–	–	–	–	–	–	–	–	+
c_{11}	+	+	+	–	–	–	+	–	+
c_{12}	–	–	–	+	+	–	–	–	+
c_{13}	–	–	–	–	–	+	–	+	+
c_{14}	+	–	–	–	–	–	+	–	+
c_{15}	–	–	–	–	–	–	–	–	+
c_{16}	–	–	–	+	–	–	–	–	+
c_{17}	–	–	–	–	–	–	–	–	+
c_{18}	+	+	+	+	+	–	+	–	+

The comparison results show the advantages and drawbacks for each of the considered systems. For example, the characteristic c_2 is only represent in s_9. Availability of the characteristics c_1, c_3, c_4, c_6 and c_7 is common to all systems. As a rule, systems have one of the characteristics c_9 or c_{10}. Using the centralized algorithm of agent interactions (c_{12}) strongly limits the management system scalability.

The system s_9 refers to middleware and does not support some functions that are typical for traditional job management systems. Nevertheless, this system has the characteristics c_2, c_5, c_8, c_{11} and c_{15}, the availability of which determines its advantages in comparison with other systems. Algorithms of agent interactions that enable the characteristics of c_{13}-c_{18} provide reliable and efficient operation of the system.

III. AGENT BEHAVIOR MODEL

The proposed MAS (system s_9) includes agents for solving the following main tasks:

- Problem formulating,
- Computation planning,
- Resources monitoring and allocation,
- Job classification, specification and execution,
- Parametric adjustment of agent functioning algorithms based on simulation modeling.

The proposed agent behavior model is based on the integrated use of the following three models:

- Conceptual model of the environment that represents knowledge about both the specifics of problem subject domains and environment objects properties,
- Finite state machine model determining agent actions,
- Logical time model designed to order events that occur in a virtual community of agents.

A. Conceptual Model

The effective work of the MAS is based on the use of five interconnected layers of knowledge. The first three layers represent algorithmic knowledge. Among them are the computational knowledge about software modules to solve problems in subject domains and operate with environment objects, schematic knowledge about the modular structure of used algorithms, product knowledge to support decision making in the selection of optimal algorithms depending on the current environment state. The last two layers describe software and hardware infrastructure of the environment, and reflects properties of administrative policies at computational nodes. All layers of knowledge are represented in the form of a conceptual model of the environment that is a special case of the semantic network [20].

Let Z, F, M and R be the sets of parameters, operations, program modules and resources represented in the conceptual model.

Parameters, operations and their relations reflect the schematic knowledge of subject domains of problems. Operations from the set F determine the computability relations on the set Z of parameters. There are two subsets $Z_i^{in}, Z_i^{out} \subset Z$ of parameters for each operation f_i. The subset Z_i^{in} determines input parameters of the operation f_i whose values are to be set to calculate values of its output parameters from the subset Z_i^{out}.

Modules from the set M reflect computational knowledge. They represent the program implementation of the operations. The one module $m_j \in M$ can implement the one or several operations $f_i \in F$, where $i \in \overline{1,l}$, $j \in \overline{1,k}$, l is a number of operations, k is a number of modules. The semantics of the module and its formal parameters is expressed through the purpose of the operation and its parameters.

In the conceptual model, a module description includes the following knowledge: hardware platform, operating system, programming language, types of formal parameters, transfer parameter method, modes of the non-standard situation processing, additional program libraries, compiler and its options, call format, expert comments about module use aspects, etc.

Modules are executed on resources from the set R. Each module can be executed in different resources. Resources differ in their computational characteristics. Therefore, the module execution time in different resources is varied.

To solve a problem, we have first to formulate it. In this conceptual model, problems can be formulated in the full or shortcut forms.

A problem formulation in the full form is defined as the following: Calculate Y' knowing X', executing F', using R' and meeting the constraints $c_1, c_2, ..., c_v$, where $X' \subset Z$, $Y' \subset Z$, $F' \subset F$, $R' \subset R$, $c_i \in Z$ is the *i*th optimization criterion for a problem-solving scheme, $c_i \to \min(\max)$, $c_i^{\min} \le c_i \le c_i^{\max}$, $i \in \overline{i,v}$, $c_i^{\min}$ and $c_i^{\max}$ are the limits for c_i. This formulation coincides with problem-solving scheme (workflow).

A problem can have several solutions. Users can formulate less strict (shortcut) problems with elements of uncertainty. Shortcut problem formulation is defined in the following form: Calculate Y'? knowing X'?, executing F'?, using R'? and meeting the constraints $c_1, c_2, ..., c_v$?. The symbol '?' means uncertainty in the corresponding element of the problem formulation or lack of this element. The procedural and non-procedural problem formulations are formed on the base of the shortcut problem formulation. These formulations have the following forms:

- Execute F' using R' and meeting the constraints $c_1, c_2, ..., c_v$,
- Calculate Y' knowing X', using R' and meeting the constraints $c_1, c_2, ..., c_v$.

Uncertainty is eliminated at the stages of computation planning and resource allocation based on the use of heuristic methods for multi-criteria optimization in the process of local interactions between agents.

We distinguish subsets of system parameters and operations of corresponding sets of parameters and operations of the conceptual model. System parameters reflect environment object characteristics. System operations represent algorithms for the computation planning, resources monitoring and allocation, computational process modeling and other actions. During distributed computing, values of system parameters are determined by a specialized meta-monitoring system [21].

Part of the conceptual model that includes system parameters and operations represents knowledge about the software and hardware infrastructure of the environment, and reflects properties of administrative policies at computational nodes. It is used by agents to formulate their goals and plan actions.

B. Finite State Machine Model

The agent functioning is carried out using the paradigm of automata-based programming [22]. The agent model M_a is represented as the following:

$$M_a = < sm^p, \left\{ sm_{i,j}^c : i \in \overline{1,m}, j \in \overline{1,n} \right\}, Q >,$$

where sm^p is a parent finite state machine, $sm_{i,j}^c$ are child finite state machines, m is a number of virtual

communities in which agent is included, n is a number of agent roles, Q is a set of agent messages, i and j are indexes of the virtual community and agent role. The main function of the parent finite state machine sm^p is creating the child finite state machine $sm^c_{i,j}$ at each agent inclusion into the new virtual community.

A model of the parent finite state machine sm^p is represented as the following:

$$sm^p =< S^p, s_0^p, A^p, h^p, V >,$$

where S^p is a set of states, $s_0^p \in S^p$ is the initial state, $A^p \subset F$ is a set of actions, $h^p \in F$ is the logical function that determines transitions between states, V is a set of global variables that are available child finite state machines. We define the machine state as an action state, which is a sequence of system operations performed over the set of system parameters of the conceptual model.

A model of the child finite state machine $sm^c_{i,j}$ is represented as the following:

$$sm^c_{i,j} =< S^c_j, s^c_{j,0}, A^c_j, h^c_j, T_i >,$$

where S^c_o – is a set of states, $s^c_{j,0} \in S^c_j$ – is the initial state, $A^c_j \subset F$ – is a set of actions, $h^c_j \in F$ – is the logical function that determines transitions between states, T_i is a system of the logical time for *i*th virtual community.

Child finite state machines of different agents that are included into the same virtual community interact using messaging. Messages are transferred through parent finite state machines. Machines that are child of the same parent machine exchange information about shared resources through the global variables of the parent machine and agent knowledge base.

Let us denote by I and $L \subset Z$ correspondingly the set of action indexes from the set $A^p \cup A^c_1 \cup ... \cup A^c_n$ and the set of logical parameters, the values of which change because of performed actions. Logical parameters determine the current states of environment objects and the MAS. We define the functions $h^p : L \to i$ and $h^c_j : L \to i$ that determine transitions of parent and child machines correspondingly, $i \in I$, $j \in \overline{1,n}$.

C. Logical Time Model

A logical time system is created for each virtual community. Its model is represented as the following:

$$T_i =< T_l, T_m, g_d, g_m, g_c >,$$

where T_l is a domain of logical time values, $T_m \subseteq T_l$ is a domain of time markers for dating messages, g_d, g_m and g_c are functions to date events, mark messages and compare logical time values, $i \in \overline{1,m}$.

A logical time system uses a vector clock in which the number of time vector components is equal to the number of virtual community agents. It provides a partial order relation on the set of events in the virtual community taking into account their conditionality [23]. In general, information from virtual community agents enters into common message pools of agents in a random order. The use of the function for dating messages ensures their processing in the corresponding logical sequence. We use a two-message protocol [24]. It can lead to data duplication, but does not allow loss of information. The last protocol property is ensured because of all messages contain temporary message markers and identifiers of virtual communities of agents. Thus, the used protocol provides the reliability of messaging between agents.

IV. Agent Development Automation

We implement the MAS with JADE framework [25]. JADE includes a set of standard agents for managing other created agents, and a library of standard classes for Java-programs. In general, the agent platform created with JADE includes the following components:

- One or more computational nodes,
- Standard agents *Agent Management System*, *Directory Facilitator* and *Remote Monitoring Agent*,
- Agents of the created MAS.

Standard agents are created automatically when the agent platform is started using JADE tools.

The agent development with JADE is a very laborious and routine work. It requires high programmer skills to implement the representation and use of object-oriented knowledge by agents.

In this regard, we propose a new approach to the agent development automation based on the use of an additional tool over JADE that significantly simplifies the agents design and creation. This tool includes *Agent Designer* and *Agent Generator* subsystems.

Agent Designer is used for conceptual modeling the agent subject domain. It enables to describe agents, their roles, virtual communities, machine states, functions and graphs of their transitions, and relations between objects.

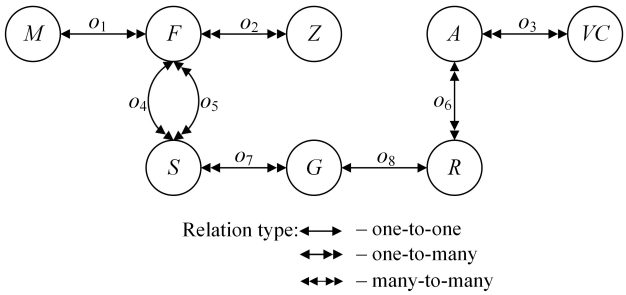

Figure 1. Fragments of the conceptual model

Fig. 1 shows fragments of the conceptual model. The model objects have the following interpretation:

- G is a set of transition graphs,
- A is a set of agents,

- VC is a set of virtual communities of agents,
- R is a set of agent roles,
- S is a set of states for parent and child machines
- $o_1, o_2, ..., o_8$ are relations between objects of the conceptual model.

Let us note that the sets F and S are connected by two relations o_4 and o_5. The relation o_4 connects states with operations that implement transition functions. The relation o_5 connects states with other system operations. The agent knowledge base is created on the basis of the considered fragment of the conceptual model.

Agent Generator is applied to create abstract programs that determine agent actions at states. Abstract programs are created based on the static or dynamic computation planning [20]. *Agent Generator* automatically generates the agent code in the Java terms according to abstract programs. It uses the conceptual model, knowledge base, a library of standard classes of JADE, and library of original algorithms of the agent functioning. Algorithms represents functions (operations) of agents. Generating the agent code is implemented based on the framework-approach to programming that ensures rapid development of agents. A support of action planning makes it possible to adapt the agent behavior to solve new problems.

V. Experimental Analysis

We compare job flow execution under the management of the MAS, Condor-G and GridWay [26]. To this end, we generated the job flow in accordance with the obtained computational history of the real job flow including jobs for solving optimization problems of warehouse logistics in practice [27].

The real flow was executed in the environment with dedicated resources for cloud computing under OpenStack management [28] and non-dedicated resources under PBS Torque management [29]. PBS Torque also was used in virtual machine images. The MAS managed the real flow that included jobs of different classes. In this context, subject domain specifics for agents is execution jobs of various classes in the integrated environment including resources for Grid and cloud computing.

The generated job flow was executed in the same environment. Condor and GridWay were used as meta-schedulers. We replaced PBS Torque with HTCondor when Condor-G was used.

Thus, we compare execution parameters of the real and generated job flows. Table I shows the following compared parameters:

- n_0 is a number of jobs with zero waiting time in queues,
- t_q is an average waiting time in queues in seconds,
- k is an average processor utilization for resources that used in solving the optimization problems,
- t_s is a summary time of solving the optimization problems in seconds.

TABLE I. Job Flow Execution Parameters

Parameter	Condor-G	GridWay	MAS
n_0	1387	1587	1683
t_q	87260	80100	75266
k	94.34%	95.24%	95.34%
t_s	87053	86231	80115

Fig. 2 demonstrates the improvement of all job flow execution parameters in percentages for the MAS versus Condor-G and MAS versus GridWay. We can see a significant improvement for the parameters n_0, t_q and t_s. At the same time, the average processor utilization k with the MAC is not inferior to the same parameters with Condor- G and GridWay, and even slightly exceeds them.

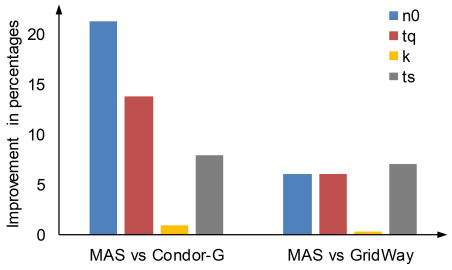

Figure 2. Improvement of job flow execution parameters with the MAS

The parameters improvement with the MAS is due to the development and adjustment of agents with the special behavior model for scheduling the job distribution between dedicated and non-dedicated resources in accordance with job classes that determine requirements to resources. In comparison with the MAS, Condor-G and GridWay do not have this capability.

All experiments were carried out in the environment based on the resources of the public access computer center "Irkutsk supercomputer center of SB RAS" [30].

VI. Conclusion

We address a relevant problem related to the multi-agent management of distributed computing. To this end, we developed the MAS for job flow management in the heterogeneous distributed computing environment including virtualized resources. We also propose new tools to create agents and design their behavior models.

We provide practical experiments and extensive modeling to evaluate the effectiveness of our approach to multi-agent management and utility of the MAS capabilities.

The conducted experimental analysis shows that applying the special behavior model that can be implemented for agents and adjusted to their subject domain specifics enables to significantly improve distributed computing management in comparison with the known management systems.

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Multi-Agent Systems in E-Learning

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Abstract - New technologies have influenced the development of e-learning systems, especially in terms of improving the learning process and more efficient knowledge acquisition by adapting to the mental model of a user. One of the solutions for complexity of designing such systems is the integration of multi-agent technology into e-learning systems. A multi-agent system is a group of independent agents which come up with an optimal solution through mutual communication. This paper defines and explains the concepts related to agents and multi-agent systems in e-learning and presents an overview of the research in the context of multi-agent system application in e-learning with emphasis on the types of agents.

Keywords: e-learning, multi-agent systems, types of agents, users' mental models

I. INTRODUCTION

The development of information and communication technology brings changes in all aspects of human life and activities and in the educational process as well. The digital environment provides new opportunities for individualization and modernization of teaching. New technologies are becoming an integral part of the education system, being either a teacher's support in implementation of traditional teaching or a substitute for such type of teaching using the whole range of new methods and ways of conducting the teaching process and learning process as well [1]. The current society has increased the need for improving learning process and the effective application of knowledge [2]. Therefore, in recent years, the focus is on improvement and more frequent use of technology-assisted learning and teaching that can be achieved through development of electronic learning [3]. E-learning is a form of learning realized with the help of information and communication technology. In the beginning, it meant just the simple use of computers in traditional classroom teaching (PPT presentations, computer simulations of various processes, multimedia presentations, the use of web content, etc.) from which gradually emerged so called "blended" ("mixed-mode", "hybrid") teaching that uses direct contact in the classroom as well as on-line activity [4]. Multimedia, computer networking and software engineering, the introduction of the Internet and the hypermedia service of the World Wide Web induced a new generation of computer systems for learning and teaching. Computer networking technologies, i.e. Intranet, Internet, WWW, and particularly hypermedia, all have contributed in establishing of the so called "advanced learning technologies" and development of teaching organized entirely on-line in which all the activities by teachers and students are performed remotely and without any physical contact [1].

E-learning, as an integral part of educational process, is an efficient way of acquiring knowledge as it minimizes the space and time constraints allowing students to learn anytime and anywhere through its applications and processes including computer and web-based learning, smart virtual classrooms, conferencing and digital collaboration. With the advanced growth rate of the technologies in education, the focus has been shifted from teacher-centred to learner- centred to provide guidance to the learners based on their interest, desire, belief, ability to learn, goals and skills [5].

The increasing popularity of e-learning systems and the rapidly growing number of users as well as the sizes of the learning material repositories make this type of learning a complex system. In addition, e-learning faces a number of challenges, such as adaptation, collaboration, and standardization [6].

E-learning systems development encounters numerous difficulties, among which the most important is transition from traditional e-learning which is passive and content-oriented towards the more user-oriented, interactive and collaborative learning model that involves interactions between different people or organizations with different goals and intentions, with the danger of a potential conflict. For this reason, it is crucial to define an architecture that is capable of accommodating these users and their corresponding accounts and privileges; can efficiently maintain and deliver learning content, including multimedia material and collaborative facilities; and is able to track student performance [7].

Utilizing agent technology appears to be an essential approach to addressing these challenges. The use of intelligent agents in an e- learning architecture makes it possible to achieve a powerful system adapted to the needs and characteristics of every learner and to provide adaptability and intelligence to the e-learning system through the introduction of agents [8].

According to available literature, this paper explains the basic concepts related to agent technology and multi-agent systems. It also gives an overview of research related to multi-agent systems in e-learning, with emphasis on agent structure and possible guidelines for further research.

II. AGENT TECHNOLOGY

Agent technology is closely related to the area of artificial intelligence. Therefore, before stating agent technology explanation and its definitions, it is necessary to say something about the concept of intelligence itself.

The definition of "intelligence" was signed by 52 scientists who joined together in the group "Mainstream Science of Intelligence" in 1994. It says [9]:

"Intelligence is a very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly, and learn from experience. It is not merely book-learning, a narrow academic skill, or test-taking smarts. Rather, it reflects a broader and deeper capability for comprehending our surroundings "catching on", "making sense" of things, or "figuring out" what to do."

There are more definitions of intelligence and its division, but the one which is generally accepted is the approach of multiple intelligences derived from Gardner's theory of multiple intelligence, listing nine basic types of intelligence: linguistic intelligence, logical and mathematical intelligence, spatial intelligence, physical and kinaesthetic intelligence, musical intelligence, naturalist intelligence, interpersonal intelligence, intrapersonal intelligence, and existential intelligences.

Assuming that all people have a certain level of each of these types of intelligence and that most people can develop each of them to a certain level of competence, there are opportunities for implementation of the results of these studies in the teaching process as well, both in traditional teaching and in e-learning [10].

With the development of computers, some new studies emerged as to whether the previously mentioned features of "biological" intelligence can be transferred to a machine. At the end of the 1950s, the concept of artificial intelligence was introduced with the intention of encompassing all studies related to transfer of natural intelligence properties to a machine, particularly to a computer, with the aim of enabling such a computer to solve the problems (very complex tasks) which can not be solved or could be solved with great difficulties (long running time, high costs for designing and implementing such programs) [11].

Artificial intelligence can be defined as intelligent behaviour of machines with the ability of: reasoning, collecting and using of knowledge, exchanging ideas and determining a problem [12].

The concept of artificial intelligence often goes with concepts of computer intelligence and distributed or shared artificial intelligence. Computer intelligence is an area of artificial intelligence that combines fuzzy systems, neural networks and genetic algorithms [13], while distributed artificial intelligence is primarily related to agent technology and multi-agent systems.

Distributed artificial intelligence is inspired by biological systems of collective intelligence that was mentioned by Peter Russell in his 1981 book "The Global Brain". Russel starts with the so called "Gaia hypothesis", the ecological theory set by James Lovelock in 1960, in which all living beings on earth form a unique collective organism, and ends with the idea of a social intelligent super-organism. Numerous authors have followed up this theory later, and their basic idea was that intelligent behaviour can emerge as a result of interaction between a large number of individuals based on principles of cooperation or rivalry (competition). Sometimes this type of intelligence is called the intelligence of the crowd [14].

Distributed artificial intelligence has a special relation to knowledge. In the systems of distributed intelligence knowledge is not separated and stored as in the system of artificial intelligence, nor did it serve as a base to form any kind of a structure as it is the case with computer intelligence. Here, the knowledge is hidden in the laws of interaction between the separate individuals. A special area of distributed intelligence is the collectivity of intelligent individuals (intelligent multi-agent systems) which find their natural inspiration in civilization. Civilization is the result of the collective work of intelligent individuals (people). In this case knowledge is stored in each and every individual, but it is also hidden in the interactions between these intelligent individuals - agents [11].

The concept of intelligent agent is one of the most important concepts that have emerged in the field of computers since 1990. The agent technology is crucial in terms of human - computer interaction [15]. In addition to the term of "agent", there are many other similar terms used in other fields such as: autonomous agent, software agent, intelligent agent, or a bit more specific terms of virtual agent, mobile agent, information agent, and user interface agent. Various versions of the term are in use so often that, as a result, there is no commonly accepted stance on what an agent is [16].

Many different researchers have provided a definition of an agent, emphasizing its main feature – autonomy. Among these definitions we can distinguish:

"An agent is a computer system located at a certain environment that is capable of flexible autonomous actions in that environment in order to meet its design objectives." [17][18]

Along with the feature of autonomy, the weak notion of an agent includes also social ability (interaction with other agents), reactivity (agents can observe the environment and respond to its changes) and proactivity (act to reach goals). The strong notion, together with the elements mentioned, also includes mental concepts commonly applied to people (belief, desire, intention, knowledge, emotions), and in the field of artificial intelligence it includes the following features [2] [19] [20]:

- Mobility. Agent is capable of moving from one network node to another.

Every mobile agent consists of three components:

1. a program code that contains agent logic,
2. data, i.e. internal attributes that represent agent's knowledge, and
3. performance states.

- Rationality. Rationality is evident in situations in which an agent having a set of goals, of which only one is active, will not perform actions that might be in conflict with his current goals. A rational agent must always perform actions that would ultimately maximize the expected result and at the same time use its knowledge about the current and future state of the environment.

- Benevolence. Agent's goals must not be mutually conflicting if an agent is wanted to maximize the expected result.

All definitions add some other characteristics, among which interaction with the environment is mentioned by most specialists. Features as interactivity, autonomy, pro-activity and learning make agents to be an interesting approach in implementing e-Learning environments and provides flexibility for future extensions.

Except for the absence of a unique definition of an agent, studies often state their comparison with objects. Objects are defined as computational entities that encapsulate some state, are able to perform actions, or methods on this state, and communicate by message passing. While there are obvious similarities, there are also significant differences between agents and objects. The first is in the degree to which agents and objects are autonomous. The locus of control with respect to the decision about whether to execute an action is thus different in agent and object systems. In the object-oriented case, the decision lies with the object that invokes the method. In the agent case, the decision lies with the agent that receives the request. The second important distinction between object and agent systems is with respect to the notion of flexible (reactive, pro-active, social) autonomous behaviour, while in objects we find nothing about such behaviour [18]. The third difference is related to multithreading. A standard object model has only one control thread in the system. Multi-agent systems are naturally multithreaded, and each agent in the system has at least one control thread [16].

Agents are different from objects since they are not directly linked to each other. Instead of having objects that use other objects, we have a group of agents that communicate and help each other. This makes it easy to remove or replace an agent without the system breaking down. The other agents will then not be able to contact it. However, some agents may act on the environment more than others. This depends on how vital their services are. New agents can also be created on the fly as a substitute for agents that have become dysfunctional, which makes multi-agent systems more error-tolerant and more reliable [21].

Due to agent properties, agent technology is the subject of research in various scientific fields. In recent years it has been increasingly used for commercial purposes, and examples of implementation of multi-agent systems include air traffic control, electric vehicles drive systems, energy industry, robotics, computer games, e-business, and e-learning. The development of new technologies and methodologies in knowledge transfer in the domain of e-learning is conditioned by a growing number of users. Nowadays learners are often confused with the large amount of learning contents, various content formats, different methods of accessing them and more standards to be followed while teaching or learning through web based education system. To identify information that suites their needs in terms of their prior knowledge level, preference, learning style, learning personalities, interest and so on, is a challenge for many researchers in the field of e-learning. Advanced information and Internet technologies increase these challenges of modern day educational environments, so agent technology appears to be a new approach to address these challenges [7].

III. MULTI-AGENT SYSTEMS

Multi-Agent System (MAS) is characterized by a set of intelligent entities (agents) that collaborate by means of defined communication protocols to achieve predefined goals. Each agent has a defined activity area over which it has certain control i.e. certain impact. Sometimes these areas overlap, and in that case the co-operation or collaboration between agents is necessary [22] [23]. Cooperation between agents is a two-way communication process that may depend on agents' objectives, their resources, and their capabilities.

Agents' knowledge and their awareness of other agents' knowledge is crucial for development of any multi-agent system and it is the main characteristic of the whole technology.

Within a multi-agent system, it is often necessary for agents to be aware of their own actions and capabilities, as well as actions took by other agents around them and information they possess (knowledge gained through mutual communication) [24].

Along with cooperation and number and types of agents in the system, another important characteristic of multi-agent systems refers to the goal structure. The system can have one goal, whose realization is the result of co-operation of all agents within the environment. Within the system there may also be sub-goals, so the cooperation between agents is not necessary and one agent can have more different goals. Therefore, the basic features of the multi-agent system are as follows [16]:

• Each agent has incomplete information and capabilities to solve the global problem
• There is no global control of the system
• Data are decentralized
• Calculation is asynchronous

Thanks to its features and characteristics,, the multi-agent system is a promising platform for building software. The advantages of multi-agent systems in large software systems are as follows [25]:

- acceleration and efficiency (due to asynchronous and parallel calculation)
- robustness and reliability (cancellation of one agent results in degradation but not cancellation of the entire system)
- scalability and flexibility (it is easy to add new agents to the system)
- cost reduction (the price of an agent is much lower compared to the price of the system)
- development and reusability (it is easier to develop and maintain modular than monolithic software)

Despite these advantages, there is an opinion on the need for further research in the field of agent-based software development before the multi-agent paradigm becomes widely accepted.

IV. RESEARCH OVERVIEW OF MULTI-AGENT SYSTEMS IN E-LEARNING

The dominant approach in technology-enhanced learning has been for many years the information transfer, which is based upon the central figure of the teacher whose primary activity is the provisioning of educational contents to be transferred to learners who consume these contents in a passive way. As a consequence, many e-learning solutions provide a simple "digitalization" of this approach and, in most cases, they are mostly distance learning software platforms, where the focus is on the educational resources, that is only an input of the whole learning process, and on their presentation (delivery). This aspect, together with other relevant omissions, like the support for pedagogies, the contextualization of the learning experience, the engagement of the learner in activities, are considered the main barriers to e-learning adoption and in many studies, it follows the efforts of scientists to overcome them with the use of new technologies [26].

The recent trend in the field of e-learning and tutoring systems is to utilize agent technology and develop and use different kinds of agents in virtual learning environments.

Bokhari and Ahmad [27] state the main advantages of applying multi-agent systems in e-learning:

- Cooperativity: the possibility of intelligent interaction between team members;
- Adaptability: the possibility of personalization by the model of a learner and a mentor; storing all information about users from routine operations; provides better interactions between learners and teachers.
- Intelligence: providing intelligence for e-Learning system, thus enabling it to have knowledge of the user model and provide help.
- Reusability: eliminates duplication of activities - tasks are shared among various applications of the system.

These advantages can contribute to the development of prospects in the field of e-learning, particularly in terms of personalized learning (individual learning of presented content, individual experience and prior knowledge of an individual, motivation and mental effort they make, some social norms and values, current learning environment) and improvement of self-organized and informal learning in general. The concept of personalization and adaptation is crucial to the efficiency of acquiring knowledge in e-learning. The potential of application of multi-agent systems in e-learning lies in the function of intelligent teaching that can support the mentor/teacher in his activities, lead the students in achieving their educational goals based on their performance, progress and learning styles, all tailored to personalized process of learning.

Over the last twenty years, there have been numerous studies about agent technology in e-learning systems. However, the studies were based on the application of multi-agent technology from a certain point of view, representing different types of architecture (logical, reactive, BDI, hybrid), agent-oriented methodology (Gaia, AEIO, MaSE, etc.), agent-oriented programming languages (JAVA, KQML, FIPA-ACL, FIPA-OS, etc.), agent-based software platforms (JADE, JATlite, MadKit, PMA3) with emphasis on agent types.

During the search of available literature related to this area of interest, a special attention was focused on the papers dealing with research, development and implementation of multi-agent systems in e-learning. The research was based exclusively on the types of agents in e-learning systems. The research was based exclusively on the types of agents in e-learning systems, with an emphasis on:

1. The structure of agents and their role within the system
2. Author's contribution to the research

Analysing the above mentioned research, the following was observed:

1. Most authors come from Asia, but there is also an interest in such research in Europe.
2. According to available literature, the largest number of research papers was published in 2015.
3. Interactivity between a student and a teacher, as one of the most important factors of e-learning, is not taken into account in all systems. The emphasis is on the interaction between the system/agent and the user (student), while the interaction agent-mentor (teacher) appears in the form of instructional design, and as a help to a mentor in realization of assigned tasks, and giving advice to students while monitoring their learning process [28].
4. Each of the systems has some kind of an agent in charge of personalization and/or adaptation of educational content to the user model.
5. The role of a security agent in e-learning systems was observed only in research by Bokhari and Ahmad [29], and Arif et al. [30].
6. The contribution of the above-mentioned studies of multi-agent systems application in e-learning is reflected in:

- scalability, availability, distribution of computer power systems and storage systems, as well as sharing of services and information among users and organizations that contribute to the e-learning system [31];
- the ability of combining intelligent agents with the Moodle e-learning platform [17];
- problem solving in adaptive hypermedia systems such as inconsistency that occurs when two or more rules conflict, convergence that occurs when two or more rules are equal, and insufficiency that occurs when one or more rules required are not defined [32];

- the introduction of agents whose role is to increase user motivation (a new concept of useful and misleading pedagogical agents) [33];
- various possibilities of system customizing to the user 's mental model;
- the implementation of cooperative learning in e-learning systems, the ability of monitoring its progress without involvement of a mentor/teacher, the possibility of a group discussion in real time [34] [35];
- the possibilities of combined learning [36];
- the possibilities of upgrading the system and implementation of intelligence feature into e-learning systems;
- integration of MAS benefits with the learning management system and cloud computing services [28].

7. As suggestions for future research, the authors state:
- additional possibilities of adaptation to the user model (e.g. introduction of agents with data mining techniques) [36];
- the application of ontology in educational models in order to set additional rules to enhance adaptive functionality based on facts modelled in the knowledge base and with the help of additional relationships [37];
- proposing a method of chat and forum content analysis in the field of cooperative learning [38];
- the use of Moodle as cloud LMS and JADE platform (Java distance learning framework) as a MAS framework development [17].

V. CONLUSION

New information and communication technologies brought about changes in the educational process, enabling development of new methods and ways of learning and teaching implementation.

Traditional teaching is less and less responsive to the needs of contemporary society whose requirements have an emphasis on personalization and adaptation, as well as on elimination of limiting factors such as spatial distance, time constraints, age or individual needs. In this respect, learning in the electronic environment offers new opportunities in modernizing of the teaching process. In order to respond to these requirements, numerous studies have been conducted regarding development of e-learning system, and they include implementation of various methods of instructional design and pedagogical support. The authors' aspiration is focused on improvement of the process of acquiring knowledge to suit to the mental model of users.

Artificial Intelligence combines research from technical, social and biological areas, and implies the use of intelligent methods for solving tasks in complex systems. Due to its multidisciplinarity, its potential is recognized in e-learning research as well.

The multi-agent system developed for e-learning runs simultaneous processes and distributes to multiple functions in the process of e-learning. In addition to these features, such a system has the capacity of intelligence and ability of social learning, autonomy, social ability, reactivity and proactivity. The role-based approach for multi-agent systems is based on a meta model that can potentially simulate components of the education system (ie. people or environment) in the form of intelligent agents.

This paper provides explanations of the concepts of e-learning, intelligence, artificial intelligence and agent. It presents features of agents and significance of their implementation in the field of e-learning. It describes the concept of multi-agent systems as well as their features and benefits of their application in large software systems, especially in e-learning systems.

The application and significance of agent architectures, agent-oriented methodologies, agent-oriented programming languages, and agent software platform in e-learning systems are not included in research review analysis of these systems. The literature covers 19 studies conducted in the period between 2010 and 2017.

These studies are analyzed from the aspect of structure and role of agents in the system, the contributions of researchers and their proposals for future research.

Further research will focus on additional analysis of these systems in terms of implementation of agent architecture, agent-oriented methodologies, agent-oriented programming languages, and agent software platforms, on more detailed analysis of agent types in terms of determining agent population that could meet users' requirements, as well as on their implementation in an intelligent tutoring system.

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ANFIS based expert system for urban mobility estimation based on user's telecommunication activities in public mobile network

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***Abstract* - New approach of urban mobility estimation using urban mobility indicators is presented in the paper. Indicators are calculated from anonymized data from public mobile communication network. The data set is derived from Call Data Records database that contains information about user's telecommunication activities in the predefined area of the corresponding base stations. New approach is realised as expert system based on fuzzy logic and neural network. The result is ANFIS based expert system framework for urban mobility estimation trained using set of rules that were determined using method of surveying experts in domain of urban mobility.**

Keywords - urban mobility estimation, indicators, index, ANFIS

I. INTRODUCTION

Urban mobility can be defined as the possibility of movement of individuals in urban space in an organized and coherent manner in accordance with their physiological, intellectual and socio-economic needs, using existing transport, utilities and ICT infrastructure [1]. The goal of this paper is to establish a process of the population's urban mobility estimate as a quantitative measure of the process of urban migrations caused by socio-economic activities, one which is in the function of determining a new urban mobility estimation index. This paper will use an approach that will use previously defined indicators of urban mobility as an input into the process of urban mobility estimation. Urban Mobility Indicators are defined by the appropriate process from Call Data Record database (data generated by communication events when some telecommunications activities are performed by subscribers in the network), and need to be consolidated into a unique urban mobility index. The data needed to define the relationship between the value of the fundamental indicators and the value of the urban mobility index estimation will be collected by a survey of experts from the domain of urban mobility. This process is known in the theory of expert systems as "gathering" the expert knowledge and its mapping into the software solution of the expert system (knowledge base, rule base). The survey will include questions in the form of scenarios that include the values of fundamental indicators of urban mobility, defined to include characteristic indicators of values (from predefined ranges), as well as the proposed procedure for estimating urban mobility, based on the findings from the scientific literature. On the basis of its own judgments, experts will assign each scenario the appropriate value using the proposed mobility estimation procedure. The results of the survey will provide a link between the value of the fundamental indicators from the scenario and the value of the mobility estimates. This set of data will be used to form an expert system for estimating urban mobility.In the future, it is possible to apply this methodology through advanced applications of Intelligent Transport Systems (ITS). ITS is an holistic, control and information & communication technologies (ICT) upgrade of classic traffic and transport systems which significantly improves system performance, traffic safety, efficiency in transportation of goods and passengers, increases passenger protection and comfort, reduces pollution, etc, [2]. Typical examples of such applications are driver and passenger information systems, traffic management, incident management systems, urban public transport management, and so on, [3, 4].

II. ESTIMATION OF URBAN MOBILITY USING PUBLIC MOBILE NETWORK

Previous approaches to urban mobility estimation utilizes the use of procedures that include indicators and mobility indices [5, 6]. Urban Mobility Indicator can be defined as the value based on data from the traffic system subsegment (transport, economy, ecology, society or others) which describes the phenomena that affect urban mobility or is the result of urban mobility. The Urban Mobility Index is defined as the value that is the result of the fusion of the relevant indicators of urban mobility with the aim of obtaining urban mobility estimate. Urban mobility is generally estimated by first identifying relevant indicators of urban mobility, and then by creating an urban mobility index. Urban mobility data are of heterogeneous nature and are collected from a variety of sources that are generally divided into three groups [4]. Conventional data sources include well-known data sources such as traffic infrastructure sensors, meteorological senses, ecological senses, and the like. The second group of data sources include information and communication systems of stakeholders in urban mobility (organizations involved in

providing public passenger transport services, infrastructure charging and the like. The third group of data comprises the so-called new data sources, which include the application of relatively new technologies, whose use in urban mobility estimation has not yet been widely used (e.g. public mobile communications networks, social networks, autonomous vehicles).

This paper will focus on data from public mobile communication network, generated from Call Data Record (CDR) database. CDR represents the data generated by (communication) events and represents the records that are created when some telecommunications activities are performed by subscribers in the network. Events include activities such as voice calls, SMS or MMS services, data traffic usage, roaming information. In this paper a expert from this data will be used, that contains information on the start time of the activity and duration of the service, as well as the type of activity, and operators use them for the purposes of recording the customer's telecommunications activities based on which the account for the services provided is formed. The structure and content of data from CDR for telecommunications services are standardized [8] and are independent of the manufacturer of the equipment or of the service provider.

The possibilities of using data from public mobile communication networks for analysis purposes in the field of traffic technology and Transport has been analysed for many years, as is evident from numerous scientific and professional bibliographies from this area.

Conventional methods of gathering information on urban mobility (surveys, cross-sectional measurements) have proved to be impractical, costly and ineffective. They use a small sample of respondents, have limited spatial and temporal coverage and are often carried out at inappropriate time intervals (large differences between data collection). As an alternative source of data for studying patterns of movement in urban agglomerations, the potential of public mobile communications networks was also heavily investigated, which is characterized as a new source of data that needs to be further explored. Overall, the current research has proven that this new source of data presents great potential in urban mobility research, primarily because it encompasses almost the entire population sample (the use of mobile devices is characterized by high penetration rates in almost all developed countries), and related to baseline station information can approximately reconstruct and the movement of the user. Also, increasing the number of mobile phone users has reduced and almost eliminated the difference between the number of people who have a mobile phone and those who do not have them, thus making this data source more suitable for mobility research [9]. According to the literature review in this area [10-15], we can conclude that authors have been paying close attention in the last two decades to the use of data CDR for monitoring traffic flows, urban planning and similar purposes. The authors have proved that the sample covered by the CDR record is representative, that the reliability of the method is high and that it has a high correlation coefficient by comparing such generated indicators with those indicators from traditional sources. Several different indicators are suggested that can be derived from a subset of data, although there are no unified procedures for obtaining and calculating them. Most authors identify an indicator of urban mobility (e.g. travel matrix), with more frequent emphasis on personal mobility, i.e. mobility of individual users within urban agglomeration, and less on the assessment of mobility at urban agglomeration level. Also, depending on the purpose and purpose of the research, the indicators are set for a time frame ranging from a few hours up to one year.

III. URBAN MOBILITY INDICATORS AND EXPERT KNOWLEDGE GATHERING

This chapter will outline the methodology for collecting expert knowledge to be used to establish an expert system for modelling urban mobility estimates. The expert system is defined as a system in which human knowledge is embedded with the help of which it solves the problems of a specific area in a manner that is solved by an expert [16]. Thus, from the record of telecommunications activities in public mobile communication network, an appropriate subset of data was extracted containing the following information; the time of realization of telecommunications activity, the position of the base station to which the user is connected during the telecommunication activity and the replacement identification of the user who conceals the actual identity). These data are used to define the following indicators of urban mobility: number of migrations (number of trips), trip duration and Euclidean distance among base station pairs [1]. These indicators will be used as an input for assessing urban mobility. The first indicator is the indicator of the number of trips. An algorithm for determining this indicator is applied, and the result is the data stored in the travel matrix whose fields contain the total number of trips between certain pairs of base stations (corresponding urban space) in the predefined time frame. The second indicator is the time travel indicator, which is calculated as the mean value of the all recorded travel times between certain pairs of base stations in the time frame. Then the third indicator, the indicator (Euclidean), between the pairs of base stations is determined. The input data needed to define the relationship between the value of the urban mobility indicators and the value of the mobility estimation can be collected by an expert method and by surveying experts from the domain of urban mobility. The survey questionnaire consists of a set of questions. The question arises from an expert's opinion ("knowledge gathering") on how and to what extent the combination of values of indicators affects the urban mobility. Survey questions include all permutations of the value of indicators included in the urban mobility estimation. The expert answers to the question of giving the appropriate value of the mobility estimate based on their own knowledge and experience in each issue. All values of mobility indicators are relativized, and therefore, those values can be used for urban mobility estimation in different kind of urban agglomerations, irrespective of their size, surface or number of inhabitants. The scenarios are formed used following principle:

If <value of number of trips indicator> & <value of travel time indicator> & <value of distance travel indicator>, mobility is <mobility estimation>.

The example is shown in Figure 1.

Figure.1. Principles for forming scenarios

Through the questionnaires, experts then point to the value of the offered scale for which the mobility estimate can be ranked in different categories.

Upon completion of the survey process, the responses of all the experts participating in the research will be appropriately evaluated and processed and will then be used in further steps in the mobility estimation process. It is necessary to make a preliminary analysis of the data for checking the consistency of the response, as well as identifying individual questions where there is a strong consensus or difference in the opinion of the expert. Differences in expert opinion are expected, as experts see mobility from different areas, depending on their field of study.

IV. ANFIS BASED EXPERT SYSTEM FOR URBAN MOBILITY ESTIMATION

In order to establish an expert system for mobility estimation, a method of fuzzy logic, or an adaptive neuro-fuzzy inference system (ANFIS), will be used. Fuzzy logic is a form of many-valued logic in which the truth values of variables may be any real number between 0 and 1. It is employed to handle the concept of partial truth, where the truth value may range between completely true and completely false [15]. By contrast, in Boolean logic, the truth values of variables may only be the integer values 0 or 1. An adaptive neuro-fuzzy inference system or adaptive network-based fuzzy inference system (ANFIS) is a kind of artificial neural network that is based on Takagi–Sugeno fuzzy inference system. The technique was developed in the early 1990s. It integrates both neural networks and fuzzy logic principles, it has potential to capture the benefits of both in a single framework. Its inference system corresponds to a set of fuzzy IF–THEN rules that have learning capability to approximate nonlinear functions. ANFIS is a machine learning technique that uses fuzzy logic to convert the given input data into the corresponding output values [16]. It contains a neuron network as a structured network consisting of a number of nodes (neurons) interconnected by a directed link. Each node is characterized by a specific function with fixed or variable parameters. Changing parameter values causes adaptive (meaning their outputs depend on parameters that change through the network by passing through the links and other nodes) and non-adaptive (fixed) nodes of the network, but in conjunction with the learning rules that specify in what way these parameters will be changed in order to minimize the prescribed error measure. ANFIS works on the principle of the application of the conclusion methods characteristic for neural networks with the purpose of determining the parameter of fuzzy interference system (FIS) [17]. The result is a system that allows the use of well-known algorithms for learning artificial neural networks, which cannot be used in fuzzy systems, while at the same time retaining the ability to use fuzzy logic and fuzzy conclusions. For the modeling of an inconclusive conclusion of the ANFIS type, the appropriate Neuro Fuzzy Toolbox program is used within the Matlab program tool.

ANFIS process overview is presented in Figure 2. Training process begins by obtaining training data set and checking data set. Training data consist of two vectors, first is input and second is output vector. Those vectors are used to train the ANFIS system. Training data set is used to determine parameters for membership function and threshold value for the error between the actual and desired output is determined. Consequent parameters are found using least square method, and when the error becomes less than threshold values process will terminate.

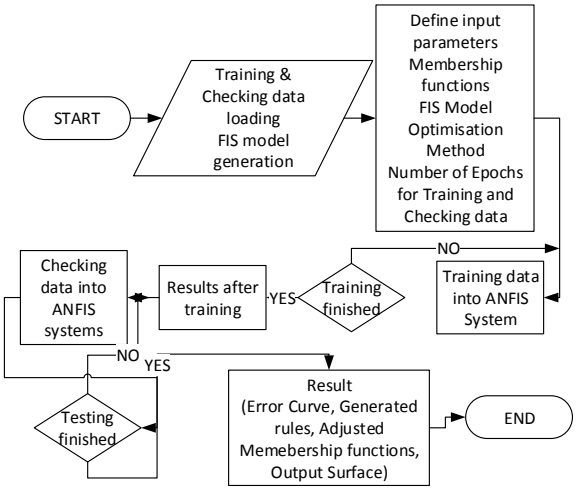

Figure 2. ANFIS training process, based on [19]

ANFIS training learning rules use hybrid learning, combining the gradient descent and the least squares method. Training begins by creating a set of training data to be able to train the Neuro-Fuzzy system. The data set used as the input must be in a matrix form. First three columns represent input data with values of urban mobility indicators, as presented to the experts, and the last column in the matrix is the output, value of mobility estimation, generated by processing responses from survey data. Initial membership functions for al input variables are created (for three mobility indicators), and the parameter of membership function is determined. Input and output variables for fuzzy interference system are presented at Figure 3. Following the initial membership functions creation, system training begins. When the training process is finished the final

membership functions and training error from the training data set are produced. In order to identify the most appropriate system, system has to be trained with a variety of settings for items such as data set sample, epoch number, membership function type and number, and number of inputs in order to achieve the best performance. The checking data is then used in conjunction with the training data set for accuracy enhancement.

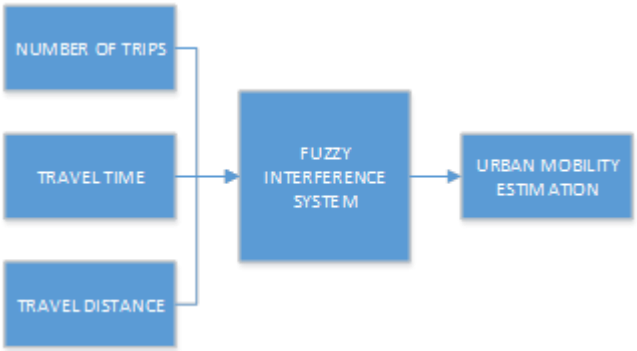

Figure 3. Input and output variables to fuzzy interference system

The result of this process is ANFIS based expert system for urban mobility estimation based on user's telecommunication activities in public mobile network.

V. CONCLUSION AND FURTHER WORKS

The goal of this paper was to establish an ANFIS based expert system for urban mobility estimation. It utilizes urban mobility indicators derived from data expert from public mobile operators CDR database, and uses them to create urban mobility index. For proposed expert system based on ANFIS methodology, a set of rules had to be determined. Those rules were identified by using method of expert knowledge gathering, in which the experts were presented with urban mobility scenarios, and had to provide an urban mobility value for them, based on their expertise. The results of the survey provided a link between the value of the urban mobility indicators from the scenario and the value of the mobility estimates, and this set of data was used to form rules required for ANFIS based expert system creation. Therefore, this paper has proven that urban mobility indicators derived from excerpt of data from public mobile communication network, can be used to form an urban mobility index, by using ANFIS based expert system. Future work will explore the possibility of applying these results to the improvement of the various components of urban mobility, particularly in the area of advanced urban traffic management applications [20], the help of city authorities when proposing future solutions from urban transport infrastructure [21], urban population consultation actions [22], etc.

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A Generic Approach for Order Picking Optimization Process in Different Warehouse Layouts

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Abstract **– The warehouse layout directly affects the process of receiving and storing of goods, as well as the order picking process. A standard layout has its pallet places arranged in parallel shelves with aligned cross-aisles. However, a big number of warehouses use a shelf layout in which the complete warehouse cannot be represented as a sequence of parallel shelves. Effective calculation of distances between positions in the warehouse presents a significant step towards the effective order collection and distribution of goods. This paper describes a generic approach for calculating distances within a warehouse which does not necessarily have standard layout. It describes the application of the algorithm on different warehouse layouts in which the shelves can be split into smaller units so that inside of each unit the shelves are distributed in a standard way. Dynamic programming was used for the calculation of distances inside of those units. An analysis and testing of the algorithm were performed on two middle-sized warehouses with non-standard shelf layout. The algorithm was tested in the process of collecting orders, as well as the process of moving goods from the stock to the pick zone.**

Keywords – Warehouse Management System; Warehouse Layout; Order Picking Optimization Process; Calculating Distances

I. INTRODUCTION

A warehouse management system (WMS) consists of many challenges that need to be solved in order to improve warehouse working process. A high-quality warehouse management system can improve business process and lead to lower costs. An efficient management system is extremely important for workers, because even in medium-sized warehouses, workers are not able to make optimal decisions in every situation.

Hompel and Schmidt [1] concluded that the activities of the warehouse optimization process can be divided into three groups: *technical structure*, *operational and organizational framework* and *coordinating and controlling systems* for warehouse optimization.

In this paper, a subset of problems from the second group will be mostly researched, but it must be noted that the process of solving operational problems largely depends on the technical structure of a warehouse. The operational and organizational framework and coordinating processes can be divided into four steps: receiving, storing, retrieving and shipping of goods. Each step must be optimized to enable an optimal flow of goods. To be more precise, every sub-step needs to be optimized.

The processes of receiving, storing, retrieving and routing largely depend on the method for calculating distances inside the warehouse. Many algorithms have been created to solve the problem of distance calculation, but they are mostly adjusted and researched for warehouses with standard layout. In the real world, many warehouses do not have standard layout due to practical limitations.

The main contribution of this paper is the algorithm for calculating the distance in a warehouse with a non-standard layout. The algorithm is used for solving order picking problems and for finding a location for transferring goods from the stock to the picking zone in warehouse management. The efficient heuristic for order picking problem largely depends on the distance calculating process inside the warehouse.

The paper is organized in five sections. In this section the basic warehouse management system and warehouse optimization problems are described in order to give motivation to the paper. In the second section, related work and most used warehouse layouts and routing methods are presented. In the third section, the process of dividing warehouse layout to smaller organizational units is described. The process of calculating distances between two pallet places inside the warehouse layout is also described as the heuristic algorithm for order picking and transferring goods from the stock to the picking zone. In the fourth section, the usage of the algorithm in one of the largest warehouses in Bosnia and Herzegovina and an example of dividing non-standard layouts to basic layout units are explained. In the last section, appropriate paper remarks and future research opportunities are presented.

II. RELATED WORK

In this paper, picker-to-product warehouses will be in focus. Picker-to-product warehouse is a warehouse where the worker is traveling to picking locations through aisles and picking items from pallet places [2]. Pallet places are divided in two zones: picking and stock, and pallets are placed to shelves. Items that are in the stock zone are not reachable to worker without a forklift. On the contrary,

the worker can reach every item in the picking zone by hand [3].

Processes in goods distribution centers are well researched because they have a huge influence on the operational costs savings and the complete business process [4]-[7]. Baker et al. [7] stated that three areas of research are considered in warehouses with pallet storage:

- Stock location policy selection.
- Travel time and/or distance consideration.
- Floor space allocation.

Rouwenhorst et al. [8] stated that the warehouse design should consider a large number of interrelated decisions and that layout cannot be decided by observing only small number of decisions. Gue and Meller [9] described standard warehouse layouts. In most cases, in the process of the warehouse design, layouts are created in a way that all picking aisles and cross-aisles are straight. The picking aisles are parallel in pairs. The cross-aisles meet picking aisles at the right angle. The goods are usually stored in pallet quantities and placed in shelves (see Figure 1). The shelves are organized in many levels.

Pohl et al. [10] researched standard layout modifications that are called Fishbone and Flying-V. They have proved their advantages over standard layouts. Berglund and Batta [11] researched an optimal placement of warehouse cross-aisles in warehouses with standard layout. Methods for creating warehouse layout are researched and reviewed [7]. A heuristic approach to warehouse layout design is shown [12]. All those methods comprise standard warehouse layout and their insignificant modifications.

Warehousing can be described in three functions [12]. Goods are received and stored on the appropriate pallet places. Customers are making orders. Worker travels through aisles and collects goods from an order in picking carts [9]. Parikh [13] defined order picking as the operation through which items are retrieved from storage locations to fulfill customer orders.

Order picking route is a path that worker has to walk to pick all supposed goods. Routing is a process of creating an optimal route so that a picker has to walk minimal distance. The warehouse layout has a major impact on the complexity of the travel route and the picking process [12].

Chiang et al. [14] stated that the order picking process takes for about 55% of the warehouse operating costs. The order picking process can be broken into few parts. The traveling takes 55% of the order picking time. The process of searching takes 15%, extracting 10% and paperwork and other activities 20%. That makes the order picking the most time consuming process in most warehouses. That confirms that routing is a process of huge interest for creating high-quality WMS.

Roodbergen and De Kostner [15] described various routing heuristics (S-shape, largest gap, aisle-by-aisle). De Koster et al. [16] reviewed design and control of the warehouse techniques. Roodbergen and De Koster [17] described an algorithm for finding the shortest path in a warehouse with a middle aisle. Ratliff and Rosenthal [18]

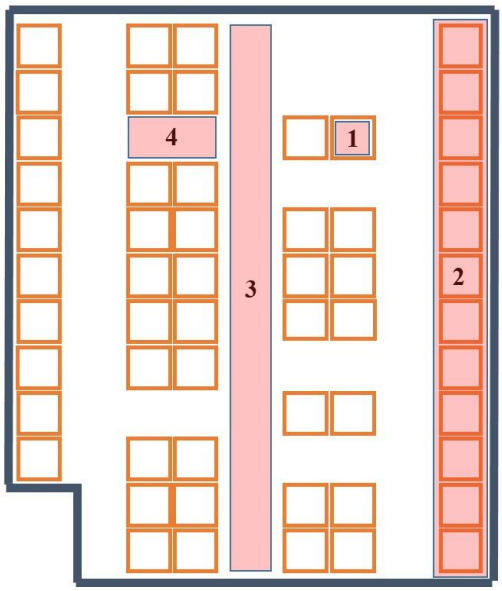

Figure 1. Warehouse layout representation. (1) pallet place (2) shelf (3) picking aisle (4) cross-aisle

developed an efficient algorithm for rectangular warehouse layouts with two cross-aisles. The algorithm is based on dynamical programming and it is solving the order picking problem by transforming it to the traveling salesman problem (TSP).

The heuristic that can solve routing problem in warehouses of any layout where aisles are straight and cross-aisles are perpendicular to them is described. That is a significant improvement, because the layout does not have to be rectangular. The heuristic is also based on dynamic programming and it is transforming the problem to TSP. One of the most significant contributions is an algorithm for calculating distances in warehouse of any standard layout with an arbitrary number of cross-aisles that are connecting picking aisles. The cross-aisles do not have to be aligned [19].

As mentioned, the stock zone is defined as the warehouse zone that is not reachable without a forklift, and if the worker has to pick an item from the stock zone, he has to wait for the forklift to put the complete pallets down from the top shelves. That is a time-consuming negative process that increases the operational costs. A huge improvement can be achieved by finding the optimal quantity of goods that can satisfy daily needs for warehouse orders. In that case, a forklift can transfer goods in the beginning of the day, so the worker does not have to pause on their walking route and wait for the forklift. A heuristic method for transferring the optimal number of items is given. With the usage of the mentioned method the number of transactions can be reduced by 25 times [3].

In the process of goods transferring from stock to the picking zone, every item has to be transferred to the best location. Finding the best location depends on calculating the minimum distance from the position in the stock zone

to all potential pallet places where goods can be transferred to. For doing that, the efficient method for calculating distances is necessary.

Process of initial goods placement also depends on distance calculation. When goods arrive in the warehouse, they need to be placed to the stock or the picking zone. Best location has to be found. In many cases, the method which is used is to find the closest free location and place goods there [20].

III. CASE STUDY

Order picking process is a special case of the traveling salesman problem. As TSP is one of the most researched problems of combinatorial optimization, with time some efficient algorithms, which give good results, were discovered, but also techniques for the approximation of the lower bound of the optimal tour. Johnson et al. [21] provided a way of finding a lower bound that is at average 0.8% below the optimal tour. In that way some simple (but efficient) local search algorithms, like 2-opt or 3-opt, which usually give results that differ from this lower bound about 5% for 2-opt and 3% for 3-opt, were developed. Aside from that, some advanced algorithms were also discovered, like the Lin-Kernighan algorithm, which gives results that differ about 2% from this lower bound [22].

Thus, the TSP can be considered as solved for practical needs. Because of that, it is necessary to provide all required input information for the TSP in the order picking process. That input information includes the distance between any two cities which have to be visited as well as the starting city. In the case of the order picking process those distances represent the distances between any two places where the articles from the order are located. If some article from the order is located on more than one place, higher priority is given to the locations in the picking zone and places where the expiry date of the article is the most recent. In that way the possibility that some articles expire is lowered. The starting city in this case is the input/output gate.

So, the main problem is to calculate the distance between any two places in the warehouse. If the warehouse has a simple rectangular layout (Figure 2), then the process of distance calculation is straightforward [23]. Namely, let x_i represent the picking aisle number of the stock-keeping unit (SKU) of the article i and y_i ($y_i \in \{1,2,\dots,S\}$) its pallet place number in the associated shelf, where the number S represents the number of in-depth locations of the picking aisle, as is shown in Figure 2. Also, let z_i ($z_i \in \{1,2\}$) represent the side within the picking aisle of the article i. The width of a picking aisle is γ, the depth of a pallet place is α, and its width is β. In order to consider the complex characteristics of the real world application under study, a turning radius Ω is also being considered. It is trivial to get the distance d_{ij} between the articles i and j if they are in the same picking aisle, according to the formula:

$$d_{ij} = |y_i - y_j| \cdot \beta + |z_i - z_j| \cdot \gamma \quad \text{if } x_i = x_j. \quad (1)$$

If that is not the case, that is $i < j$, the distance can be calculated as:

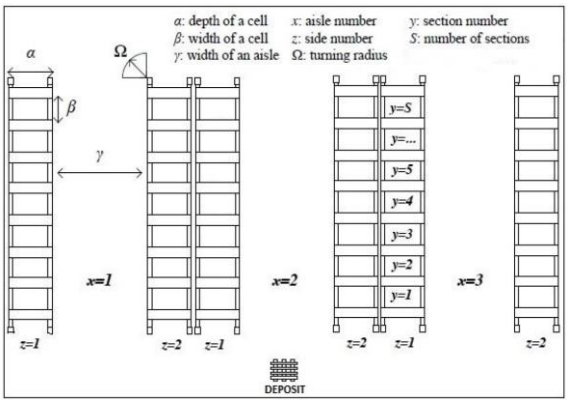

Figure 2. Rectangular warehouse distance calculation [23]

$$d_{ij} = \begin{cases} |x_i - x_j| \cdot (2\alpha + \gamma) + v & \text{if } z_i = z_j \\ (x_j - x_i) \cdot (2\alpha + \gamma) + \gamma + v & \text{if } z_i = 1, z_j = 2 \\ (x_j - x_i) \cdot (2\alpha + \gamma) - \gamma + v & \text{if } z_i = 2, z_j = 1 \end{cases} \quad (2)$$

Here, v is the vertical distance and it is equal to $v = \min\{\beta \cdot (2 - y_i - y_j), \beta \cdot (y_i + y_j)\} + 2 \cdot \Omega$. It is clear that the equality $d_{ij} = d_{ji}$ holds. The distance between any location and the input/output gate can be calculated in a similar way.

However, real-world warehouses often have a more nonstandard layout. It is possible that within one shelf there are more cross-aisles and that the cross-aisles in different shelves are not aligned. Aside from that, it is even possible that the shelves are not aligned, that is the starting and ending points of different shelves are not on the same height. All of these irregularities can be seen on Figure 1.

The algorithm for calculating distances in the case of the mentioned irregularities is described, as long as the shelves are parallel to each other [19]. It is necessary to align the cardinal numbers of the pallet places within different shelves so that locations with same numbers have same height. However, that is not sufficient because there can be a wall or empty space in the extensions of the shelves through which movement is possible. Because of that, fictive pallet places are introduced which align the shelves so that each shelf has the same number of pallet places and its beginning and ending are at the same height. Each pallet place (fictive or real) has a Boolean label which indicates whether it is a cross-aisle or not.

In this paper the crucial part is calculating the distances between any two cross-aisles. That is done with dynamic programming. At first the distances between cross-aisles in the same shelf are calculated, then the distances between cross-aisles in neighboring shelves are calculated, then the distances between cross-aisles in shelves that differ by two and so on. After that, calculating distances between any two locations is straightforward. It is enough to find appropriate cross-aisles for both locations and sum the distance between the cross-aisles and the distances from the locations to the cross-aisles.

The main objective of this paper is calculating distances in warehouses where not all shelves are parallel,

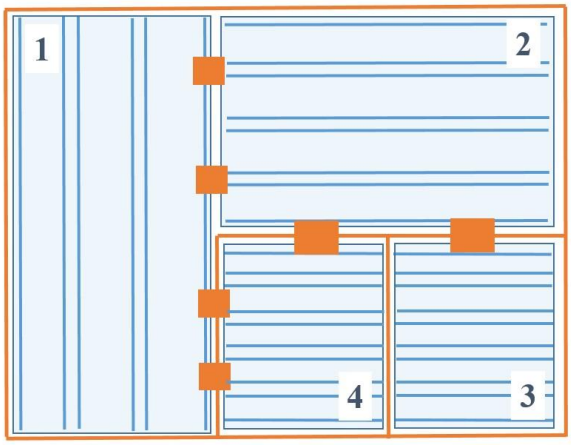

Figure 3. Example of nonstandard warehouse layout. Warehouse sectors are marked by numbers.

as is the case in the warehouses on Figure 3. It was noticed that if the whole warehouse could be split in basic units which have parallel shelves and if all the links between these sectors could be found, then it would be possible to calculate the distance between any two locations in the warehouse. The basic layout unit is called sector (on Figure 3 there are 4 sectors). Links between sectors are marked by field rectangles.

The links between the sectors differ from case to case. Sometimes, between those parts there is a single link as between sectors 2 and 3 (or 2 and 4), but at other times there can be more links as between 1 and 2 (or 1 and 4). A link is defined by five parameters: the first sector, the second sector, the length of the link, the corresponding pallet place in the first sector and the corresponding pallet place in the second sector. The corresponding pallet place of a link represents the location of the ending of that link in a sector. It is also possible that between some sectors a link does not exist (sectors 1 and 3 or 3 and 4).

The sectors have to be connected so that the order picking process could make sense. It is necessary to be able to get from each sector to any other. The sectors can be considered as vertices of an undirected graph where two vertices are connected by an edge if the corresponding sectors have at least one link between them (Figure 4).

Now it is simple to calculate the distances between pallet places in neighboring sectors (sectors connected by an edge in the corresponding graph). Let x be a pallet place in sector A and y a pallet place in sector B (A and B are neighboring sectors). Let $S_i = (A, B, d_i, a_i, b_i), i = 1,2, \dots, n$, be all the links between these sectors. Now the distance between x and y is equal to:

$$\min\{d(x, a_i) + d_i + d(y, b_i)\},\ i = 1,2, \dots, n \quad (3)$$

In the equation (3), the distance between pallet places p and q is denoted by $d(p, q)$. Distances $d(x, a_i)$ and $d(y, b_i)$ can be calculated because a_i and x are inside the same sector A and b_i and y are inside the same sector B, for all $i = 1,2, \dots, n$.

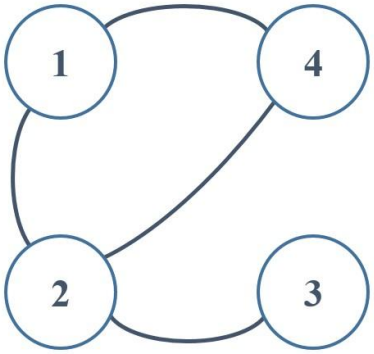

Figure 4. Graph corresponding to the warehouse layout shown in Figure 3

The next step is to find a way of calculating distances between pallet places in nonadjacent sectors. That can be done in the following way: let all the links in the warehouse and the two locations for which the distance is being calculated represent vertices of a graph. Then all vertices which correspond to links which come out of the same sectors get connected by an edge. Also, the two locations get connected to all the links in their corresponding sectors. As it is possible to calculate distances within any sector, the weights of all those edges are already determined. Now, using one of the well-known algorithms for finding the shortest path in a graph (such as the Dijkstra's algorithm) the required distance can be computed.

However, this method is quite ineffective because the graph may have a lot of vertices. For an order that contains n articles it is necessary to calculate $\binom{n}{2}$ distances, which means $\binom{n}{2}$ graphs will be required. These graphs would be very similar because the links and the distances between them are fixed and the only differences are the two locations for which the distance is being calculated. For this reason, it is more efficient to calculate the distances between the links before starting the calculation of the distances between the locations.

That is done by creating new links, even between sectors that do not have direct links. It is done in the following way: let X and Y be two nonadjacent sectors, then for each exit a from X and for each entrance b into Y, if there exist a path from a to b which does not go through A, calculate the distance $d(a, b)$ between a and b. Now a link L can be defined as $L = \{X, Y, d(a, b), a, b\}$. If the sectors of the warehouse are connected, for each two sectors there will be at least one link between them. All these links are calculated and stored in the memory.

Now it is more efficient to calculate distances between any two locations in nonadjacent sectors. It can be done in the same way as for the adjacent sectors because now there exists a link between every two sectors. So, for every two locations and for every warehouse layout which can be parted into sectors which have all shelves parallel, the distance between these locations can be calculated. It means that the order picking problem can be successfully transformed to TSP.

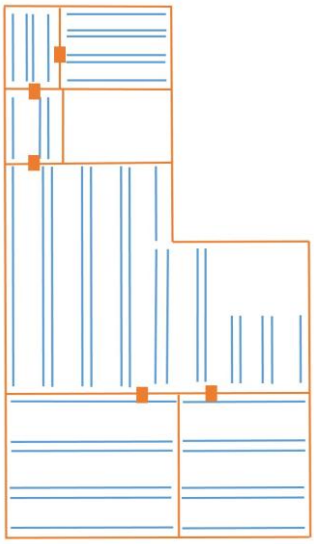

Figure 5. Real medium-sized warehouse layout

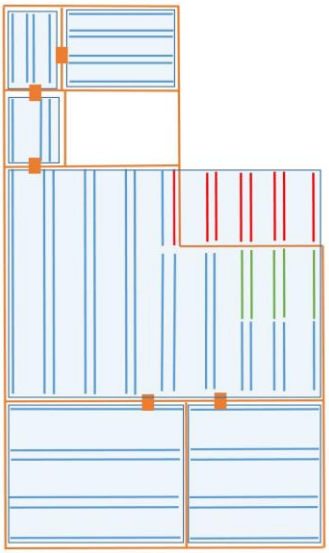

Figure 6. Real medium-sized warehouse divided in sectors

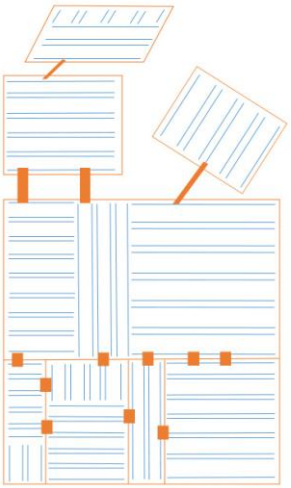

Figure 7. Representative warehouse layout

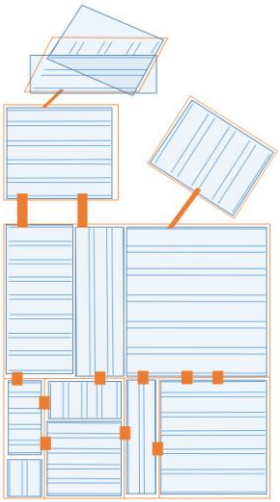

Figure 8. Representative warehouse layout divided into sectors

IV. RESULTS

The algorithm for distance calculation described in the previous section is used and tested in warehouse optimization processes for one of the largest warehouse in Bosnia and Herzegovina. It is used for routing and for the optimization of transferring goods from stock to pick zone. The algorithm is generalized for warehouse layouts of different shapes and sizes. Before implementation of this algorithm, only slight modifications of standard layout were supported by algorithm presented in [19]. These modifications include solving the TSP for every room and then visiting every room in some order. With the new algorithm, the distance has been shortened by 16,2%. Intuitively, the reason for that is that with the old algorithm it is possible that the last article in one room is far away from the next room and it is also possible that a worker, while picking articles from one room, passed next to the entrance to another room.

In the practical case, the layout shown in Figure 5 is given. The layout is represented by the ground plan of the medium-sized warehouse. The layout is not standard and its parts are separated by walls because different types of articles need different temperature conditions. The algorithm mentioned above was not useful because of few specific situations (horizontal and vertical shelves and walls)

To implement the algorithm for distance calculation, the complete warehouse layout must be divided into sectors. The given layout is divided into six sectors as shown in Figure 6. The next step was to find links between sectors. All sectors are transformed and fictive pallet places are added as described in the previous section and as is shown in the largest sector of the divided layout. Green shelves represent empty space where the worker can walk. Red shelves represent obstacles where movement is not possible. After that step the base is

ready and the process of distance calculation between every two pallet places inside warehouse can easily be done.

The same process can be used on various layouts that can be seen in practice. In Figure 7, one of those representative layouts is given. The partition of this layout is given in Figure 8. It can be observed that the layout can contain even slanted shelves which can lead to fictively overlapping sectors. That is not a problem for the distance calculating process, because the links can still be described by five key parameters, which is sufficient for the algorithm. The given layout contains standard layout parts, horizontal, vertical and slanted shelves, walls and parts that are connected to other parts only by a passageway(s).

In any layout that can be represented as a combination of cases described in previous paragraph, the presented algorithm can be used. The algorithm is tested on various warehouse layouts and the results are more than satisfactory.

V. CONCLUSION

An algorithm for calculating distances by using dynamic programming for warehouses of standard layouts is introduced in previous research. This paper describes the improvement of the aforementioned algorithm for calculating distances in warehouses with a non-standard layout.

The application of the algorithm is described for order picking, route calculation process and in process of transferring goods from stock to pick zone. The algorithm can be used for a wide range of warehouses. It is implemented as a set of procedures within the warehouse management system and it is used to optimize operational processes in one of the largest warehouses in Bosnia and Herzegovina. The algorithm has made a significant improvement in the warehouse working process.

The largest limitation of the described algorithm is non-existence of method for dividing warehouse layout into the basic units. The algorithm is currently not given due to many constraints caused by finding the entrances and exits for the found basic layout units.

Future research will focus on creating an algorithm for dividing warehouses into basic layout units and finding entrances and exits for the found units. The distance calculation algorithm will be used to optimize other operational and organizational processes, such as storing and receiving of goods. The algorithm is already used for the order-picking process and the future research will be focused on improving results by adding more constraints, such as weight, volume, fragility, or capacity of picking cart.

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Assessing emotional responses induced in virtual reality using a consumer EEG headset: A preliminary report

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Abstract – We report on a pilot study involving emotion elicitation in virtual reality (VR) and assessment of emotional responses with a consumer-grade EEG device. The stimulation used HTC Vive VR system showing pictures from NAPS database within a specifically designed virtual environment. The stimulation consisted of two distinct sequences with 10 pictures of happiness and 10 pictures of fear. Each picture was contained in a separate virtual room that the participants traveled through along a preset path. The estimation employed EMOTIV EPOC+ 14-channel EEG headset and a custom-developed application. The software wirelessly received EEG signals from alpha, beta low, beta high, gamma and theta bands, time-stamped them and dynamically stored in a relational database for subsequent analysis. Our preliminary results show that statistically significant correlations between valence and arousal ratings of pictures and EEG bands are present but highly personalized. Simultaneous correct placement of VR and EEG headsets is demanding and precise localization of electrodes is difficult. In fact, if emotion estimation is not strictly necessary we recommend using devices with fewer electrodes. Nevertheless, we found the EEG to be effective. By acknowledging its limitations, and using the headset in the correct context, experiments involving emotions may be significantly amended.

I. INTRODUCTION

The aim of this paper is to evaluate the feasibility of detecting emotional reactions induced in virtual reality (VR) using a commercial EEG system. Previous studies have clearly demonstrated that elicitation of specific emotions with films, videos and pictures is challenging but possible [1][2][3]. High stimuli realism, sufficient personal relevance, and strong engagement have been suggested as the most significant factors contributing to immersion and presence leading to a successful elicitation [1][4][5][6]. Key advantages of exposure in VR overexposure *in vivo* are 1) greater flexibility, 2) safety, 3) cost-effectiveness [7].

VR and multimedia systems have been previously employed for detection, prevention, and treatment of phobias, anxiety and other stress-related mental disorders [5][7][8]. They have proven themselves very useful in a whole spectrum of therapies such as exposure therapy [9], stress inoculation therapy [10], stress resistance training [11], relaxation [12] and biofeedback [13]. Additionally, multimodal systems that combine VR and different multimedia formats have been successful as assistive tools in psychotherapy of PTSD patients [14][15]. However, only recent advancements in computer hardware have made it possible to render photorealistic graphics in real-time and with sufficient detail to provoke emotional responses on the same level as real-world photographs [16].

II. RELATED WORK

Recently, a number of related studies concerning detection of emotion-related phenomena using customer-grade EEG equipment have been published. One research proved initial usability of low-cost EEG equipment paired with VR in the detection of low-intensity and long duration emotion states such as moods [17][18]. This research obtained results that are in accordance with scientific literature regarding frontal EEG asymmetry, which supports the possibility of using the portable EEG as a reliable instrument to measure emotions in VR. In another research, the same type of low-cost EEG was demonstrated to be useful in providing emotional awareness information for synchronous collaborative editing systems [19]. These previous investigations motivated the exploration of emotional responses on EEG bands using low-cost commercial devices, as employed in our study. Also, scholars have been successful in combining commercial facial analysis software and EEG in emotion detection [20]. They have achieved 53% accuracy in emotion classification by fusing both information sources, which is higher than 19% accuracy when using only facial expression analysis tool.

III. COMMERCIAL-GRADE VR AND EEG SYSTEMS IN THE ASSESSMENT OF EMOTIONAL RESPONSES

HTC Vive is a high-end VR display device made by HTC and Valve Corporation (Figure 1) [21]. It is commercially available since April 2016. The device was designed to take advantage of available physical space and to use it as a free 3D environment within VR. This is accomplished by means of special sensors that allow a person to be tracked while moving through a

predetermined space in the room. Tracking sensors are mounted on pedestals.

Movement involves moving users around the virtual world as they move in the room, but it also tracks movements and position of the headset so it is possible to move the camera inside the game and, for example, to descend into the VR environment or to approach and explore the objects in the simulation.

Fig. 1. HTC Vive headset (center) and controllers (left and right) [21].

In addition to the head mounted device (HMD) there are also two motion controllers that allow users to interact with objects within the VR environment. In VR, they are most often presented in the form of a hand or some facility that the user uses in the environment.

Recording of EEG signals was accomplished with EMOTIV EPOC+ 14-channel mobile system (Figure 2) [22]. This device is one of the few commercially available solutions that meet most of the required clinical electroencephalograph standards [23]. It was primarily developed for use in advanced Brain-Computer Interface (BCI) and for neurological research, but it can be applied in other areas such as research of emotion and attention. The system is highly mobile, easily operated and provides a powerful Software Development Kit (SDK) to programmers. Raw signals can also be recorded if needed.

Fig. 2. EMOTIV EPOC+ 14-channel EEG wireless headset [22].

Using the EMOTIV SDK we developed a Java desktop application (Figure 3) that can wirelessly record EEG signals from alpha, beta low, beta high, gamma and theta bands, time-stamped them and dynamically stored in a SQL database. The recording application was synchronized with the VR stimulation. Before measuring data, the user can define the rate of data collection per second, as well as minimums and maximums of recorded input data. This process is enabled due to the high possibility of interference with diode signals. Some of these issues can be reproduced by exerting a force on the diodes or facially expressing emotion.

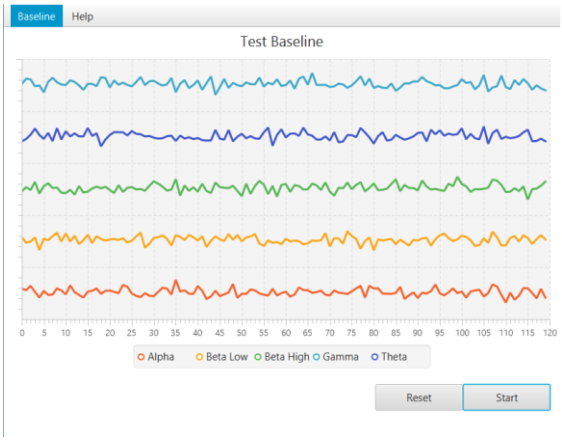

Fig. 3. Application interface for baseline acquisition and calibration of EEG measurements.

Before the recording starts, the user first performs a calibration or baseline measurement based on which data is measured together with stimulus presentation. The recording of baseline data lasts for 2 minutes, during which the user is asked to relax and have a neutral facial expression. After this process, it is possible to access the analysis window, where the evaluation of baseline measurement and test measurements is presented. The application also supports measuring participant's EEG signals while reproducing auditory stimuli in the form of music or various white noise signals.

IV. Experimental Protocol

A homogeneous group of N=6 participants (5 men, 1 woman) with an average age 26.67 years (std = 1.11) participated in the experiment. Participants were visually stimulated with images from the Nencki Affective Picture System (NAPS) [24] embedded in a 3D VR environment. The NAPS affective multimedia database has 1356 realistic pictures and, together with its extensions NAPS BE [25] and NAPS ERO [26], is currently the largest such database with general semantic content. Pictures' context contains semantic categories, multi-word stimuli annotations and normative ratings in discrete and dimensional models of affect [27].

Each participant was exposed to two emotion elicitation sequences. A single sequence consisted of 10 VR rooms with 10 NAPS pictures, one picture in each room. The first sequence displayed pictures with dominating happiness and the second with dominating fear. The pictures were selected based on discrete emotion values from NAPS BE: 10 pictures had the highest level of happiness and the other 10 the highest values of fear. The length of each stimulus was exactly 15 seconds after which the participant enters an empty room

without any emotion provoking picture to rest for 10 seconds. Therefore, in total each participant was exposed to 20 pictures in 20 VR rooms. Spatial and visual characteristics of all rooms, including those in rest phases, were identical (Figure 4). The rooms were initially designed to be emotionally neutral. Only emotion provoking content were the NAPS pictures (Figure 5).

Participants followed a preset path through the VR stimulation. They could freely change their direction of view but they could not change the path or speed of the movement in the 3D environment.

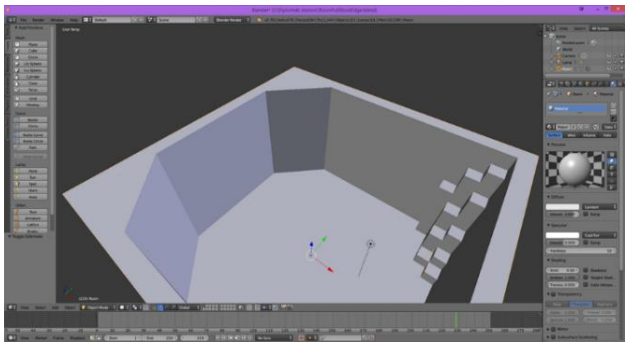

Fig. 4. A VR room during the development of stimulation sequences with Unreal Engine tools.

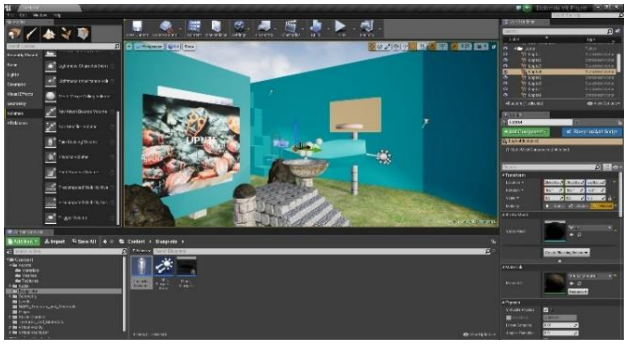

Fig. 5. A VR room with a picture from the NAPS database inserted on one of the walls.

Participants wore HTC Vive VR and EMOTIV EPOC+ headsets at the same time (Figure 6). This proved to be technically challenging because these systems were not designed for simultaneous use. Some HTC Vive elastic straps had to be loosened to provide space for EEG sensors. Also, before the experiment participants were advised to support by hand the front section of the VR headset because of its significant weight.

During the entire experiment, the illumination in the laboratory was dimmed as required by HTC Vive manual and psychophysiological laboratory guidelines [28]. Participants removed the headgear and rested between the two sequences. The exposure resumed only after the participants were fully relaxed.

Fig. 6. On the left, a participant is wearing VR and EEG headsets during the experiment. One of the HTC Vive VR sensors is visible in the background. The supervisor station is on the right.

V. RESULTS

In the experiment, we monitored alpha (α), beta low (β_L), beta high (β_H), gamma (δ) and theta (θ) bands. The signals were recorded at 128 Hz sampling rate. EMOTIV EPOC+ acquisition software automatically filtered out the noise and removed artifacts if electrodes were appropriately positioned on a participant's scalp. Features were derived off-line from the signals' values stored in the SQL database. In this preliminary analysis we cal,culated one feature: absolute difference between signal average (AVG) and baseline for each stimulus (BAS).

$$\begin{aligned} AVGBAS_{\alpha} &= |\alpha_{AVG} - \alpha_{BAS}| \\ AVGBAS_{\beta_L} &= |\beta_{L_{AVG}} - \beta_{L_{BAS}}| \\ AVGBAS_{\beta_H} &= |\beta_{H_{AVG}} - \beta_{H_{BAS}}| \\ AVGBAS_{\delta} &= |\delta_{AVG} - \delta_{BAS}| \\ AVGBAS_{\theta} &= |\theta_{AVG} - \theta_{BAS}| \end{aligned} \quad (1)$$

The feature $AVGBAS$ was obtained in 10 sec fixed windows for each stimulus in both sequences. The feature was then correlated (Pearson correlation coefficient r) with valence (Val) and arousal (Ar) emotion values from the NAPS database for the displayed picture. Correlation measures between aggregated average $AVGBAS$ for all participants and picture emotion values are shown in Table 1. Valence and arousal of pictures in the happiness sequence are denoted Val_H and Ar_H, while valence and arousal in the fear sequence are Val_F and Ar_F, respectively.

TABLE I
Correlation measures (r) among aggregated average $AVGBAS$ feature for all participants and picture emotion values per each EEG band.

	α	β_L	β_H	δ	θ
Val_H	-0,112	0,009	0,113	0,054	-0,063
Ar_H	0,019	0,003	0,182	-0,017	0,081
Val_F	0,168	0,071	0,123	0,063	-0,259
Ar_F	0,019	-0,054	-0,012	0,051	0,047

As can be seen in the table the largest correlation pairs in the happiness sequence are (β_H, Ar_H) and (β_H, Val_H). The fear sequence stimulated statistically more significant correlations (θ, Val_F) and (α, Val_F). This is in agreement with findings from previous studies where stimulation of negative polarity emotions is more powerful than with positive emotions. Alpha and theta bands indicate that participants were simultaneously less relaxed and experienced stronger cognitive processing than with stimuli in the positive sequence, as should be expected. Although this study is only preliminary, it acquired quality data for further analyses.

VI. Discussion and Conclusion

The experiment demonstrated that VR is a great asset for emotion elicitation techniques surpassing the potential of pictures, films, and video clips. Contemporary VR systems enable development of provoking storylines with personally meaningful narratives. This is of the utmost importance for a successful emotion stimulation. The other vital factors are realistic and engaging visuals. Continuous progress in computer graphics has made it possible to eliminate differences between photographs and computergenerated graphics. We found that using modern development tools creation of VR environments is swift and intuitive. Subsequent customizations are also greatly simplified. During the design, it is very important that a VR room is emotionally unprovocative and that participants are actually looking at a stimulus in the room. This can be accomplished by forcefully directing their line of sight when entering a room. Constant monitoring of participants' point of view from the supervisor's station should be obligatory.

Unfortunately, consumer-grade EEGs have not yet reached capabilities of professional laboratory devices. Nevertheless, we found EMOTIV EPOC+ EEG ideally suited for student experiments and quite adequate in the detection of emotion-related phenomena where exact placement of electrodes is not crucial. The system is very easy to work with, develop new code and record signals. However, the headset is not ideally suited for usage in tandem with a VR device. At the current level of development, these two technologies (EEG and VR) have conflicting requirements in experimental protocols. Better immersion requires obscuring upper face region and forehead with a large display, and elastic straps needed for immobilizing the heavy screen cover wide scalp regions. Calibration of EEG's electrodes' location is particularly demanding. Electrodes must be placed within c. 5−10 mm of the ideal spot to record signals with an acceptable artifact level (i.e. noise). This is especially noticeable for prefrontal (dorsolateral and ventrolateral) electrodes because the VR display almost completely obscures these brain regions and cannot be moved. However, VR headset straps can be loosened and even partially removed to allow access to parietal and occipital brain lobes. However, this may limit participants' head movements or even cause some physical discomfort and must be taken into account during the planning of an experiment.

EEG spectral bands are a good measure of attention and alertness. To obtain power spectral analysis of EEG activity, a simpler single-electrode headset can be used. Such device is more easily manageable and could be compatible with a VR headset simplifying the whole problem with the simultaneous use of EEG and VR devices.

Our experience in this study shows that a number of questions must be considered to accomplish an emotion experiment with consumer-grade equipment. But if the protocol is carefully designed all issues can be successfully solved. Accurate electrode localization remains an open challenge, however.

VII. Acknowledgement

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Lyrics Classification using Naive Bayes

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***Abstract* - Text classification is an important and common task in supervised machine learning. The Naive Bayes Classifier is a popular algorithm that can be used for this purpose. The goal of our research was prediction of song performer using Naive Bayes classification algorithm based solely on lyrics. A dataset that has been created consists of lyrics performed by Nirvana and Metallica, 207 songs in total. Model evaluation measures showed very good results: precision of 0.93, recall of 0.95 and F_1-measure of 0.94, therefore lyrics classification using Naive Bayes can be considered as successful.**

Keywords* - *Naive Bayes classifier, text classification, machine learning

I. INTRODUCTION

Text classification is an important and common task in supervised machine learning. Its application is in email spam detection, sentiment analysis, language detection of written text, classification etc. Many classifiers can be used for document classification. Some of them are neural networks, support vector machines, genetic algorithms, Naive Bayes classifier, k-nearest neighbours and Rocchio classifier [1].

The quantity of music, especially on the internet, is growing rapidly and its organizing is a challenging task. Given the huge size of music collections, classification of music should be made automatically. Classification can be made according to genre, mood, performer, geographical region, etc.

To make classification successful, one can rely on audio features such as tempo, rhythm, timbre, pitch, loudness or lyric features such as word and sentence length, word frequencies, word n-grams, sentence and phrase structure, errors, synonyms, rhyme patterns etc. According to [2] most existing work on automatic music mood classification is based on audio features (spectral and rhythmic features are the most popular).

Depending on type of classification, combining audio and lyrics information is a common approach.

In [3] four very distinct genres (classical, jazz, metal and pop) were chosen for audio-based classification using Mel Frequency Cepstral Coefficients. Accuracy in genre prediction when Direct Acyclic Graph Support Vector Machines was applied varied from 67 % to 97 %. When Neural Networks were used, accuracy varied from 76 % to 100 % depending on genre.

Automatic identification of music performers, given a set of piano performances of the same piece of music is an interesting research described in [4]. Pianists played two pieces by Frederick Chopin. Success rate was high: the accuracy was 70 % in 10-class task.

Fell and Sporleder in [5] dealt with problem of finding out whether it is possible to automatically predict the approximate publication time of a song given its lyrics. They chose pop/rock songs and divided them into three periods: 2008 and newer, from 1998 to 2001, and those published before 1988. Results showed that songs which are published 20 years and more ago can be distinguished relatively well, but for newer songs results of classification are relatively low.

Authors in [6] report that there is no significant difference in results of music mood classification depending on whether stemming was used or not. In [7] authors highlight that stemming and removing of stop words may do more harm than good when dealing with multilingual lyrics.

Text authorship identification is a field with long research history [8]. The main idea behind statistically or computationally supported authorship attribution (which started at the end of 19th century) is that the texts written by different authors can be distinguished by measuring some textual features [9]. This field rapidly evolved with the development of machine learning classification techniques.

The goal of this research was testing whether the Naive Bayes classifier can successfully predict song performer based solely on lyrics. A dataset consisting of lyrics of two performers (Nirvana and Metallica) was created for this purpose. Two performers are chosen deliberately to separate problems of classification according to performer from the problem of classification according to the genre of music because genres of their music are not far away from each other. Nirvana is a rock band, while Metallica is heavy metal (which is one sub genre of rock) band. No single author writes lyrics for one performer, but songs are written having a performer in mind (and audience of course), so style and genre of songs should be close to each other. As a matter of a fact, sometimes one song is written by more than one author. In the case of Metallica, many songs are written by three or four authors.

As dataset has 127 Metallica's and 80 Nirvana's songs, Naive Bayes Classifier was used, because it is suitable for small datasets [10].

The remainder of this paper is organized as follows. In the next section we briefly describe the methods and measures we used. In Section 3 we describe our

experiment and present the results. In Section 4 we draw conclusions and point out future directions.

II. METHOD AND MEASURES

A. Naive Bayes

Naive Bayes is a machine learning algorithm whose classification efficiency is proved in applications such as document categorization and e-mail spam filtering [11]. This classifier learns through a document classification algorithm, and is based on a simple usage of the Bayes' rule [12]:

$$P(c \mid d) = \frac{P(d \mid c)P(c)}{P(d)} \quad (1)$$

wherein:

- c is a class,
- d is a document,
- $P(c)$ is a class probability,
- $P(d)$ is the probability of a document,
- $P(d|c)$ is conditional probability of the class for the given document d,
- $P(c|d)$ is conditional probability that document d belongs to class c.

Naive Bayes classifier is characterized by: [13]

- computational efficiency,
- low variance,
- incremental learning,
- direct prediction of posterior probability,
- robustness to noise and
- robustness on missing values.

Computational efficiency in modeling and predicting is an unquestionable advantage over some other classification algorithms, which is due to the possibility of easy parallelization, especially important for large datasets. To fore mentioned characteristics it is valuable to add two more: resistance to overfitting and ability of handling with large number of attributes without need their selection [14].

B. Performance measures

After creating a machine learning model, it is necessary to measure model performance to decide if the model is satisfactory, whether it can be improved or even discarded. Model should make as low mistakes as possible - but the concept of mistake can be defined on different ways, depending also on the problem domain. Below are some of the most common evaluation measures. They originate from the confusion matrix (Table 1) which contains the classifier's decisions in the rows, and the actual decision about classification in the class in the columns. The four fields of the table contain number of true positive (TP), true negative (TN), false positive (FP) and false negative (FN) classified documents.

Table 1. Confusion matrix

		actual	
		YES	NO
predicted	YES	TP	FP
	NO	FN	TN

Precision is expressed as the proportion of positive cases that are correctly recognized as positive over all cases classified as positive and is calculated according to the formula:

$$\text{precision} = TP / (TP + FP) \quad (2)$$

Recall is expressed as the proportion of positive cases that are correctly recognized as positive over all actual positive cases and is calculated according to the formula:

$$\text{recall} = TP / (TP + FN) \quad (3)$$

Accuracy is expressed as the proportion of correctly classified cases over all cases and is calculated according to formula:

$$\text{accuracy} = (TP + TN) / (TP + TN + FP + FN) \quad (4)$$

Error is expressed as the proportion of incorrectly classified cases over all cases and is calculated according to formula:

$$\text{error} = (FP + FN) / (TP + TN + FP + FN) \quad (5)$$

or simpler:

$$\text{error} = 1 - \text{precision} \quad (6)$$

Individual measures should not be considered separately. It would be easy to construct a completely useless classifier which would classify all cases as positive, making the recall measure perfect 1. Precision and recall are complementary, as one represents the ability to detect positive cases, and the other ability to avoid incorrect detection of negative cases. By increasing one measure it is likely to decrease another (or, at best, another will remain the same) [14].

A measure that combines precision and recall is called the F_1-measure and represents their weighted harmonic mean. It is calculated according to the formula:

$$F_1 = ((2 \times \text{precision} \times \text{recall}) / (\text{precision} + \text{recall}) \quad (7)$$

The F_1-measure is one of the most commonly used single-number measures in information retrieval, natural language processing and machine learning. It is worth mentioning that this measure has more practical issues, some of which are: [15]

- like precision, recall and accuracy, it is also focused only on one class,
- like precision, recall and accuracy, it is also biased towards a dominant class,
- it does not consider true negative (TN) cases and

- it assumes that the actual and the prognosed distributions are equal.

The last evaluation measure to be mentioned here is the ROC (Receiver Operating Characteristic) curve. It is a graphical representation (Figure 1) of the binary classifier performance on which the curve represents a compromise between true positive and false positive cases.

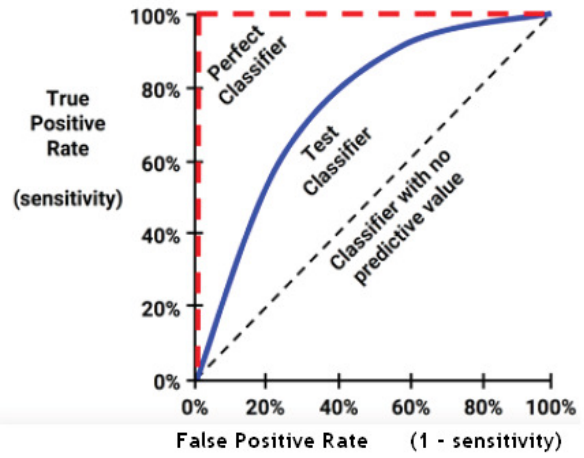

Figure 1. ROC curve (source: [10])

The black line on the diagonal represents a classifier that true positive and false positive cases detects at the same rate, therefore is not useful in the classification. In the contrast, a perfect classifier marked with red line predicts 100 % true positive with 0 % false negative cases. What is the curve of the actual classifier closer to the red, it is better for detecting positive cases.

III. EXPERIMENT AND RESULTS

The goal of this research was to find out if the selected classifier can correctly identify the performer (Metallica or Nirvana) only by lyrics. A set of data was made for the purpose of research, and the data was prepared for processing. Subsequently, the model was trained and evaluated. The last step was model improvement.

A. Data collection and preprocessing

The research question in this paper was whether a classifier (and to what extent) based only on lyrics can recognize whether it is a song of Nirvana or Metallica.

The first step was creation of a dataset. All songs were obtained from azlyrics.com website. Dataset consists of three columns (type, title and song lyrics) and 207 rows (127 Metallica's and 80 Nirvana's songs). The first column, *type*, contains one-letter information about to whom the song belongs ('M' for Metallica or 'N' for Nirvana). The second column, *title*, contains song titles – it was not used in the research, but it is important to easily recognize particular song and control possible duplicates. The third column, *lyrics*, contains song lyrics. In some cases it was not entirely clear whether particular song actually belongs to observed band (due to the music career of band's frontman before establishing band, for example). To resolve such issues, only songs listed on Wikipedia's pages (precisely https://en.wikipedia.org/wiki/List_of_songs_recorded_by_Metallica and https://en.wikipedia.org/wiki/List_of_songs_recorded_by_Nirvana) could be included into the dataset. It is also important to emphasize that dataset does not represent entire discography of two bands.

After initial dataset creation, randomization of rows was made. Since at the end of dataset creation there was a known share of songs (61,4 % Metallica and 38,6 % Nirvana), and the fact that two-thirds of data (138) would be used for learning and the remaining third for testing, in the training set proportional number of both band's songs was placed (85 Metallica's and 53 Nirvana's songs).

At the end, once again set for training and set for testing were separately randomized. This adjustment later enabled simplifying training and testing operations in the R tool. Part of the final dataset is shown in Figure 2.

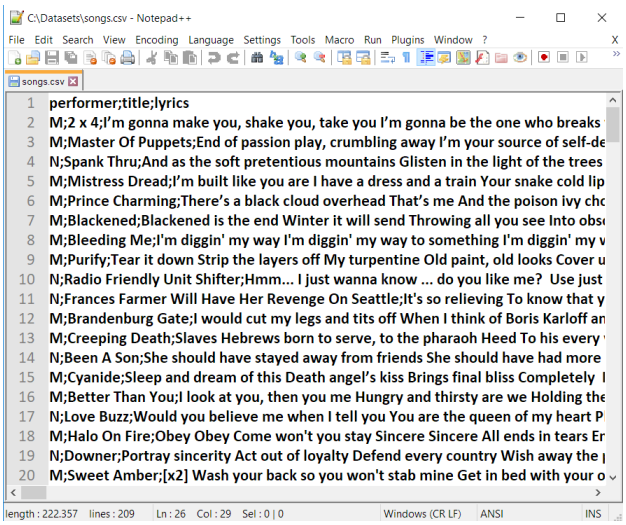

Figure 2. Dataset

The last step in dataset preprocessing were common transformations: changing all the letters into lowercase, removing the stop words, numbers, punctuation and white spaces, and finally, stemming. Sample of lyrics before and after transformations is shown on Figure 3.

And as the soft pretentious mountains Glisten in the light of the trees And the flowers sing in D minor And the birds fly happily We'll be together once soft pretenti mountain glisten light tree flower sing d minor bird fli happili togeth
I'm diggin' my way I'm diggin' my way to something I'm diggin' my way to somethin' better I'm pushin' to stay I'm pushin' to stay with something I'm pushin' to stay with something diggin way diggin way someth diggin way somethin better pushin stay pushin stay someth pushin stay someth
Tear it down Strip the layers off My turpentine Old paint, old looks Cover up the past White heat, white light Super white bones Bones of you and I Pure if I... can't you help me? tear strip layer turpentin old paint old look cover past white heat white light super white bone bone pure help

Figure 3. Lyrics before and after transformations

After preprocessing document-term matrix was created. Dictionary consists of 2.932 terms and the document-term matrix sparsity is 98%. List of the most frequent terms for both artists is shown in Table 2.

Table 2. Most frequent terms

Metallica		Nirvana	
term	**freq**	**term**	**freq**
see	157	like	85
never	156	yeah	67
just	152	know	57
now	141	take	48
one	130	got	47
come	128	feel	46
take	128	one	46
away	118	said	46
feel	118	away	45
life	110	can	44
will	106	way	41
time	96	never	36
let	95	make	35
death	87	get	34
way	87	love	34
can	86	want	33
die	85	just	32
like	85	think	32
want	82	mind	30
day	81	see	30

The threshold of frequent words was set to 8. Words that appeared less than 8 times were eliminated before training the model. The model showed the best results when threshold was 8 or 9. By increasing or decreasing the threshold, the classifier made more incorrect decisions.

B. Results and evaluation

Results of classification by Naive Bayes are shown in confusion matrix (Table 3). It can be noticed that the classifier incorrectly prognosed performer 8 out of 69 times.

Table 3. Confusion matrix

Predicted \ Actual	Metallica	Nirvana
Metallica	40	6
Nirvana	2	21

Cases of special interest are those in which classifier did not make the correct decision. Looking at probabilities in such cases (Table 4), it is noticeable that in five of the eight cases the classifier was very confident (more than 95 %) in his decision.

Table 4. Probabilities in incorrect decisions

Actual	Predicted	Probability Metallica	Probability Nirvana
Metallica	Nirvana	0.02909	0.97091
Nirvana	Metallica	0.97369	0.02631
Nirvana	Metallica	0.54434	0.45566
Nirvana	Metallica	0.99939	0.00061
Nirvana	Metallica	0.52747	0.47253
Metallica	Nirvana	0.02356	0.97644
Nirvana	Metallica	0.52038	0.47962
Nirvana	Metallica	0.99992	0.00008

For the evaluation measures computing, in the confusion matrix class of interest is Metallica and it represents a positive class. Therefore, Nirvana is a negative class.

The accuracy is (40 + 21) / (40 + 21 + 6 + 2) = 61/69 = 0.88406
The error is 1 – 0.88406 = 0.11594
The precision is 40 / (40 + 6) = 40/46 = 0.86957
The recall is 40 / (40 + 2) = 40/42 = 0.95238
The F-measure is (2 × 0.86957 × 0.95238) / (0.86957 + 0.95238) = 1.65632 / 1.82195 = 0.90909

ROC curve is shown on Figure 4. Area under the ROC curve is 0,969, which is a very good result.

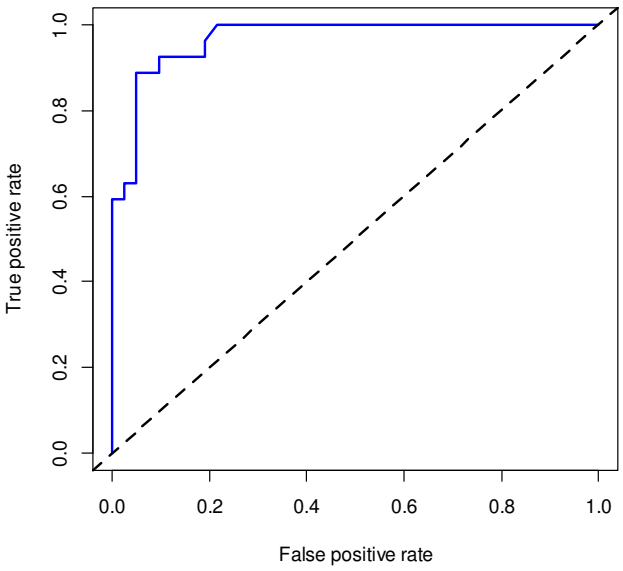

Figure 4. ROC curve

C. Model improvement

In order to improve the model, Laplace smoothing was applied. The best results model gave when Laplace estimator's value was 0.06. With this adjustment, classifier correctly recognized three more Nirvana's songs (Table 5).

Table 5. Confusion matrix of improved model

Predicted \ Actual	Metallica	Nirvana
Metallica	40	3
Nirvana	2	24

In the end, we checked the performance of the model without two transformations: removing the stop words and word stemming. The results without Laplace smoothing and with it were identical. Table 6 shows comparison of results.

Table 6. Comparison of results

Measure	Without Laplace smoothing	Laplace estimator = 0.06	Without stemming and removing stop words
precision	0.86957	0.93023	0.88636
recall	0.95238	0.95238	0.92857
F_1-measure	0.90909	0.94117	0.90697

IV. CONCLUSION

Creating a dataset was tedious and time-consuming task, partly because it was created manually, and partly because of doubt about inserting some songs into a dataset. Namely, cases such as guest appearances of other musicians on the album or two versions of the same song (a studio and a slightly altered live version) had to be handled with care. Besides, it was not always clear whether a song belong to a performer or not – the doubt was resolved with a help of Wikipedia's list of songs recorded by chosen artist.

Results of a created model are very good. Naive Bayes classifier is a good choice for this task – once again it proved its capabilities. Since the dataset was quite small, it was a logical candidate for the model.

Result showed that Nirvana's and Metallica's songs have textual 'signatures' that can be distinguished to a large degree solely on reading text. Results are more interesting when one takes into account the fact that songs for one band are often written by more authors. In some future research, it would be interesting to examine how the model behaves in a larger number of classes (artists) and to compare result obtained by Naive Bayes classifier with results obtained by other classifiers, especially with support vector machines.

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Classification and Differentiation Between Ijekavian and Ikavian Pronunciation

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***Abstract* - The paper describes a method for the differentiation and classification between two different types of pronunciation: ijekavian and ikavian. It is based on the coding of written text, which is further represented as an image. This image is subjected to pattern analysis in order to extract the feature vector. Then, the feature vector is differentiated by classification tools. The experiment includes the database of texts in ijekavian and ikavian pronunciation which is subjected to the proposed technique. At the end, the proposed method is compared to the other methods. The obtained results are promising.**

Keywords - classification; coding; image processing; pattern analysis; pronunciation.

I. INTRODUCTION

The Shtokavian dialect is the most widely used in the Balkan region and spoken in much of Croatia. In fact, this dialect is widely spread in the Croatian regions of eastern Slavonia, the Adriatic coast to Dubrovnik. Also, the traditional Croatian literaly language, which was based on the Shtokavian dialect, appeared in the second half of 19th century. Accordingly, the Shtokavian dialect was adopted by many Croatian intellectuals of the 19th century.

Basically, the Shtokavian dialect incorporates three different pronunciations: (i) Ijekavian, (ii) Ekavian, and (iii) Ikavian. They are differentiated by the change of the previously adopted *jat* letter into a new disyllabic (triphonemic) *ije* or diphtongal *je* sequence (Ijekavian), a new letter *e* (Ekavian), or a new letter *i* (Ikavian). Ijekavian pronunciation is the most widespread, while Ikavian pronunciation is the least used. Currently, the Ikavian pronunciation is used in Dalmatia, east Slavonia and western Vojvodina by the Bunjevci.

It is interesting to observe that the Ikavian pronunciation was also used in the Glagolitic documents from XIII to XVII century but it was not using the words on the same way. Today, the Bunjevci have tried to create a compact pronunciation.

From all aforementioned, it is clear that identifying text excerpts given in the different pronunciations of the Shtokavian dialect represents a current problem, and an interesting and appealing challenge. In this paper, we try to differentiate by different classification tools text excerpts given in Ijekavian and Ikavian pronunciations of the Shtokavian dialect.

A. Related works

In the literature, a very few contributions have been introduced for the classification of dialects from text excerpts. In fact, most of the works have been focused on the dialect classification based on the speech.

In particular, Ref. [1] introduced a method for the categorisation of linguistic varieties spoken in Ethiopia into dialect areas by applying agglomerative clustering together with lexical distances on text strings. Also, Ref. [2] employed semi-supervised learning from text of social media for the classification of Arabic dialects. It was accomplished by adopting different classifiers trained by weakly supervised, strongly supervised and unsupervised samples. Another work about Arabic dialect identification was proposed in Ref. [3], where features based on characters and words were the input to a support vector machine classifier and a meta-classifier using stacked generalization. Also, Ref. [4] proposed a supervised classification method for the identification of the dialects in the Kurdish texts. On the contrary, Ref. [5] used an *n*-gram language model and conditional random fields for the classification of English dialects from Australia, United Kingdom, and United States, inside text documents. Finally, Brodić and Amelio [6] introduced a method for the identification of text excerpts given in

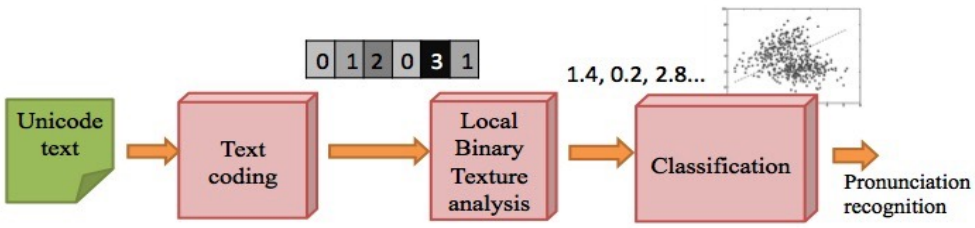

Figure 1. Overview of the proposed method

(b)

Figure 2. Coding of the letters in the text line

Ijekavian and Evakian pronunciations of the Shtokavian dialect.

B. Current limitations and our contribution

It is clear that in the current literature all works are mainly focused on the classification of text excerpts in different dialects or sub-dialects. Consequently, to the very best of our knowledge, any work was introduced for the identification of different pronunciations of the same dialect.

From all aforementioned, our contribution is based on extending the previous work introduced in [6] for the identification of text excerpts given in Ijekavian and Ekavian pronunciations of the Shtokavian dialect. In particular, we try to differentiate text excerpts given in Ijekavian and Ikavian pronunciations of the Shtokavian dialect. It is accomplished by coding the text document with a sequence of numerical codes representing the disposition of the letters in the text line area according to their energy profile. Then, texture analysis is applied on the grayscale image representing the numerical code in order to extract texture features which define the document feature vector. At the end, it is classified by using three classification tools in order to identify its pronunciation as given in Ijekavian or Ikavian pronunciation. An experiment performed on a database of text excerpts in the two pronunciations of the Shtokavian dialect shows very promising results and sheds light on a possible extension of the method for the classification of other types of dialects in different countries.

The paper is organised as follows. Section II gives an overview of the proposed method. Section III describes the process of feature extraction, including text coding and texture analysis. Section IV presents the classification tools. Section V describes the experiment. Section VI introduces the experimental setting. Section VII presents the result of the experiment and discusses it. Finally, Section VIII concludes the paper and outlines future work directions.

II. The Proposed Method

The proposed algorithm is composed of the following steps: (i) transformation of the Unicode text into a sequence of numerical codes by considering the energy profile of the letters (text coding), (ii) texture analysis of the grayscale image corresponding to that sequence in order to extract the feature vector, and (iii) identification of the pronunciation of the text using a classification tool on the feature vector. Fig. 1 shows an overview of the proposed method. The text coding aims at capturing the letters' height and their disposition along the text line in order to generate distinguishable patterns for each pronunciation. It provides distinctive characteristics of the pronunciations which are represented by the texture analysis. In particular, the image mapping has the advantage that texture operators can be applied in order to extract interesting patterns from the numerical sequence. These patterns are related to the co-occurrence of typical numerical codes in the sequence. At the end, the natural variations codified by the texture feature vectors are used by the classification tool for distinguishing one pronunciation from the other one, and for recognising texts given in the different pronunciations.

Poštivana bunjevačka čeljadi i svi naši prijatelji prid vama je drugi broj

10110000010300011010301000000010200201030200100002010020100 2

Figure 3. Text sample in Ikavian pronunciation and its equivalent EPC generation

III. Feature Extraction

A. Unicode text coding

In the first step of the method, each letter of the Unicode text is mapped to a numerical code according to the position of that letter in the text line. It is accomplished by computing the energy profile of each letter by considering the typographical features. Consequently, each text line is divided into: (i) lower zone, (ii) middle zone, and (iii) upper zone. These zones are bounded by the following virtual lines: (i) top line, (ii) upper line, (iii) base line, and (iv) bottom line. Each letter is categorised according to the zone(s) it occupies in the text line. In particular, a letter can be categorised as follows: (i) base letter (middle zone), (ii) ascender letter (middle and upper zones), (iii) descender letter (middle and lower zones), and (iv) full letter (upper, middle and lower zones). The letter categories are mapped according to Energy Profile Code (EPC) respectively to the numerical codes 0, 1, 2, and 3. Fig. 2 shows the coding of the letters in the text line. Also, Fig. 3 illustrates a text sample in Ikavian pronunciation and its equivalent EPC.

B. Texture analysis

The text conversion trasforms the Unicode text into a sequence of numerical codes as a combination of 0, 1, 2, 3. It can be considered as a grayscale image, where each numerical code is a gray level. Fig. 4 illustrates the grayscale image obtained from the script coding sample of Fig. 3. Accordingly, texture analysis can be applied on the image in order to extract a feature vector. In particular, the Local Binary Pattern (LBP) is applied on the grayscale image, which revealed its potential in the discrimination of Ekavian and Ijekavian pronunciations of the Shtokavian dialect [6].

LBP is a texture approach which captures the local contrast variations in the image [7]. It is accomplished by scanning the image pixel by pixel using a 3x3 Window of Interest (WOI). For every position, the center pixel *c* in

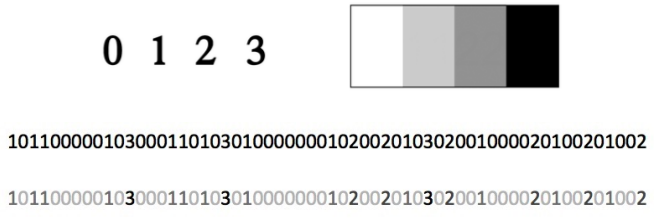

Figure 4. Grayscale image obtained from the script coding sample of Fig. 3

the WOI is identified and its intensity compared with the intensity of the surrounding pixels of the WOI. At the end, each surrounding pixel takes the 1 value if its intensity is higher than the intensity of *c*. Otherwise, it takes the 0 value. Hence, each obtained value is multiplied by powers of 2 based on its position. Then, all values are summed in order to create a binary label for *c*. This label corresponds to a decimal code which characterises the pattern at center pixel *c*.

LBP is computed as follows:

$$LBP_{d,r} = \sum_{i=1}^{d} sign(I_i - I_c) \times 2^{i-1}, \quad (1)$$

where I_i and I_c are the intensity values respectively of the center pixel *c* and the i_{th} surrounding pixel, *d* is the number of surrounding pixels, and *sign(y)* is the following function:

$$sign(y) = \begin{cases} 1, & if\ y \geq 0 \\ 0, & if\ y < 0 \end{cases}. \quad (2)$$

Because the obtained grayscale image has size 1x*N*, where *N* is the number of the letters in the text, only 2 surrounding pixels can be considered in the WOI, which are on the left and on the right of the center pixel *c*. Accordingly, *d*=2 and the number of possible binary labels is 2^2=4. Also, the closest surrounding pixels are considered in the WOI (*r*=1). Finally, the decimal codes computed from the binary labels are used for the generation of a histogram, counting the frequency of occurrence of the different codes inside the image. This set of frequencies defines the feature vector of LBP, which is composed of only 4 elements. Fig. 5 shows the generation of an LBP from a script coding sample.

The problem of LBP in its current form is that it generates a small feature vector which could exhibit a low discriminatory ability. For this reason, LBP is substituted by the Adjacent Local Binary Pattern (ALBP) [8]. It is characterised by two LBPs which are combined in the horizontal direction in order to generate an ALBP. It extends the number of possible binary labels to 2^4=16. Consequently, the histogram counts the frequency of 16 patterns inside the image, and the feature vector is extended from 4 to 16. Still, the number of surrounding

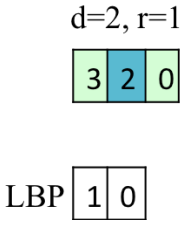

Figure 5. LBP generation from a script coding sample. The center pixel *c* is cyan-colored, while surrounding pixels are green-colored

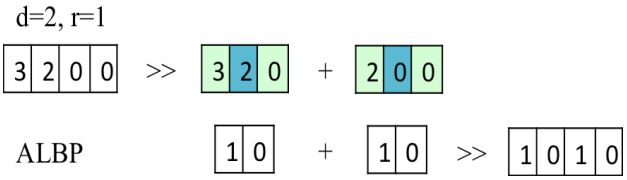

Figure 6. ALBP generation from a script coding sample. The center pixel *c* is cyan-colored, while surrounding pixels are green-colored

pixels is set to 2 (*d*=2) and the closest surrounding pixels from the center pixel *c* are considered (*r*=1). Fig. 6 shows the generation of an ALBP from a script coding sample.

IV. CLASSIFICATION

The extracted feature vector is subjected to classification in order to identify the pronunciation of its corresponding Unicode text. In particular, three example classification tools are adopted for this task: (i) Support vector machine (SVM), (ii) K-nearest neighbour (KNN), and (iii) Random forest (RF). The SVM and KNN are statistical-based classifiers, while random forest is a well-known ensemble learning method.

A. Support vector machine

The SVM classifier aims at solving a binary classification problem [9]. Its main objective consists of finding the linear separating hyperplane which maximises the margin between the closest element of the first class and the closest element of the second class inside the feature space. Accordingly, it finds the solution of the following optimisation problem:

$$\min_{w,b,\xi} \frac{1}{2} w^T w + F \sum_{j=1}^{s} \xi_j, s.t.\ y_j (w^T \phi(x_j) + b) \geq 1 - \xi_j,\ \xi_j \geq 0,\ j = 1,...,s, \quad (3)$$

where ϕ is the kernel function, *F* is the penalty factor of the training error, x_j is an element of the training set with class label y_j, and *s* is the size of the training set. After finding the parameters *w* and *b* of the hyperplane, a test element x_i is classified based on the following decision function:

$$y_i = \text{sgn}(w^T \phi(x_i) + b), \quad (4)$$

where *sgn(x)* is the sign function.

B. K-nearest neighbours

The *K*-nearest neighbours method aims at classifying a test element by computing its distance with each of the *s* elements in the training set [10]. Then, the *K* closest training elements (neighbours) are considered. Finally, the class label of the test element is that occurring most frequently among the class labels of the *K* neighbours. In particular, the *K* value determines the amplitude of the neighbourhood and it is an input parameter of the method. In order to avoid class labels with the same frequency inside the neighbourhood, the *K* parameter is usually set to small odd values. Also, multiple distance functions can be adopted by the method when the elements are feature vectors of real-values and fixed length. The most used one is the Euclidean distance. However, based on the context, the Manhattan distance and the Chebyshev distance can be also employed.

C. Random forest

The RF is an ensemble learning method which is based on a set of decision trees [11]. Each tree is learned by randomly choosing a subset of features at a given node. According to this subset, the best split for that node is selected. It allows to generate unrelated decision trees inside the forest by avoiding a strong predictor feature of the dependent variable to be selected in multiple decision trees. A bagging approach is employed for training the decision trees from the training set. In particular, *R* samples of the training set are randomly selected using re-sampling with replacement. Hence, each sample is adopted for training a decision tree. At the end, a test sample is classified by the random forest adopting a majority voting on the different class labels generated by the decision trees.

V. EXPERIMENT

The experiment is performed on a database of 83 Unicode text excerpts given in the Ijekavian and Ikavian pronunciations of the Shtokavian dialect. In particular, 25 out of 83 text excerpts are written in Ijekavian pronunciation, while the other 58 out of 83 text excerpts are written in Ikavian pronunciation. The documents are randomly selected among the most recent daily newspaper articles and periodicals. The length of the extracted documents ranges between 774 and 1973 characters.

The aim of the experiment is the application of the proposed method on the aforementioned database in order to test the performances in recognising text excerpts given in Ijekavian or Ikavian pronunciation of the Shtokavian dialect.

VI. EXPERIMENTAL SETTING

Experimentation has been performed in Matlab R2017a on a laptop computer Quad-Core with 2.2 GHz, 16 GB RAM and Unix operating system.

Each text excerpt of the database is represented by a feature vector of ALBP micro patterns. Because the KNN and SVM classification tools require the computation of a distance function, the feature vectors have been normalised before any classification task. In particular, let $x_j=\{x_j^1, x_j^2,...,x_j^n\}$ be a feature vector of the database which is composed of n features (in this case $n<=16$). The normalisation of the generic feature x_j^i is performed as follows:

$$\overline{x}_j^i = \frac{x_j^i}{\sum_{h=1}^{n} x_j^h}. \quad (5)$$

The obtained value $\overline{x}_j^i$ represents the fraction of i_{th} micro pattern inside the feature vector x_j representing the text document.

The SVM classification tool has been applied on the database using multiple kernel functions, including: (i) linear, (ii) polynomial with order 3, and (iii) Gaussian radial basis with scaling factor of 1. At the end, all kernel functions obtained the same classification performances on the database. Accordingly, the well-known linear kernel function has been definitively employed for this task. Also, the KNN classification tool has been run on the database with the Euclidean distance and different values of the *K* parameter from 1 to 15. At the end, no meaningful performance variations have been observed in the experiment at the different *K* values. Consequently, a baseline value of 5 has been set for the analysis.

In order to evaluate the performances of the proposed method on the database, the confusion matrix is generated from the classification result, from which precision, recall, f-measure and accuracy are computed. Because of the binary classification problem, the confusion matrix *CM* is defined as in Table I. In particular, the actual class is the ground-truth class of the text excerpts, while the predicted class is the class label of the text excerpts predicted by the classifier. Inside *CM*, C_{11} denotes the number of text excerpts correctly classified as Ijekavian pronunciation. On the contrary, C_{22} indicates the number of text excerpts correctly classified as Ikavian. Also, C_{21} and C_{12} denote respectively the number of text excerpts in Ikavian pronunciation which are incorrectly classified as Ijekavian pronunciation, and the number of text excerpts in Ijekavian pronunciation which are incorrectly classified as Ikavian pronunciation.

According to these elements, the precision is defined as an average per-class agreement of the ground-truth class labels with the class labels obtained by the classifier. It is computed as follows [12]:

TABLE I. CONFUSION MATRIX CM

Actual class	**Predicted class**	
	Ijekavian	*Ikavian*
Ijekavian	C_{11}	C_{12}
Ikavian	C_{21}	C_{22}

$$Precision = \frac{1}{m}\sum_{i=1}^{m}\frac{C_{ii}}{\sum_{j=1,j\neq i}^{m} C_{ji}}. \quad (6)$$

On the contrary, the recall is defined as an average per-class efficacy of the classifier to pick out class labels. It is computed as:

$$Recall = \frac{1}{m}\sum_{i=1}^{m}\frac{C_{ii}}{\sum_{j=1,j\neq i}^{m} C_{ij}}. \quad (7)$$

From the harmonic mean of precision and recall, the f-measure is computed as follows:

$$F-Measure = 2\times\frac{Precision\times Recall}{Precision+Recall}. \quad (8)$$

Finally, the accuracy, which quantifies the total efficacy of the classifier, is defined as follows:

$$Accuracy = \frac{\sum_{i=1}^{m} C_{ii}}{\sum_{i,j}^{m} C_{ij}}. \quad (9)$$

In this case, m=2 because of the binary classification problem.

For each classification tool, the evaluation is performed by using a subset of the database for training the classifier (training set). After that, the *CM* is generated from the remaning subset of the database (test set) in order to assess the performances of the method.

In particular, for each classification tool, the k-fold cross validation is performed for making the evaluation independent from a specific training and test set. It consists of randomly dividing the database into k folds. Then, each fold is used as the test set, while the remaining k-1 folds are employed as the training set. For each test and training sets, the precision, recall, f-measure and accuracy performance measures are computed from the generated confusion matrix. At the end, the average performance measures over the k folds together with the standard deviation are computed and reported as the final performance values. Also, each classification tool is tuned by using the best combination of training and test sets from the k-fold cross validation and employed for the classification of the overall database. The adopted k values of the fold cross validation range from 2 to 10, which are typical values used in the literature.

VII. Results and Discussion

In the following, a study of the feature vectors extracted from the database of text excerpts in Ijekavian and Ikavian pronunciations of the Shtokavian dialect is performed in order to assess their ability in discriminating between the different pronunciations. Then, the classification results obtained by the SVM, KNN and RF methods on the feature vectors are reported and compared in terms of: (i) confusion matrix generated from the overall database, (ii) precision, (iii) recall, (iv) f-measure, and (v) accuracy.

A. Features analysis results

Fig. 7 shows the statistics of the feature values from the database of text excerpts in Ijekavian and Ikavian pronunciations of the Shtokavian dialect in terms of normalised median and quartiles at 25% and 75% for each ALBP micro pattern.

It is worth noting that the statistics values are well-separated in the two pronunciations (Ijekavian and Ikavian) for most of the ALBP micro patterns. In particular, this difference is best visible for '0000', '0010', '0011', '0100', '1001', '1010', and '1100'. It indicates that the features globally exhibit very good discriminatory characteristics which can be used by the classification tools in order to reliably discriminate among the pronunciations.

B. Classification results

Table II shows the confusion matrix obtained from the overall database of text excerpts in Ijekavian and Ikavian pronunciations of the Shtokavian dialect.

It is visible that every classification tool is able to perfectly identify the text excerpts as given in one of the two pronunciations. In fact, the percentage of samples

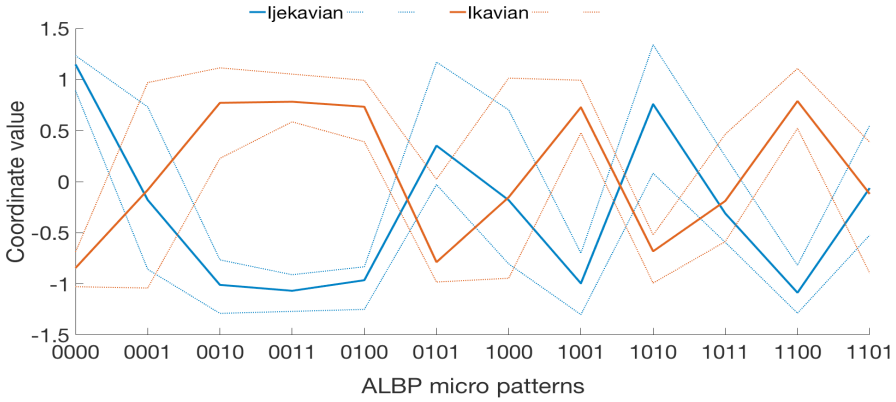

Figure 7. Feature values statistics from the database of text excerpts in Ijekavian and Ikavian pronunciations of the Shtokavian dialect. Only ALBP micro patterns which are different from zero are depicted in the x axis. For each pronunciation, the normalised values of median (continuous lines) and quartiles at 25% and 75% (dotted lines) are reported for each micro pattern over the y coordinate

correctly classified as Ijekavian is 100% corresponding to 25 text excerpts of the database. Also, the percentage of samples which are correctly recognised as Ikavian is also 100% corresponding to the 32 text excerpts given in Ikavian pronunciation in the database.

The results observed from the confusion matrix are confirmed in Table III reporting the average performance measures (precision, recall, f-measure and accuracy) obtained by the *k*-fold cross validation on the database. It is worth noting that the proposed feature representation is able to perfectly discriminate between the Ijekavian and Ikavian pronunciations independently from the adopted classification tool. In fact, the average values of precision, recall, f-measure and accuracy are always equal to 1 with a standard deviation of 0. It indicates that the classification tools are able to perfectly recognise the pronunciation of the text excerpts in each of the *k* test sets. Also, the same very good results are obtained when the KNN method is employed with different values of the *K* parameter.

From all aforementioned, it is worth noting that the proposed system represents a quite robust and reliable method for the discrimination and identification of documents written in the different pronunciations of the Shtokavian dialect.

VIII. CONCLUSION

This paper introduced a method for the discrimination and identification of Unicode text excerpts as given in Ijekavian and Ikavian pronunciations of the Shtokavian dialect. It was accomplished by mapping the letters of the document into numerical codes based on their energy profile which defined their position in the text line area. It corresponded to a grayscale image which was subjected to texture analysis by using ALBP in order to extract the feature vector. Then, three example classification tools were employed for recognising the pronunciation of the obtained feature vector. The proposed system showed very promising results on a database of text excerpts in the Ijekavian and Ikavian pronunciations of the Shtokavian dialect.

Future work will extend the proposed system on a larger database for the identification of the Southern Italian dialects, which will complement the work proposed in [13].

TABLE III. CLASSIFICATION RESULTS

Method		***Precision***	***Recall***	***F-Measure***	***Accuracy***
RF	Avg.	1.00	1.00	1.00	1.00
	Std.	(0.00)	(0.00)	(0.00)	(0.00)
SVM	Avg.	1.00	1.00	1.00	1.00
	Std.	(0.00)	(0.00)	(0.00)	(0.00)
KNN	Avg.	1.00	1.00	1.00	1.00
	Std.	(0.00)	(0.00)	(0.00)	(0.00)

TABLE II. CONFUSION MATRIX OBTAINED FROM THE OVERALL DATABASE OF TEXT EXCERPTS IN IJEKAVIAN AND IKAVIAN PRONUNCIATIONS OF THE SHTOKAVIAN DIALECT

Actual class	**Predicted class**	
	Ijekavian	*Ikavian*
Ijekavian	25	0
Ikavian	0	32

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Modeling of Verbs Using the Node of Knowledge Conceptual Framework

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***Abstract* – The paper analyzes the semantics of verbs in sentences in Croatian and English language. It gives a representation of different verb tenses in both languages and shows how the sentences containing these tenses are modeled using the Node of Knowledge (NOK) conceptual framework. The NOK conceptual framework is used for formal knowledge representation expressed in text, i.e. to represent the knowledge network. The models are presented using the Formalized Node of Knowledge (FNOK) formalism. These models are a part of the meta-model of language that is necessary for the development of an intelligent information system.**

Keywords - NOK, Node of knowledge, verbs, FNOK, representation, conceptual framework

I. INTRODUCTION

Knowledge representation is a central problem in artificial intelligence [1]. One of the groups of methods for representing knowledge are sematic networks [2]. Semantic networks are graphs, in which words (or concepts) are represented as nodes, while edges signify relations between them [3]. The Nodes of Knowledge (NOK) method [4], [5] belongs to semantic networks. Node of Knowledge also uses nodes and links, but is simpler than other methods (having fewer elements), more expressive (allows to display knowledge at different levels of abstraction) and easier to read (in the NOK method it is possible to read the knowledge starting from any node, but with the use of the link role) [6].

Creating a system of artificial intelligence that could communicate intelligently with the user is closely related to natural language processing [7]. Natural language systems must map between language and meaning [8]. By studying certain types of words in a sentence, a meta-model of the language is built, which is the basis for building an intelligent information system. The adjective analysis was performed in [9].

In [10], [11] and [12] it was shown that it is possible to use the conceptual framework NOK to model sentences in different languages.

In this paper, the emphasis is on verbs and different verb tenses in two natural languages - Croatian and English. Also, the same examples are given in Croatian and English (wherever possible) and shown that the models are in some cases the same, but there are also cases where they are very different.

The paper is organized in the following way. After introduction in Section I, Section II gives research motivation. Section III describes the research methodology. In Section IV authors analyze the verbs in Croatian and English language. Also, rules are given to convert verbs and verb tenses from the natural language into a formalized FNOK record, as well as how to graphically display them in DNOK. Section V provides conclusions and plans for future research.

II. RESEARCH MOTIVATION

The idea of developing an intelligent information system includes/predicts the entry of natural language sentences into a relational database and enabling communication with that database using questions that are also expressed in natural language [13]. Before entering the database, natural language sentences are first enriched and represented in the FNOK record [14] which enables storing knowledge and its processing using a computer program [15], [13].

In order to be able to represent knowledge in a formal form, it is necessary to clearly define the rules. Therefore, it is necessary to analyze and define the rules for all word types in the sentence. The verbs are especially important as the verb is the top of the representation hierarchy in FNOK and DNOK. All the other nodes are underneath it. In other words, a process node (and this is usually a verb) is the backbone of the whole model. Verbs (i.e. process nodes) are first searched for in sentences, and after that the other words and their hierarchical dependence. Then the model is built around the process node, and then around the other nodes.

Research motivation is the development of an intelligent information system whose components are textual records, where it is necessary to create a meta-model of language, of the enrichment process, and also of verbs in all their forms and tenses.

III. METHODOLOGY

Since the very beginning of the development in 2011, several formalisms have been developed within the NOK method. The method itself is presented in [15] as part of the conceptual framework for knowledge-based system development „Node of Knowledge“, abbr. NOK method conceptual framework.

The conceptual framework „Node of Knowledge (NOK)“ is a set of methods, rules, corresponding analysis tools and the representation of semantics contained in natural language sentences. The conceptual framework NOK includes:

- NOK method
- DNOK formalism (Diagram Node of Knowledge) - formalism for graphic representation (graphic representation in the form of a NOK diagram),
- FNOK formalism (Formalized Node of Knowledge) - formalism for displaying knowledge in textual form (formalized textual entry) and
- QFNOK formalism (Question Formalized Node of Knowledge) - formalism for representing questions in textual form (formalized textual question representation)

DNOK formalism is described in [16], [4], [10]. Algorithms for conversion of sentences to FNOK records and algorithms for the conversion of interrogative sentences (questions) into QFNOK records, i.e. a detailed description of the transformation algorithm and the corresponding software product in Python for the selected positive and interrogative sentences are given in the papers covering the NOK method [14], [15]. Other parts of the conceptual framework „Node of Knowledge" (NOK) are still in development.

The basic concepts of the NOK method are: node (label: rectangle), process node (label: ellipse) and link (label: straight line) with a single role related to the link between two nodes, closer to the node asking the question. The link connects either two ordinary nodes, or two process nodes or the ordinary and the process node. Each link between the nodes has only one role. It connects the two nodes so that it moves from one node to another. The link between the two nodes is accomplished by asking a question related to the first node, and the response results in another node (which is on the other side of the link). By using the NOK concept, DNOK is created. The verb in the sentence of natural language corresponds to the process node, and the other words correspond to nodes.

In addition to the graphical representation of textual knowledge (DNOK), the formalized representation of knowledge in textual form was developed, the FNOK (Formalized Node of Knowledge). FNOK can textually express sentences with a semantic link between nodes using wh-questions.

Each word in a natural language sentence corresponds to one node in the FNOK record. The verb corresponds to the process node at the highest hierarchical level. Brackets mark the beginning and end of the hierarchy, i.e. different levels within the hierarchy. The end of the hierarchy is marked with a closed bracket. After that label, we return to a higher level.

The representation in the hierarchy also includes a role (question word, question) linking a „lower" node with a higher node, where the lower node is the node at a lower level, i.e. a node at the lower level answers the question word. The question is marked by quotation marks and a question mark („?")

General FNOK representation:

process node („role 1?" node 1, „role 2?" node 2 („role 3?" node 3 („role 4?" node 4, ...), ...), „role n?" node n)

where *role 1?* to *role n?* are wh-questions, *node 1* to *node n* are nodes, and *process node* is the process node

Each node can have its own hierarchy. Hierarchical dependence can be defined with [17]:

Let *N1* and *N2* be two nodes. Hierarchical dependence of these two nodes can have two cases:

1. *N1* is hierarchically superior to *N2* (i.e. *N2* is hierarchically subordinate to *N1*), which can be shortly represented as *N1*(*N2*), or
2. *N2* is hierarchically superior to *N1* (i.e. *N1* is hierarchically subordinate to *N2*), which can be shortly represented as *N2*(*N1*).

Graphical representation of the hierarchical dependence is shown in Figure 1.

The rules for converting verbs and verb tenses and forms into the FNOK record and DNOK diagram will be described below.

IV. RESEARCH RESULTS

The verb is a word class that states action, state or event. In Croatian, verbs change in tenses, persons and moods. We differentiate the finite and nonfinite form of the verb (in Croatian, the same verb can be formed as to state an action which has started and finished – a finite form, or an action which has started, but not finished yet – a nonfinite form, with a single form, eg. verb *sit – sjesti* (finite state – *to sit down*) or *sjediti* (nonfinite state – *to be sitting*). Auxiliary verbs in Croatian *to be* (*biti*) and *to want* (*htjeti*) serve to form complex verb tenses and the creation of past and future verb tenses [18], [19].

In English, verbs also express action, state and event. The English language verb features are: singular and plural, persons (three persons singular and three persons plural), verb tenses (present, past and future tense), nonperfect and perfect aspect, active and passive voice, and moods (imperative, indicative and conjunctive) [20].

When converting verbs or sentences containing the verbs to FNOK formalized record, we distinguish a few rules explained in detail in the subsections A, B and C.

A. Verb at the Beginning of the Record

The verb (which is the process node) in the FNOK record is placed at the highest level of hierarchy. All other word types are hierarchically dependent on it, which we can represent like this:

$V, X \rightarrow V(X)$, where V stands for verb, and X for any

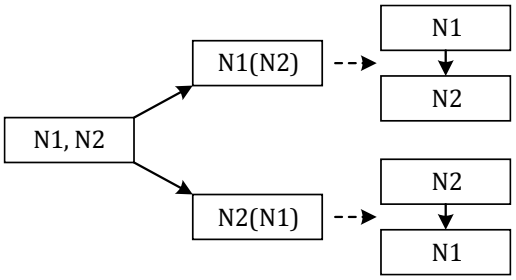

Figure 1. Hierarchical dependence of nodes

other word type.

More precisely, if we include the question (role) in the previous record, we can write:

V, X → *V*(„*role?*“ *X*), where *V* stands for verb, *X* for any other word type, and *role?* for a wh-question.

For example, the sentence *Vedran drives a car.* (cro. *Vedran vozi auto.*) has one verb, *drives* (cro. *vozi*), which is also a process node. It is placed at the beginning of the FNOK record, and then other words connected to the verb are searched for.

- Vedran **vozi** auto. → **Vozi** (…)
- Vedran **drives** a car. → **Drives** (…)

Symbol „→” marks the mapping of the sentence into FNOK record.

B. Verb Under a Verb

The verb is always under a verb (hierarchically dependent on the verb) when the action is stated one after the other, in the order in which the verbs appear in the sentence. For example:

- **Daj** mi nešto za **piti**. →**Daj** („što?“ **piti** („što?“ za), „kome?“ mi, „što?“ nešto)
- **Give** me something **to drink**. →**give** („what?“ **drink** („what?“ **to**), „whom?“ me, „what?“ something)

C. Hierarchy of Verb Tenses

In certain verb tenses, there are one or more auxiliary verbs in the sentence along with the main verb. The question arises as to how to translate the main verb and auxiliary verbs that form a certain verb tense into FNOK.

In the Croatian language we can see the hierarchy in:

- Verb tenses:
  - *Past Tense (cro. perfekt)*. Form: active verb form + present of the auxiliary verb „*biti*” („*to be*”). For example: *sam pisao, si pisao, je pisao, smo pisali, ste pisali, su pisali* etc.
  - *Past Perfect (cro. pluskvamperfekt)*. Form: perfect or imperfect form of verb „*biti*” („*to be*”) + active verb form. For example: *bijah (bjeh) pisao, bijaše (bješe) pisao, bio sam pisao, bio si pisao* etc.
  - *Future Simple (cro. futur prvi)*. Form: verb infinitive + present of the auxiliary verb „*htjeti*” („*to want*”). For example: *ću pisati, ćeš pisati, pisat ću, pisat ćeš, ću ići, ići ćeš* etc.
  - *Future Perfect (cro. Future drugi)*. Form: finite present of the auxiliary verb „*biti*” („*to be*”) + active verb form. For example: *budem pisao, budeš pisao, budete pisali* etc.
- Verb moods:
  - *Conditional First or Present (cro. kondicional prvi ili sadašnji)*. Form: aorist of the auxiliary verb „*biti*” („*to be*”) + active verb form. For example: *bih trebao, bi trebao, bismo trebali* etc.
  - *Conditional Second or Past (cro. kondicional drugi ili prošli)*. Form: present conditional of the verb „*biti*” („*to be*”) + active verb form. For example: *bih bio trebao, bi bio trebao, bismo bili trebali* etc.

The hierarchy of verb form in English language is depicted in Figure 2. Levels of hierarchy depend on the particular verb tense. In English, the hierarchy is observed in the following verb tenses:

- *The Simple Present Tense*. Form: auxiliary verb „to do” + main verb in infinitive form. For example: *works, does work* etc.
- *The Present Continuous Tense*. Form: auxiliary verb „to do” + the present participle of the main verb. For example: *am walking, is watching, are sleeping* etc.
- *The Present Perfect Tense*. Form: auxiliary verb „to have” + the past participle of the main verb. For example: *have written, has written, have lived, has lived* etc.
- *The Present Perfect Continuous Tense*. Form: the perfect of auxiliary verb „to be” + the present participle of the main verb. For example: *have been writing, has been reading* etc.
- *The Past Continuous Tense*. Form: past simple form of auxiliary verb „to be” + the present participle of the main verb. For example: *was reading, were writing* etc.
- *The Past Perfect Tense*. Form: past simple form of auxiliary verb „to have” + past participle of the main verb. For example: *had asked, had written* etc.
- *The Past Perfect Continuous Tense*. Form: had been + the present participle of the main verb. For example: *had been drinking, had been working* etc.
- *The Future Simple Tense*. Form: will / shall + base form of verb. For example: *will learn, will read* etc.
- *The Future Continuous Tense*. Form: will + be + the present participle of the main verb. For example: *will be running, will be competing* etc.
- *The Future Perfect Tense*. Form: will have + the past participle of the main verb. For example: *will have ended, will have left* etc.
- *The Future Perfect Continuous Tense*. Form: will + have + been + the present participle of the main verb. For example: *will have been working, will have been waiting* etc.
- *Going to future*. Form: „to be” + going to + base form of verb. For example: *is going to wait, am going to finish, are going to quit* etc.

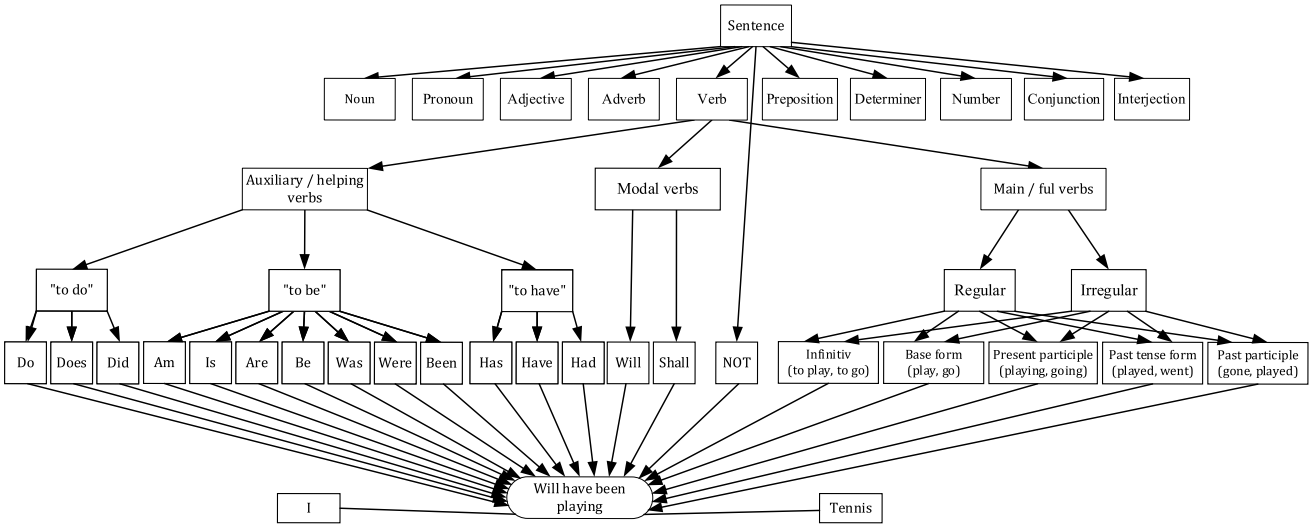

Figure 2. English language verb tense forms and their hierarchy

When creating FNOK we have two options:

1. present all the words that make up one verb tense with one process node, or
2. divide the words (nodes) into several levels of hierarchy in a certain order.

Since we want to keep the sentence structure and semantic content in FNOK, the following rule is set:

If the verb tense consists of several parts, they are in a hierarchy one below the other. The main verb is placed at the lowest level of hierarchy, and all auxiliary verbs or verb forms are above it (hierarchically dependent, they form a hierarchy).

A completely opposite order of words would also be a good solution because it contains the same semantics. The solution that better suits the implementation process should be chosen.

The hierarchy in FNOK for verb tenses and verb moods in Croatian language is as follows: at the highest level, there is any form of auxiliary verb „to be" (*biti*) or „to want" (*htjeti*) which is superordinate to the active verb form or verb in the infinitive.

Let us observe this rule over a few examples. Table I.

TABLE I. EXAMPLES FOR MODAL VERBS AND DIFFERENT VERB TENSES IN CROATIAN AND ENGLISH LANGUAGES

NR	TCRO	FNOK CRO	TENG	FNOK ENG
1	Ti **možeš kupiti** auto.	**možeš** („što?" **kupiti** („što?" auto,"tko?" ti))	You **can buy** a car.	**can** („what?" **buy** („who?" you, „what?" car („art?" a)))
2	Ti **možeš dotaknuti** sestrinu bilježnicu.	**možeš** („što?" **dotaknuti** („tko?" ti, „što?" bilježnicu („čiju?" sestrinu)))	You **can touch** sister's notebook.	**can** („what?" **touch** („who?" you, „what?" notebook („whose?" sister's)))
3	Mi **bismo mogli biti** prijatelji.	**bismo** („što?" **mogli** („što?" **biti** („tko?" mi, „što?" prijatelji)))	We **could be** friends.	**could** („what?" **be** („who?" we, „what?" friends))
4	On **može čitati**.	**može** („što?" **čitati** („tko?" on))	He **can read**.	**can** („what?" **read** („who?" he))
5	Ja **ću raditi** sutra	**ću** („što?" **raditi** („tko?" ja, „kada?" sutra))	I **will work** tomorrow.	**will** („what?" **work** („who?" I, „when?" tomorrow))
6	Naš brod **je prešao** Atlantik.	**je** („što?" **prešao** („što?" brod („čiji?" naš), „što?" Atlantik))	Our ship **crossed** the Atlantic.	**crossed** („what?" ship („whose?" our), „what?" Atlantic („art?" the))
7	Marija **ne izgleda** umorno.	**ne** („što?" **izgleda** („tko?" Marija, „kako?" umorno))	Mary **doesn't**[1] **look** tired.	**doesn't** („what?" **look** („who?" Mary, „how?" tired))
8	Automobil njegovog oca **je ukraden**.	**je** („što?" **ukraden** („što?" automobil („čiji?" oca („čijeg?" njegovog))))	His father's car **was stolen**.	**was** („what?" **stolen** („what?" car („whose?" father's („whose?" his))))
9	Čovjek **ide** na putovanje.	**ide** („tko?" čovjek, „kamo?" putovanje („kamo?" na))	A man **is going** on a journey	**is** („what?" **going** („who?" man („art?" a), „where?" journey („where?" on, „art?" a)))
10			I **will have been working** for ten hours.	**will** („what?" **have** („what?" **been** („what?" **working** („who?" I, „how many?" hours („how many?" for, „how many?" ten)))))
11			Sofia **has been playing** violin.	**has** („what?" **been** („what?" **playing** („who?" Sofia, „what?" violin)))
12			He **will have been** learning English.	**will** („what?" **have** („what?" **been** („what?" learning („who?" He, „what?" English))))
13			Mark **will have played** soccer.	**will** („what?" **have** („what?" **played** („who? Mark, „what?" soccer)))

[1] negation „does not" or abbreviated „doesn't" represents one node

consists of 5 columns: NR (ordinal number), TCRO (sentences in Croatian language), FNOK CRO (FNOK sentence record in Croatian language), TENG (sentences in English language) and FNOK ENG (FNOK sentence record in English).

In table I, under ordinal numbers from 1 to 4, examples of modal verbs in English are given, while under 5 to 13, examples of different verb tenses (the future, the past, and the negative form) are given. Where possible, examples are given in both languages. However, examples from 10 to 13 have sentences where the tense implies hidden semantics which cannot be appropriately translated into Croatian. In other words, such sentences cannot be unambiguously translated into Croatian language, so the examples of such tenses are given in English language only. The use of FNOK in other verb tenses and modal verbs is the same as these.

For example, Future perfect continuous tense has the following form:

Subject + auxiliary verb „will“ + auxiliary verb „have“ + past participle of „be“ + present participle of the main verb.

Hierarchy in FNOK retains the order of form that appears in the sentence, hence the FNOK hierarchy for Future perfect continuous tense is:

- *Auxiliary verb „will“*
  - *Auxiliary verb „have“*
    - *Past participle of „be“*
      - *Present participle of the main verb*
        - *Subject.*

For example, for sentence: *He will have been learning English.*, the corresponding FNOK is:

will („what?” have („what?” been („what?” learning („who?” He, „what?” English))))

The corresponding DNOK is given in Figure 3.

The model presented in this paper was the basis for development of the first system prototype. It was initially tested on 26 sentences and 36 questions in English language, and 23 sentences and 32 questions in Croatian language. These sentences used different verb tenses and verb modes. The system responded with 83% and 79% of correct answers to questions in English and Croatian respectively. Future work will include development of the second prototype with a goal to increase percentage of correct answers.

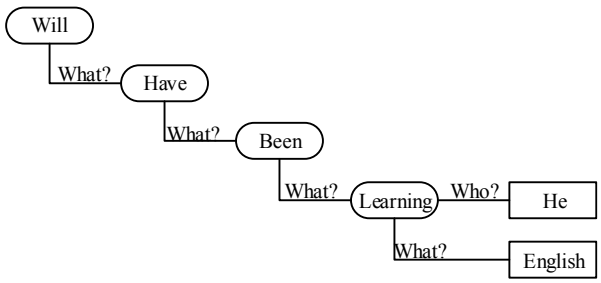

Figure 3. DNOK for sentence *He will have been learning English*

V. CONCLUSIONS AND FUTURE WORK

The paper presents the representation of verbs and different verb tenses in Croatian and English language and defines the rules for converting them into formalized text expressed knowledge representation (FNOK), as well as DNOK. The definition of hierarchical dependence is given and the hierarchy of English verb tense forms is shown. When creating FNOK, all the words that form a single verb tense are decomposed into several levels of hierarchy in a certain order. A rule was set: „If the verb tense consists of several parts, they are in a hierarchy one below the other. The main verb is placed at the lowest level of hierarchy, and all auxiliary verbs or verb forms are above it (hierarchically dependent, they form a hierarchy)”. A completely opposite order of words would also be a good solution because it contains the same semantics. The solution that better suits the implementation process should be chosen. For a better understanding of the set rules, several examples are shown in both languages.

The presented models are part of the meta-model of language that is necessary for the development of an intelligent information system capable of providing the system with answers to all the questions contained in the text, in a way a human would do it. The meta-model of language will continue to be built in future research.

Previous research has identified many problems, and these are planned to be solved in the future. Some of the plans are improving the rules of transformation according to the word types for interrogative and relative pronouns, conjunctions, interjections and particles, improving algorithms for answering questions, solving the problem of redundancy in sentences, analysis of complex sentences, and analysis of correlated sentences. In general, the work on the improvement of the NOK conceptual framework is in progress.

ACKNOWLEDGMENT

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Automated classification of Croatian traditional music

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***Abstract* - Croatian traditional music is rich with different music styles. Four of them are on the UNESCO Representative list of the intangible cultural heritage of humanity: two-part singing and playing in the Istrian scale, Becarac singing and playing from Slavonia, Klapa multipart singing of Dalmatia and Ojkanje singing. Every region of Croatia is represented by different instruments, singing styles, rhythm and dynamics. This paper describes an automated classification of Croatian traditional music into regions. The regions are defined by historical and geographical factors and music style similarities: Slavonia, central Croatia, Međimurje, Istria&Kvarner and Dalmatia. Each region is presented with 20 typical music songs. A sample of each song lasts for 30 seconds. The primary used features are mel-frequency cepstral coefficients, as well as zero crossing rate and sound volume. Extracted features are used in machine learning. As a result, more than 80% of the songs are correctly classified. The result shows how specific Croatian traditional music is and how important is to preserve it for future generations.**

Keywords - classification, mel-frequency cepstral coefficients, machine learning, traditional music

I. INTRODUCTION

Four of traditional music styles are on the UNESCO Representative list of the intangible cultural heritage of humanity: two-part singing and playing in the Istrian scale, Becarac singing and playing from Slavonia, Klapa multipart singing of Dalmatia and Ojkanje singing. In general, Croatian traditional music gathers a great variety of music styles on an extremely small geographical area. Each part of Croatia has its own traditional singing developed during history. Every region is represented by different instruments, different rhythm and dynamics. In this paper, an automated classification of Croatian traditional music into geographical and musical regions will be presented. The regions are defined by historical and geographical factors and music style similarities.

A lot of papers proposed automated classification of musical instruments or musical genres. Xu et al. [1] present an automatic classification algorithm for pure and vocal music. Features which properly characterize music content such as zero-crossing rates, spectral power, mel-frequency cepstral coefficients (MFCCs) and spectrum flux are calculated. Classification is done using support vector machine (SVM) learning. Quinto et al. [2] propose solution for sub-genre classification for a specific music genre. On a dataset of three sub-genres of jazz music (Acid, Bebop and Swing) using MFCCs and different machine learning methods songs are classified with efficiency ranging from 77% to 90%. Soboh et al. [3] use dynamic, rhythmic and timbre features to automatically classify Arabic songs based on their cultural style (Moroccan, Egyptian, Shami and Khaliji). A set of 23 acoustic features are extracted from a dataset of 400 songs and an overall accuracy of 80.25% is reached using a Decision Tree classifier. Nagawade and Ratnaparkhe [4] present how music classification works on musical instruments. In their work each of 5 different instruments (cello, piano, trumpet, flute and violin) is represented with 30 recordings. MFCC approach is used for feature extraction and classification is done using K-Nearest Neighbor (K-NN) classifier. Kartikay et al. [5] in their paper aim to classify a given song into one of four moods (happy, sad, peaceful and angry). Several musical features such as tempo, energy, pitch, etc. are extracted from given songs. Songs are classified using 4 different classification algorithms: Support Vector Machine, Naive Bayes, Linear Discriminant Analysis and Decision Trees and with efficiency ranging from 60% to 79%.

This paper is organized as follows. Section II. describes feature extraction and machine learning method, Section III. gives results in automated classification of traditional Croatian music. Conclusion is given in Section IV.

II. FEATURE EXTRACTION AND MACHINE LEARNING

A. Geographical and musical regions

The Republic of Croatia is divided into five regions based on its historical and geographical factors and music styles similarities: Slavonia, central Croatia, Međimurje, Istria & Kvarner and Dalmatia (Figure 1). Several parts of Croatia are remained uncovered, due to the lack of songs.

Two instruments prevail in Slavonian traditional music: bagpipes and tamburitza. The tunes of this area are characterized by a diathonic two-voice singing. They are usually performed by a smaller group of singers, so that the song starts and continues only by one singer, and all other singers perform another, accompanying voice. In older songs, both voices end up in a common tone, and in the newer ones in interval of pure quint. In some regions, such a two-voice singing is known as a bass singing [6].

The central Croatia covers several areas: Hrvatsko zagorje, the wider area of Zagreb (Prigorje, Turopolje), Žumberak, part of Pokuplje, upper Posavina and Bilogora. Folklore music in these areas is recognizable by the colorful musical features. Yet, as a whole, the music of this region is characterized by diathonics, unanimous and two-voice singing. In the instrumentation various forms of blowing instruments are present, such as flute [6].

The specialties of traditional music of Međimurje are unanimous tunes (whether sung by one or more singers). These songs develop in wide melodic lines that reach large volumes. Special charm to their performance gives a more independent rhythm with which the melody flows smoothly, without interruption, and naturally blends with the text. Instruments characteristic for this area are zither, cymbal and violin [6].

The traditional music of Istria and Kvarner is specific and stands out by its instrumentation as well as by singing style. Chromatic tonal style is characteristic for this region, in which amongst the various tone sequences, the so-called "Istrian scale" is distinguished. It is one of the tone sequences in which the (almost) half and full tone are repeatedly exchanged. Chromaticity is also base for tunes and instruments of which the most well-known are sopile, oboe type blowing instrument with very penetrating sound [6].

The music of Dalmatia is characterized by a narrow two-voice singing with less amplitude melodies and unison finishes. In addition to the two-voice singing, the town's environments have developed three-voice and four-voice singing. *Klapa*, a smaller group of five to eight singers participates in the performance. *Klapa*'s songs are sometimes performed with instrumental accompaniment of guitar [6].

Each region is represented with 20 typical songs (Table I) [6]. A sample of each song lasts for 30 seconds.

TABLE I. USED TRADITIONAL CROATIAN SONGS [6].

Slavonia	Ako zora ne svane; Ceranac; Digni Kajo; Drmendaš; Drumarac; Đuvegije gdje ste da ste; Ej, čija frula ovim šorom svira; Ej Slavonijo zemljo plemenita; Gori lampa nasrid Vinkovaca; Joj, Anice; Kad sam sinoć išla iz dućana; Neistinita pjesma; Od dvora do dvora; Seljački život; Stari glas; Svatovac; Sve su dike u kolu; Svinjarsko kolo; Voljeli se Ivica i Mara; Zavrzana
Međimurje	Baroš, oj Barice; Celo selo se spomina; Četiri frtalji; Črne Čizme; Dej mi, Bože, joči sokolove; Dobravska vuljica; Dok sam bila lepa mlada; Janica; Klinčec stoji pod oblokom; Malo Međimurje; Moj Đurinec; Mura; Mura, Mura; Novakovski čardaš; Pod oblakom slivica; Rijeka Mura tiho šumila; Rožica sem bila; Tamo kraj Mure moj je dom; Tožni zvoni zvoniju; Vehni, vehni fijolica
Central Croatia	Anđelek poje; Devojka, devojka; Drmeš; Gračanska svadbena polka; Igrajte nam muzikaši; Ja posijam lane; Ja sam Varaždinec; Jezuš dečki kak me hiče; Kad procvatu jabuke; Kćer jedinica; Letovanić; Majka čerku sprevajala; Na malenom brijegu; Oj, ti bela zorja; Pod brajde; Sviraj mi noćas valcera dva; Tužno plačem kuću ostavljam; Vigrujem; Zagorske napitnice; Zorja je zorja
Istria& Kvarner	Ala homo ča popit; Barbanski balun; Blizu Žminja grada; Brkica; Budi sretan sine moj; Con la supa Istriana; Da bi znalo sunce govoriti; Da mi tebe Istro ni; Feragosto; Hiljadu suze; Homo u Kaldir; Il valzer Istriano; Istrijanke su najlipje; Jesen u vrtu mom; Mužikanti smo mi; Piemontesina; Puna je Pula; Sve dok živu Istrijani; Sve spod mi Raklja; Zakantaj Istro
Dalmatia	Da mi je znati Bože moj; Duga rera; Dva Bračanina; Falile se Kaštelanke; Igra kolo kraj sv. Ivana; Ja nikog nemam; Kad si bila mala Mare; Kolenda; Kumpanija; Mafrina; Marijana; Meštar Ivo; Mornaru, vrati se; Ojkavica; Orzenje; Puste su kale; Ribari sa Jadrana; Svirka (Blato, Korčula); Stopro nam se kolo zametnulo; Svatovska zdravica

B. *Feature extraction*

Aim of the feature extraction is to obtain information from the input set that will be useful for machine learning and classification. Also, extraction of features reduces scope of the data, making calculation much simpler and faster.

Due to the known efficiency in audio processing, fundamental features used for the classification are mel-frequency cepstral coefficients (MFCC) [7][8]. To get certain enhancements features, zero crossing rate [9] and sound volume [7] are also calculated.

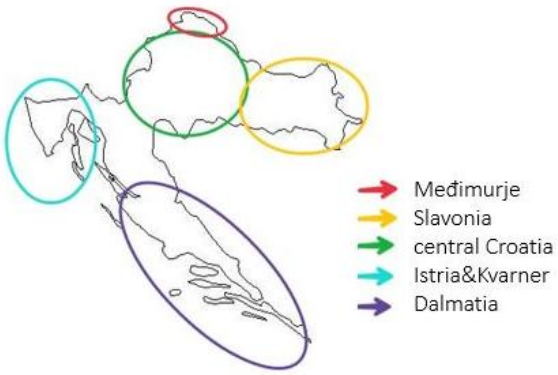

Figure 1. Geographical and musical regions of Croatia.

1) *Mel-frequency cepstral coefficients*

Mel-frequency cepstral coefficients are widely used in sound processing due to their excellent characteristic of imitating human hearing. Process of obtaining the coefficient is divided into several steps [7][8]:

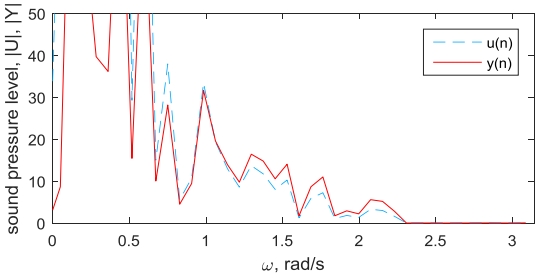

Figure 2. Spectrum for the song "Ja posijam lane" before and after preemphasis, using a=0.95.

1. Preemphasis

The goal of the preemphasis stage is to boost the amount of the energy in the high frequencies. As a result, information from higher formants becomes more available for further processing which improves accuracy.

If the input song is $u(n)$, signal after the preemphasis stage is $y(n) = u(n) - a \cdot u(n-1)$, where $0.9 \leq a \leq 1$. Spectrum for the song "Ja posijam lane" before and after preemphasis is given in Figure 2.

2. Windowing

Each song is a non-stationary signal; its statistical properties are not constant across time. By windowing the signal $y(n)$, we make its statistical properties constant within this small window. The window is characterized by its size, overlap between successive windows and a shape. We use window size 25 ms ($L = 1024$ samples) and overlap 10 ms (512 samples). As a result, we have 2581 frames per song. An example of the frame is given in Figure 3. a. Each frame is multiplied with a Hamming window (Figure 3. b) in order to keep the continuity of the frames:

$$s_i(n) = w(n)y_i(n), \tag{1}$$

where $w(n) = 0.54 - 0.46\cos(2\pi n/L)$, $0 \leq n \leq L-1$, is the Hamming window and index i represents each observed frame (Figure 3. c).

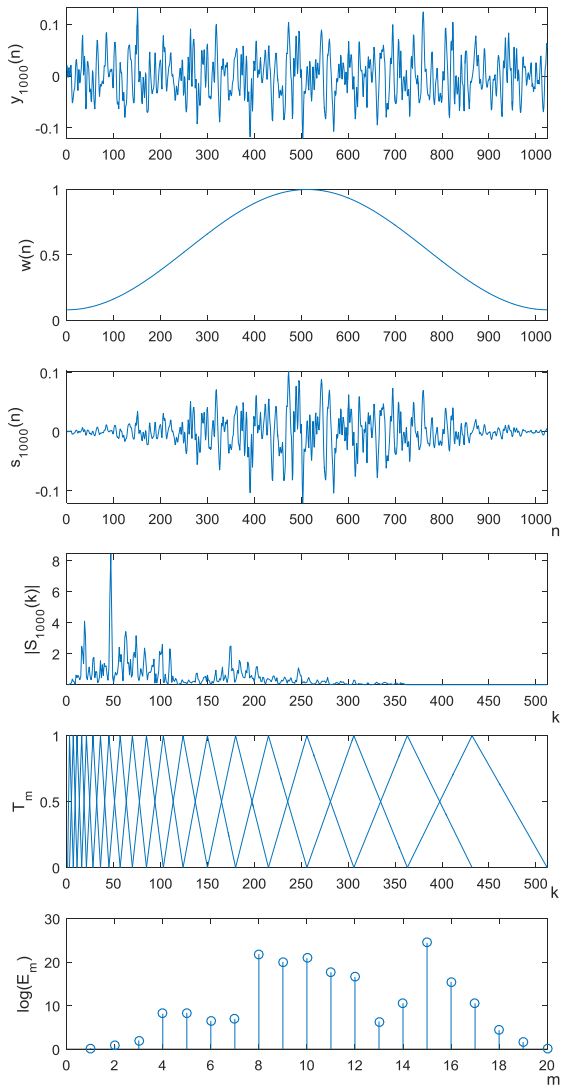

Figure 3. From top to bottom: a) one frame from the song "Ja posijam lane", b) Hamming window, c) resulting frame after multipling with Hamming window, d) Discrete Fourier Transform of $s_{1000}(n)$, e) bank of 20 bandpass triangular filters, and f) logarithm of mel spectrum energy.

3. Discrete Fourier Transform

Since different timbres in sound signals corresponds to different energy distribution over frequencies, discrete Fourier transform is used to obtain the magnitude frequency response of each frame $s_i(n)$ (Figure 3. d):

$$S_i(k) = \sum_{n=0}^{L-1} s_i(n)e^{-j\cdot 2\pi kn/N}. \tag{2}$$

4. Mel filter bank and log

Human hearing is not equally sensitive at all frequency bands. It is more sensitive at lower frequencies, with the limit around 1000 Hz. To emphasize interesting frequencies, the DFT frequency output is mapped to mel scale [10][11]. The mapping is linear below 1000 Hz and the logarithmic above. The relation between mel frequencies and linear frequencies f is given by $mel(f) = 1127\ln(1 + f/700)$.

The mapping is conducted by creating a bank of 20 bandpass triangular filters T_m. that collect mel spectrum energy E_m from each frequency band $m = 1, \ldots, 20$: $E_m = (\sum_k |S_i(k)|T_m(k))^2$. The first 10 filters are linearly distributed at frequencies below 1000 Hz and the remaining 10 filters are spread logarithmically on frequencies above 1000 Hz (Figure 3. e). For further mimic of human hearing, logarithm of each mel spectrum energy is calculated (Figure 3. f).

5. Discrete cosine transform

First 12 mel-frequency cepstral coefficients are given by the discrete cosine transform (DCT) of the log of the mel spectrum energy:

$$C_{p,i} = \sum_{m=1}^{20} \log(E_m)\cos\left(\frac{\pi p(m-0.5)}{20}\right), \tag{3}$$

where $p = 1, \ldots, 12$. DCT transforms frequency domain into time-like domain.

6. Logarithm of the energy of the frame

The 13rd feature for the observed frame is the logarithm of the energy:

$$C_{p,i} = 10\log\frac{1}{L}\sum_{n=0}^{L-1}|y_i(n)|^2, p = 13. \tag{4}$$

7. Delta cepstral coefficients

The observed song is not constant from frame to frame. We use these differences as additional features: delta cepstral coefficients or velocity feature

$$d_{p,i} = \frac{\sum_{t=-2}^{2} t \cdot C_{p,i+t}}{\sum_{t=-2}^{2} t^2}, \quad (5)$$

and double delta or acceleration feature:

$$e_{p,i} = \frac{\sum_{t=-2}^{2} t \cdot d_{p,i+t}}{\sum_{t=-2}^{2} t^2}. \quad (6)$$

Each of them gives extra 13 features. In total, we have 39 MFCC features, calculated for each frame *i*.

For the whole song with 2581 frames, we would have more than 100.000 features, which is impracticable. To reduce the number of data, statistical values across all frames and for each feature are calculated: minimum, maximum, mean and standard deviation (Figure 4. a). As a result, we have *P*=156 extracted features for further machine learning.

2) Zero crossing rate coefficients

The number of zero crossing is represented as a sign difference between successive samples:

$$Z_i = \frac{1}{2} \sum_{n=1}^{L-1} |\text{sign}(y_i(n)) - \text{sign}(y_i(n-1)|, \quad (7)$$

where *i* represents observed frame, and *L* is the length of the frame [9]. We use *L*=441 samples in each frame without overlapping and get 3.000 frames per song. Maximum value, mean value and standard deviation of calculated zero crossing rate coefficients are additional 3 extracted features for machine learning (Figure 4. b).

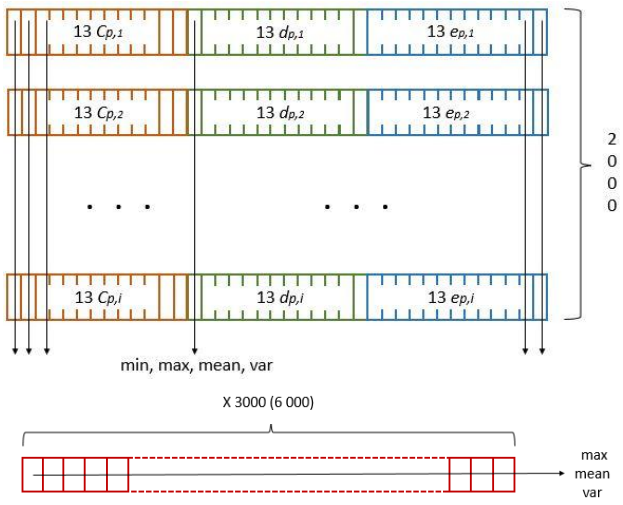

Figure 4. Statistical values of a) MFCC and b) zero crossing rate and volume coefficient that are used as extracted features for machine learning.

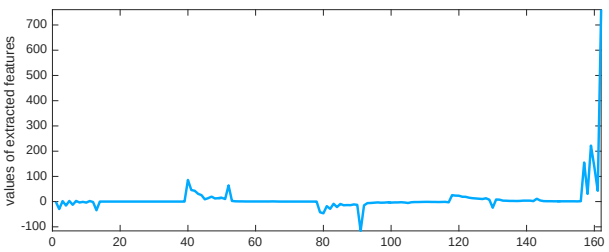

Figure 5. Extracted features for the song "Ja posijam lane".

3) Volume coefficients

Volume coefficients for each frame are calculated as:

$$V_i = \sum_{n=0}^{L-1} |y_i(n)| \quad (8)$$

where *i* represents observed frame, and *L*=441 is the length of the frame [7]. Overlap between the frames lasts for 220 samples. Each song has 6.000 frames. Maximum value, mean value and standard deviation of calculated volume coefficients are additional 3 extracted features for machine learning (Figure 4. b).

With described procedures, *P*=162 features are extracted. Examples of the features for the song "Ja posijam lane" are given in Figure 5.

C. Machine Learning

Support vector machine classifier (SVMC) is used for classification of the songs and matches them to their geographical regions.

SVMC is a binary linear classifier that assigns new data to one of two possible classes [12][13]. The classes are divided by a margin that is as wide as possible. Each data point is *P*-dimensional vector. The method searches for (*P*-1)-dimensional hyperplane that separates the points. The best hyperplane is the one which gives the largest margin between the two classes. Data samples on the margin are called the support vectors. Minimization algorithms for finding the SVMC can be based on interior point method [14], Platt's sequential minimal optimization algorithm [15] or sub-gradient descent [16]. When the number of classes is bigger than two, multiclass SVM is used. The common approach is to reduce the multiclass problem into multiple binary classification problems [17][18].

III. Results

The input set has 100 songs from 5 geographical and musical regions of Croatia. We extracted mel-frequency cepstral coefficients, zero crossing rate and sound volume coefficients and used them as a features for the support vector machine classification. Leave-one-out method is used for cross validation. The classification was conducted in MATLAB using Machine Learning Toolbox with default parameters [7][19].

In the first experiment, we used only mel-frequency cepstral coefficients and a logarithm of the energy of the frame. In total we had 52 features values. As a result, we get recognition rate of 61% (Figure 6). To get higher recognition rate, we added zero crossing rate and sound volume coefficients (Figure 7). For further improvement of the results, we added delta cepstral coefficients, without (Figure 8) and with zero crossing rate and sound volume coefficients (Figure 9), and double delta cepstral coefficients, without (Figure 10) and with zero crossing rate and sound volume coefficients (Figure 11). The final recognition rate for 162 feature values is 81%. Songs from Međimurje are correctly classified with 95%. Only 1 song from Međimurje is wrongly classified into Slavonia, and only 2 songs from other regions are wrongly classified into Međimurje. That shows how music from Međumurje is unique and recognizable.

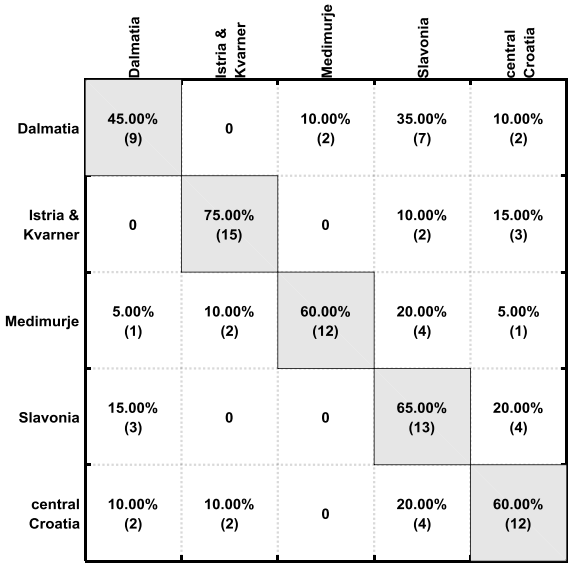

Figure 6. The recognition rate for 52 features values is 61%.

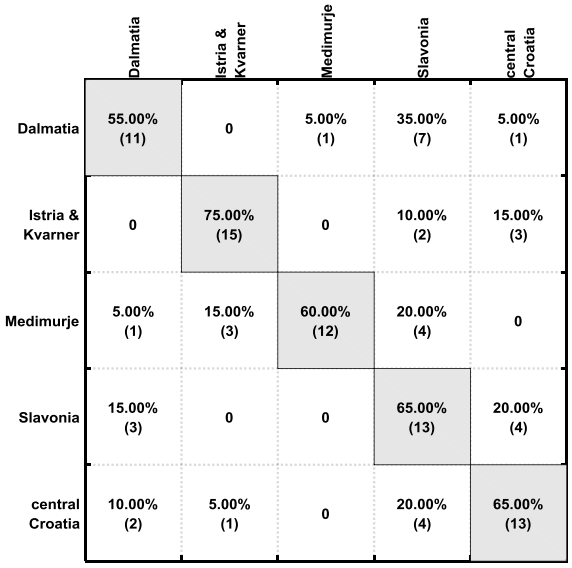

Figure 7. The recognition rate for 58 features values is 64%.

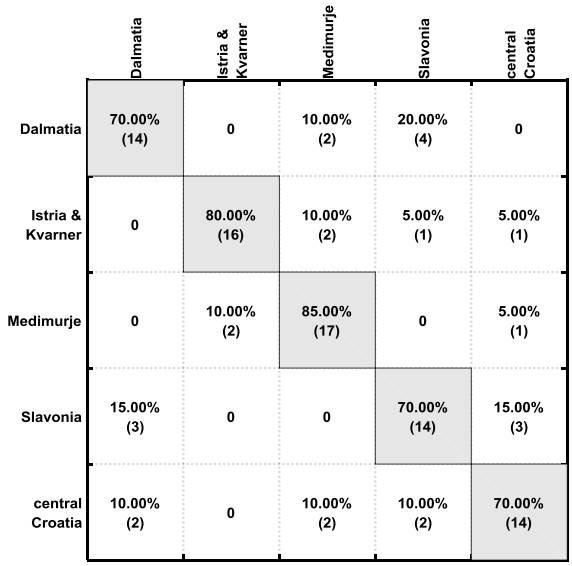

Figure 8. The recognition rate for 104 features values is 75%.

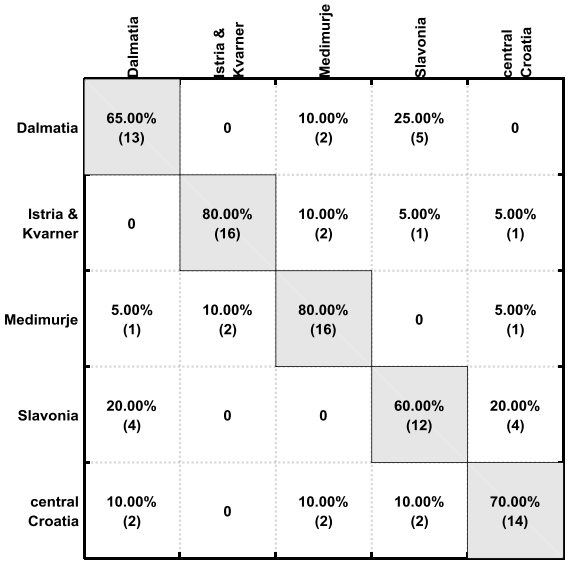

Figure 9. The recognition rate for 110 features values is 71%.

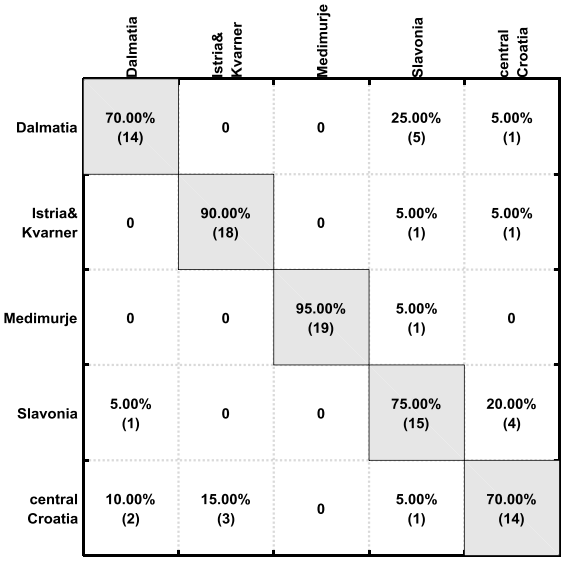

Figure 10. The recognition rate for 156 features values is 80%.

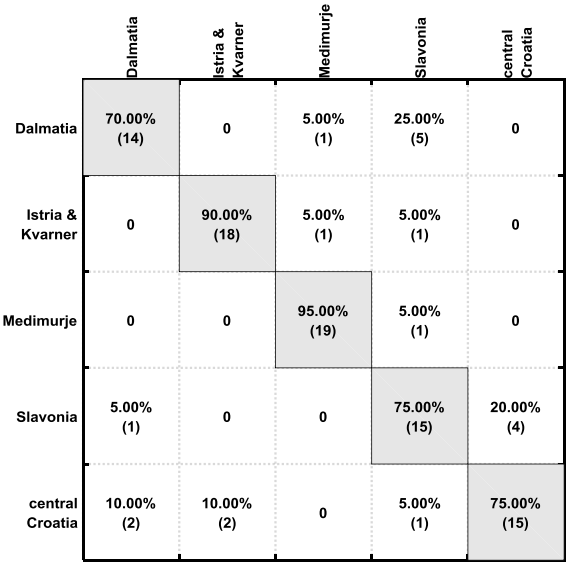

Figure 11. The recognition rate for 162 features values is 81%.

IV. CONLUSION

In this paper, an automatic classification of songs into geographical and musical regions of Croatia is presented. Five regions are used: Slavonia, central Croatia, Međimurje, Istria & Kvarner and Dalmatia. Each region is represented by 20 songs. Mel-frequency cepstral coefficients, zero crossing rate and sound volume coefficients are used as a features for the support vector machine classification. Achieved recognition rate is 81%. To increase the recognition rate, more songs from each region, additional feature coefficients and improved classification and cross-validation method can be used, which is left for future analysis.

ACKNOWLEDGMENT

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Object Detection in Sports Videos

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***Abstract* - Object detection is commonly used in many computer vision applications. In our case, we need to apply the object detector as a prerequisite for action recognition in handball scenes. Object detection, to be successful for this task, should be as accurate as possible and should be able to deal with a different number of objects of various sizes, partially occluded, with bad illumination and deal with cluttered scenes. The aim of this paper is to provide an overview of the current state-of-the-art detection methods that rely on convolutional neural networks (CNNs) and test their performance on custom video sports materials acquired during handball training and matches. The comparison of the detector performance in different conditions will be given and discussed.**

Keywords – object detectors; sports scenes; Mixture of Gaussians; YOLO; Mask R-CNN

I. INTRODUCTION

Object detection is one of the fundamental tasks in computer vision, with the aim to find instances of real-world objects such as people, cars, faces etc. in images or videos. Detection of an object implies prediction of the location of the object in an image along with the class it belongs to, so the challenge is to solve both object classification and object location problems.

Object detection is commonly used in many applications of computer vision such as image retrieval, security and surveillance, autonomous car driving, and many industrial applications but a single best approach to face that problem doesn't exist. The choice of the right object detection method depends on the problem that needs to be solved and on the set-up of the experiment.

In our case, we need to apply the object detector as a prerequisite for action recognition on handball scenes. For action recognition in team sports such as handball to be successful, object detection should be as accurate as possible, with reliable detection of relevant players, the ball and of other objects of interest [1]. Also, it should be able to deal with challenging conditions like the variable number of objects with a wide range of possible sizes ranging from players that can cover most of the image to the objects that are far away from the observer, that are occluded or those that can be as small as few pixels yet carry a lot of information, such as a ball. The environment in which sports videos are recorded is usually a sports hall, so the background is cluttered, with challenging illumination, with a variable number of players and with other not ideal conditions. In a highly dynamic setting of the handball domain, the motion blur and shadows that players cast under artificial illumination are often present in the videos, and the shape of the actors themselves vary greatly, making the problem even harder.

There are many other factors which can degrade the detection of players, of the ball and of the lines on the playground that humans don't even notice since it comes naturally to us.

To tackle the object detection problem, many approaches have been proposed including the Viola-Jones detector with Haar Cascades [2], HOG gradient-based approaches [3], segmentation and template matching approaches, and recent state-of-the-art methods that rely on deep convolutional neural networks (CNNs). In the last few years, CNNs have achieved a tremendous increase in the accuracy of object detection and are widely considered as the de facto standard approach for the most image recognition tasks.

Object detection in videos presents additional challenges, as it is usually desirable to track the identity of various objects between frames. It can be performed applying an object detector frame by frame, similarly as in case of images, or by using some kind of multi-frame fusion. The main difference between these approaches is, in fact, a compromise among speed, accuracy and required computational power.

The rest of the paper is organized as follows: in Section II. we will present used the image and video object detectors that rely on CNN and emphasize their strengths and weakness. We have examined their performance on a custom dataset consisting of indoor and outdoor handball scenes recorded during training and matches. The comparison of the detector performance in different conditions and discussion are given in Section III. The paper ends with a conclusion and the proposal for future research.

II. OBJECT DETECTORS

Object detection and recognition includes both object classification and objects location problems. The desired result is to have a bounding box around a detected object that is labeled with its corresponding class label.

One of the most notable and widely used object detectors in the past was a specialized face detector developed by Paul Viola and Michael Jones [2]. At that time, it was most precise and very fast, being able to perform face detection in real-time on webcam feed using hand-coded Haar features and a cascade of classifiers to make a prediction.

To realize more general object detectors that can detect many object categories, as opposed to detectors tailored for a specific object class, e.g. face, a viable approach is to start with a simpler task of image classification. In image classification, researchers are nowadays mostly focused on convolutional neural networks (CNN) that are strongly

influenced by the results of authors of [3]. At first, CNNs like VGGNet [4], Inception [5], etc. were used for classification only. The process of image classification takes an image as input and gives as the output a prediction of the existence of a class or multiple classes in case of multi-label classification, but without providing location information [6].

In order to extend the application of classifiers to the problem of object localization and to be able to detect object across the entire image, a sliding window approach is suggested. In that case, windows of different sizes corresponding to expected object sizes at various scales are positioned over overlapping parts of images to isolate parts of images that can be independently processed. If the classifier happens to recognize an object inside the window it will be labeled and marked by a bounding box for future processing. After processing the whole image, the result is a set of bounding boxes and corresponding class labels. However, the result can have a large number of unnecessary overlapping predictions. Also, the simple implementation of the sliding window approach can be very time consuming. With further development and by production of much more capable hardware, CNN based algorithms have been used to detect and localize objects as well. The Region with CNN features (R-CNN) (Fig. 1) [7] was a successful method that tried to optimize the sliding window approach. Before the image would be fed to a convolutional network for feature extraction, R-CNN would first create bounding boxes, called region proposals, using a selective search process [8]. After classification of each region using support vector machines, (SVM), R-CNN performs a linear regression on region proposals with regard to the determined object class to generate tighter bounding box coordinates.

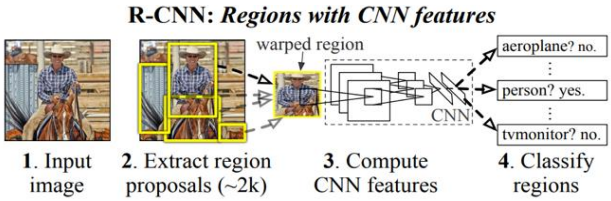

Fig. 1. Principle of Selective search inside R-CNN according to [7]

After this method was first proposed, a series of improved methods followed a similar approach. Fast R-CNN [9] brought Region of Interest Pooling (RoIPool) which reduced the number of forwarding passes and have managed to join extracting image features (CNN), classification (SVM) and bounding boxes tightening. Faster R-CNN [10] improved selective search process by reusing CNN results for region proposals instead of running a separate selective search algorithm.

A. *Mask R-CNN*

Mask R-CNN [11] is an extension of Faster R-CNN that adds a parallel branch for predicting segmentation masks on each Region of Interest (RoI), in addition to existing branches in the network that output class labels and bounding box offsets (Fig. 2). The new mask branch is a small fully connected network (FCN) applied to each RoI.

The Mask R-CNN otherwise follows the two-stage design of Faster R-CNN. The first stage is a Region Proposal Network (RPN) that proposes candidate object bounding boxes, or regions of interest (RoI). The RPN consists of a deep fully convolutional network that takes an image and outputs a feature map, upon which a smaller network is applied in a sliding window fashion. The smaller network takes a spatial window of the feature map, further reduces the feature dimension and then feeds them to two fully-connected layers, one that outputs the bounding box coordinates of proposed regions, and the other that outputs an „objectness“ score for each box, which is a measure of membership to a set of object classes vs. background. For each spatial window, k regions are proposed simultaneously based on reference boxes with pre-defined aspect ratios and scales called „anchors“, representing general object shapes, e.g. a tall box for a person.

The training data for RPNs is generated from labeled ground truth data of object boxes in images, such that positive labels are assigned to anchors with the Intersection-over-Union (IoU) overlap with a ground-truth box greater than 0.5. In this way, multiple anchors may be labeled as positive based on a single ground-truth box.

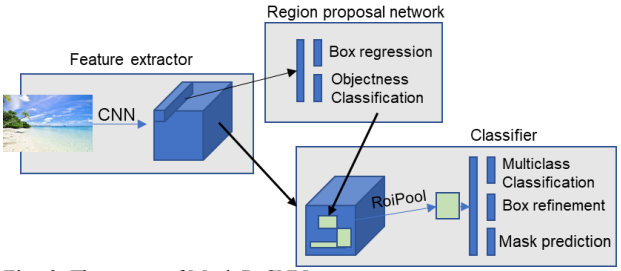

Fig. 2. The stages of Mask R-CNN

The RPNs are trained end-to-end by backpropagation and stochastic gradient descent SGD. The images are resized such that their scale (shorter edge) is 800 pixels. From each training image, N RoIs are sampled so that the ratio of positive to negatives examples is 1:3, in order to avoid the dominance of negative examples in the data. In the Mask R-CNN, the COCO dataset was used for training, while in the Faster R-CNN the PASCAL VOC was used.

Mask R-CNN generates masks and bounding boxes for all possible classes independently from classification, and finally, the result of the classification branch is used to make the selection of boxes and masks.

B. *YOLO object detector*

The “You only look once” (YOLO) [12] is another method showing promising results. It is reported to be less accurate in some cases than previously mentioned but it is much faster using the same hardware.

YOLO and its second revision YOLOv2 [13] are similar to R-CNN, in that they use potential bounding boxes from which convolutional features are extracted, but differ from the Faster R-CNN systems by using a single-stage network architecture to predict class probabilities and bounding boxes without a separate stage for the region of interest proposal.

The system divides the input image into a cell grid and produces a probability distribution of object classes for each cell. At the same time, a fixed number of candidate bounding boxes with the corresponding confidence scores

are predicted for each cell (2 in the original YOLO implementation). The confidence score measures both how confident the system is that the box contains an object, and how accurate the box is. Target confidence values for cells containing no objects is zero, while for other the confidence should be the intersection-over-union score between the predicted and the ground truth boxes.

During training, if an object spans multiple cells, only the cell containing the object center is ”responsible“ for predicting the bounding box for that object. In other words, the loss function for bounding box regression doesn't penalize all cells containing the same object, but only the central one.

Even though more than one bounding box is proposed per cell, only one class is predicted in each cell (Fig. 3). The network architecture of the original YOLO model consisted of 24 convolutional layers followed by 2 fully connected layers, where the convolutional layers extract features from the image while the fully connected layers output box predictions and probabilities.

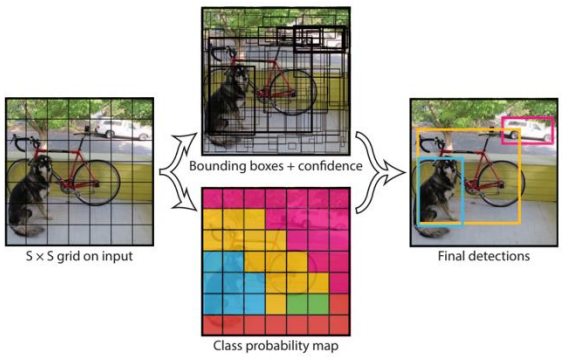

Fig. 3. YOLO object detection model divides the image into a grid and for each cell predicts bounding box, confidence for these boxes and class probability.

In the YOLOv2 system, this network architecture was replaced by a model with 19 convolutional layers with mostly 3x3 filters and 5 max-pooling layers, called darknet-19. The fully connected layers of YOLO were removed, and the bounding box proposal is modified, so instead of box coordinates, transformations of predefined anchor boxes are predicted. This is similar to the Mask R-CNN network, which also outputs shifts of pre-defined anchor boxes. In the YOLOv2 case, the anchor boxes are determined using the k-means clustering on a training set of ground truth bounding boxes and the translations of the boxes are relative to the grid cell. For each cell, 5 bounding boxes are proposed. The class predictions are now coupled with anchor boxes instead of cells, so for each bounding box, a class is predicted in addition to the objectness score, i.e. the confidence score of a box containing an object.

The network was trained on the combined dataset consisting of public available MS COCO detection dataset [14] and the top 9000 classes from the full ImageNet. The training was performed in several steps.

C. Mixture of Gaussians method

A common approach for locating moving foreground objects in scenes with predominantly static background involves background subtraction, where an approximation of background, usually an average image of several frames, is subtracted from a current frame (Fig. 4). Regions where this difference between the current frame and the background is greater than a chosen threshold are marked as foreground.

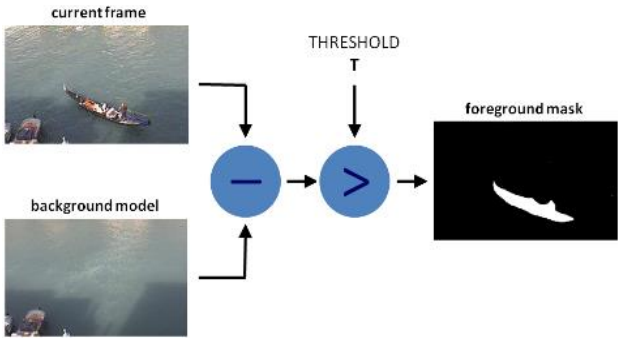

Fig. 4. The principle of background subtraction approach [15]

In practice, even in scenes shot with a stationary camera, the background is hardly ever static and can vary in time due to changes in lighting conditions, time-varying textures of background objects, e.g. waves on the water, clouds, etc. Several different background models and means of updating them have been developed to deal with this problem. Here we use the Mixture of Gaussians model (GMM) [16], where each pixel in an image is modeled as coming from a mixture of K Gaussian distributions that are continuously updated as the video progresses in time.

The GMM parameters are estimated based on the recent history of each pixel, using an online K-means approximation of the EM algorithm. Every new pixel value is checked with the existing K Gaussians to find a match, defined as a pixel value within 2.5 standard deviations of a distribution. If there is a match, the weights of distributions in the mixture are updated to give more weight to the matched distribution, and the mean and variance parameters of the matching distribution are updated to reflect the influence of the current pixel. When there is no matching Gaussian for the new pixel value, the least probable distribution in the mixture is replaced with a distribution with a low weight, whose mean is the current pixel value, and has a high initial variance.

In order to classify pixels into background or foreground classes, a heuristic rule is applied to determine which distributions in the mixture model the background. The Gaussians in the mixture are sorted in decreasing order of weight-to-standard-deviation ratio. The first B Gaussians are chosen as the background model, where B depends on a pre-set minimum portion of the data that should be considered the background.

The pixels whose values do not match one of the pixel’s backgrounds Gaussians are considered to be foreground objects and are grouped using connected components.

III. COMPARISON OF GMM, YOLO AND MASK R-CNN DETECTION PERFORMANCE ON HANDBALL SCENES

In this experiment, we have tested the YOLOv2 and Mask R-CNN object detectors based on CNNs, as well as the MOG background subtraction method on characteristic examples from the handball video domain.

The comparison was made on a custom dataset consisting of indoor and outdoor sports footage during practice and competition. The dataset contains 751 videos with 1920x1080 resolution at 30 frames per second, and the total duration of the recorded material is 1990 s. The scenes were captured using stationary GoPro cameras from different angles and in different lighting conditions. The cameras in indoor scenes were mounted at a height of around 3.5 m to the left or right side of the playground. Outdoor scenes have the camera at a height of 1.5 m. Depending on the players height, position in the field, and the camera viewpoint the size of the player in the image ranges from 40 to 240 pixels.

Both YOLO and Mask R-CNN were applied using only the CPU on the same hardware inside separate virtual machines for most reliable comparison. Publicly available pre-trained models were used with their corresponding weights build on COCO dataset, with no additional training with our own dataset.

To perform tests a high-level neural networks API Keras was applied on top of an open-source machine learning framework Tensorflow with a use of Python programing language in Ubuntu Linux environment. According to [12] the first method, YOLO, performs real-time object detection at 45 frames per second on a Titan X GPU and a fast version runs at more than 150 fps.

The other method, Mask R-CNN, predicts an object mask in parallel with the recognition of bounding boxes. This adds a small computational overhead according to [11] but gives much more information about the body posture.

On our hardware, using only the CPU, it on average 18.47 seconds for Mask-RCNN to process a 1920x1080 RGB color video frame, while YOLO performed much faster, with 0.94 seconds per frame. It is important to notice that both methods resize input data, Mask R-CNN to 1024x1024 and YOLO to 608x608 therefore using higher resolution images would not contribute much to the result.

The MOG background subtraction method is used as a baseline in the comparison vs. the full object detectors. The idea is to detect moving objects (players and balls) in the otherwise static scene of a sports field, shot with a stationary camera. Differences between consecutive frames are used to distinguish foreground objects from the mostly stationary background. It should be noted that the background subtraction methods do not attempt to determine the class of the detected foreground object, but just examine if they belong to the foreground, which may be compared with the "objectness" score of the CNN methods. In the experiment, the raw results of background subtraction were post-processed using the 3x3 square opening, 15x15 square closing and with hole-filling morphological operators.

Detectors performance are compared with the ground truth and evaluated in terms of recall, precision and F1 score [17]. For the YOLO and Mask R-CNN detectors that report confidence scores, we only considered detection whose confidence is greater than 85%, to avoid a large number of false positives otherwise reported by both detectors. For example, without the confidence threshold, the Mask R-CNN detected 27 persons per image in average, while the average number of players was in fact 10, so the confidence threshold was chosen accordingly. For MOG, all detections were considered.

To count a detection as true positive, more than half of the area belonging to the player should be inside the detected bounding box. The detector efficiency depends heavily on the number and size of objects on the scene, as well as the occlusion of objects. Fig, 5. shows the results of the evaluation of the results in the case of a simple and complex scenario. A simple scenario includes fewer objects, up to 8, close to the camera. A complex scenario is when the number of objects on the scene is equal and greater than 9, away from the camera and with the occlusions.

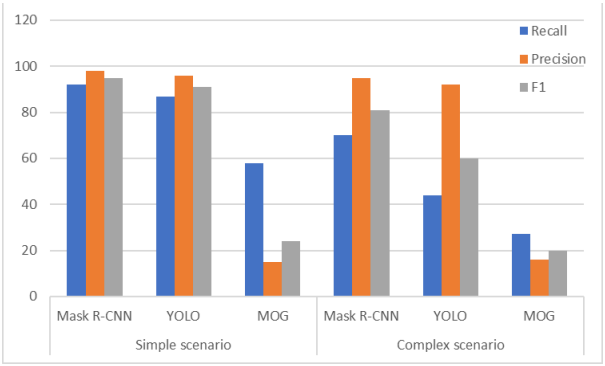

Fig. 5. Evaluation results for Mask R-CNN, Yolo and GMM in simple and complex scenarios

The detection results of three mentioned methods on characteristic handball scenes are presented in the following figures. The indoor handball scenes are presented in Fig. 6. The upper row of Fig. 6. is a result of MOG, middle of YOLO and lower of Mask R-CNN. By examining middle left figure, it is notable that compared to lower one YOLO has difficulty detecting objects smaller than 50 pixels in height.

The same is with overlapping objects which are very common in the indoor type of sports. It still made a detection of the person sitting at the far end of the court even though there are closer objects more easily distinguished to the human eye. On the other hand, MOG has detected persons that have moved, regardless of their size, but made a lot of mistakes. A lot of bounding boxers were placed where there were no players (FP), due to often highly reflective playing field, light changing and shadows that players cast under artificial illumination. Due to the different speeds of some objects, body parts such as arms and legs or head are detected as a separate object. Mask R-CNN had no problems with player detection and did not detect body parts as separate objects. Also, the players who were away from the camera, small and did not move sufficiently were not detected with MOG.

The middle picture in the second column (YOLO) shows less than a half of the objects detected by Mask R-CNN. The object of interest, the coach dressed in blue, is harder to detect compared to the rest of the video footage processed by YOLO, showing that YOLO has difficulty distinguishing objects with a similar color to the background.

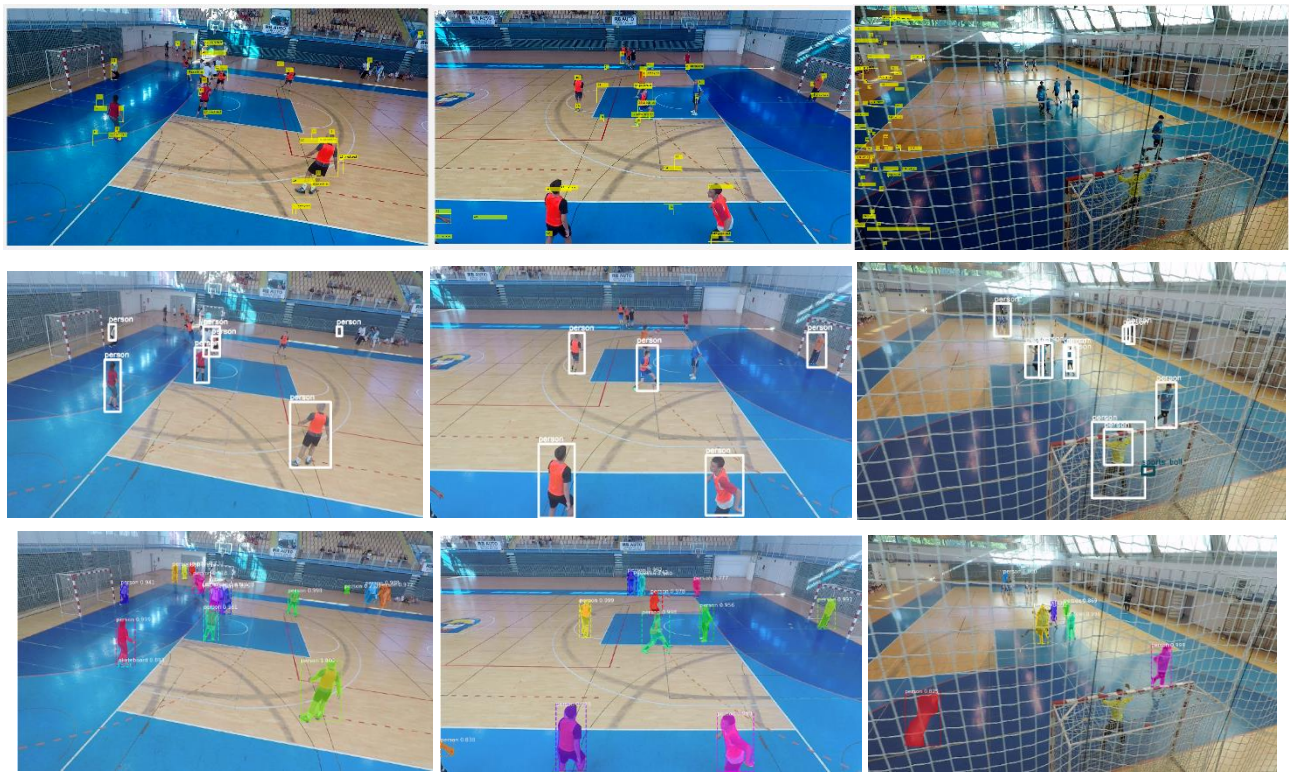

Fig. 6. MOG (upper row), YOLO (middle row) and Mask R-CNN (lower row) results on indoor sport footages

MOG has no problems if an object with a similar color to the background is moving since detection depends on differences between frames. Mask R-CNN and MOG were also successful in detecting the person coming to scene from the left, but MOG had several false positives.

In an example of occlusion, on the images in the right column, YOLO has better results. It detects more persons and even the sports ball. Mask R-CNN again has FP detecting a reflection of the light on the floor as a person

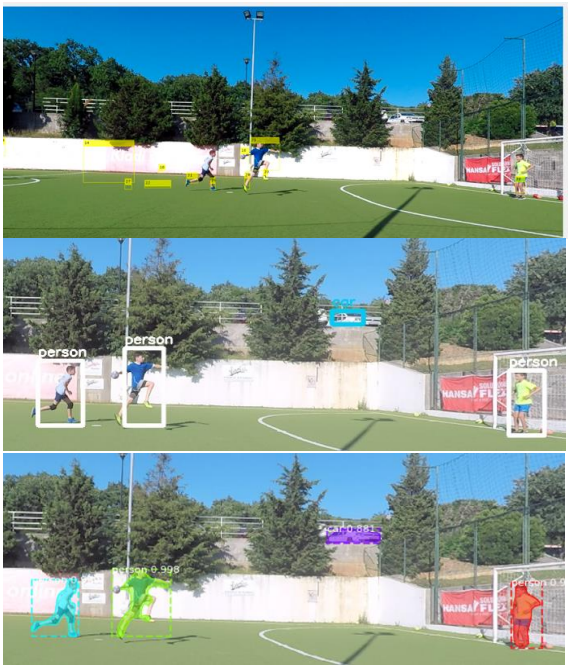

Fig. 7. Example of object detection in an outdoor scene with MOG (top), YOLO (middle) and Mask R-CNN (bottom)

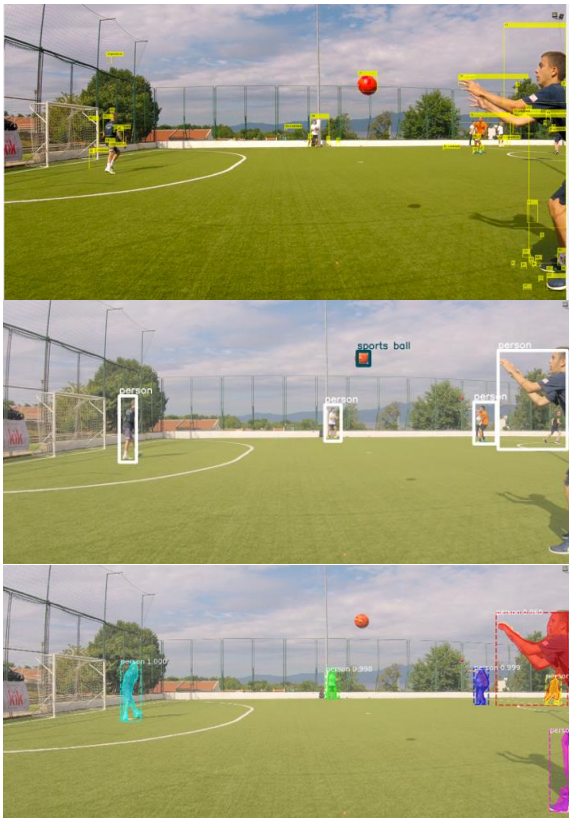

Fig. 8. MOG, YOLO and Mask R-CNN detecting a ball

(bottom left). For MOG, the net through which the scene was recorded was too big an obstacle, and as the net was shaken, MOG has detected a lot of parts of the net as foregrounds objects.

Fig. 7. shows results in an outdoor scene. The image contains few players, with no overlapping and only one partly visible object (a car) which is not important for the sport of interest. Both YOLO and Mask R-CNN have performed well, but MOG was significantly worse, with FPs and missed detections (FN).

Both YOLO and Mask R-CNN methods struggle with detecting sports balls. Figure 8. is an example where Mask R-CNN was unable to detect the ball, while YOLO and MOG detected one out of two balls. Mask R-CNN however detected one more person at a distance than YOLO. It is important to notice that shadows which can be detected as real objects have not confused any of the methods.

IV. CONCLUSION

The analysis of the obtained results shows that Mask R-CNN is more appropriate in the footages of team sports because it can successfully detect individual players even when they are inside a group. Also, it has more success detecting individuals further away from the camera. An additional benefit is a mask around the detected object, which, with slightly more computation power, provides significant information which can be used to isolate it from the background. The problem with this method is that it requires more time and computation power.

It was faster to test and finetune YOLO on real-time data with satisfying results. In the majority of acquired video footages, YOLO has proven to be sufficient and in case of occlusion even better than Mask R-CNN. The MOG detector works fast but has proved to have too many false detections in comparison with both YOLO and Mask R-CNN, as it was expected due to it being a binary background/foreground detector working only on motion data.

Even though Mask R-CNN lacks a possibility of the fast and easy on-the-field-analysis, taken into account further hardware and algorithm development it can be concluded with high probability this will be solved in the near future.

The one thing YOLO and Mask R-CNN methods had a problem with is the inability to reliably detect the sports ball. This could be due to fact that shape and texture of it share same features like many other objects (head, lamp, decorations). Probable solution would be to take into account existence and position of the ball near a player during the training phase to overcome this behavior. The interesting observation is that even though shadows of many objects resemble the actual object, they were (almost) never mistaken for a ground truth. Possible combination of the tested methods, which would result in benefits from both, should be further research but it falls outside the scope of this research paper.

This paper provides a promising base ground for further research of activity recognition in video material. By selecting the optimal solution and adjusting it to a certain activity it could be even possible to subtract the leading player and predict its movement or even an outcome of the action.

ACKNOWLEDGMENT

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Performance Analysis of an Ant Lion Optimizer in Tuning Generators' Excitation Controls in Multi Machine Power System

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***Abstract* - In this paper an ant lion optimizer algorithm is proposed for tuning excitation controls in multi machine power system. Tuning of excitation controls includes change of parameters in automatic voltage regulator (AVR) and power system stabilizer (PSS). A proposed algorithm is used as a swarm intelligence optimization method for finding a best solution for small signal stability problems. A two area – four machine model (TAFM) with two interconnected transmission lines is considered in this paper. Small signal stability disturbances observed in this paper include automatic re-closure of an interconnection line between two areas, short circuit on an interconnection line, short term load outage in first area, and a load change in first area. Performance of a proposed algorithm is compared with other swarm intelligence algorithms such as particle swarm optimization (PSO), velocity relaxed particle swarm optimization and a salp swarm algorithm (SSA). Objective functions used in performance analysis and comparison include integral of time-weighted absolute error (ITAE) and mean value of time domain transitional process quality indicators.**

Keywords - Power System Small Signal Stability, Automatic Voltage Regulator, Power System Stabilizer, Ant Lion Optimizer

I. INTRODUCTION

Power system is a complex nonlinear system that consists of different areas presented by their own inertia factors and which are interconnected. This system may exhibit several types of oscillating modes when perturbed with different types of disturbances. These perturbations may be considered as small disturbances or large perturbations. Small disturbances commonly include short term outages and load changes, while large disturbances may include appearances of significant short circuit currents, large generator outages or even the isolation of some large areas in a system.

These issues are investigated through power system stability analysis. This analysis observes oscillatory modes defined through several system stability definitions [2]. When an oscillatory mode is observed it can be recognized through disturbance type and appropriate frequency analysis methods. In a rotor angle stability analysis, which observes behaviour of the system through fast dynamic responses, transient stability is defined as a system's stability after large perturbation occurs, and a small signal stability defines a system's ability to return to its starting operating point after a small disturbance occurs. In both situations low frequency modes will appear, with local (1.5 – 2.5 Hz) and inter-area (0.2 – 1 Hz) modes being significant [2 – 5]. Local area mode occurs with generating units oscillating locally against each other within one area, while inter-area modes occur when generators in different areas interconnected with transmission lines oscillate against each other. This may have an undesired impact on various elements in power system, especially on heavy loaded interconnected tie lines.

In addressing this problem, various control methods have been proposed and implemented. Elements that can be tuned include automatic voltage regulators, power system stabilizers on the excitation systems, and FACTS systems on transmission network side. Lately, several of these tuning methods proposed include implementation of coordinated strategies for parameter tuning driven by different AI techniques such as fuzzy regulation [8 – 10], neural networks [8] and swarm intelligence methods [8, 10 – 16]. With the latest blooming of swarm intelligence algorithms [7] this problem has become more interesting in state of the art control techniques.

In this paper one such algorithm, known as Ant Lion Optimizer (ALO) [6] is implemented, tested, compared with several other swarm intelligence algorithms and proposed as a coordinated control design as a solution to small disturbance and transient stability problems.

II. TWO-AREA-FOUR-MACHINE TESTING MODEL

A. Description of a model

Model used for testing is a standard power system model used in stability analysis, introduced in [1]. Model consists of two areas with two generator units in each area, with two areas interconnected with a 220kV transmission tie line [1, 5]. Generator units are equipped with turbine governors, excitation systems and control units for each of these systems. On the excitation side DC exciters are modelled and equipped with AVR and PSS regulators for damping local and inter-area modes of frequency. Speed deviations, voltage disturbances and tie line power changes are here considered as main variables for observation and feedback information for parameter changes. Described model is shown in fig. 1. Technical data is shown in table I. Roles of PSS and AVR controllers are described in [4].

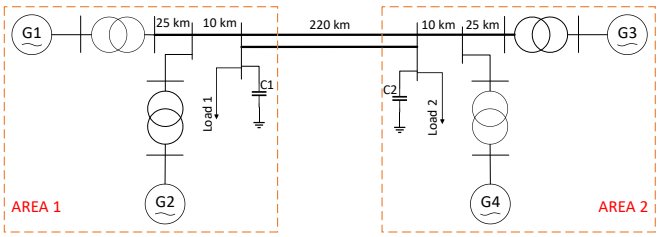

Figure 1. Testing model for stability considerations

TABLE I. TECHNICAL DATA OF TESTED MODEL

Element	*Area*	*Technical characteristics*
Generator 1	Area 1	$20kV,\ 900MVA,\ 50Hz$ $X_d = 1.8pu,\ X'_d = 0.3pu, X''_d = 0.25pu,\ R_a = 0.0025pu$ $X_q = 1.7pu,\ X'_q = 0.55pu, X''_q = 0.25pu, X_l = 0.2pu$ $T'_{d0} = 8s, T''_{d0} = 0.03s, T'_{q0} = 0.4s, T''_{q0} = 0.05s$ $H_{G1} = H_{G2} = 6.5,\ H_{G3} = H_{G4} = 6.175,\ K_D = 0$
Generator 2	Area 1	
Generator 3	Area 2	
Generator 4	Area 2	
Load 1	Area 1	$P_{load1} = 967MW, Q_{load1} = 100MVAr$
Load 2	Area 2	$P_{load2} = 1767MW, Q_{load2} = 100MVAr$
Transmission lines 1, 2	Area 1	$l_{line1} = l_{line3} = 10km, l_{line2} = l_{line4} = 25km$ $l_{line5} = 220km, V_{nom} = 230kV$ $R_l = \frac{0.001pu}{km},\ L_l = 0.001pu,$ $b_l = 0.00175pu/km$
Transmission line 3, 4	Area 2	
Transmission line 5	Area 1 – Area 2	
Transformers 1, 2	Area 1	$900MVA, {}^{20kV}/_{230kV},\ 50Hz,\ D1Yg$ $R_1 = R_2 = 10^{-6}\ pu, L_1 = 0pu, L_2 = 0.15pu$
Transformers 3, 4	Area 2	
Capacitor 1	Area 1	$Q_{C1} = 300MVAr$
Capacitor 2	Area 2	$Q_{C2} = 350MVAr$

B. Controller design

Controllers used in parameter tuning AI technique proposed in this paper include AVR as PT1 regulator with gain K_a and time constant T_a as its parameters. PSS is a PSS1 type with overall gain K_{PSS}, washout block defined with time constant T_w, and two lead-lag blocks whose constants $T_{1n}, T_{1d}, T_{2n}, T_{2d}$ are to be optimized, along with overall gain. The structure od PSS is shown in fig. 2.

C. Observed scenarios

For the purpose of algorithm performance evaluation, four cases are studied as perturbation scenarios. These include:

- Case 1 – outage and automatic reclosure after 1 second of one of two interconnection lines,
- Case 2 – Short circuit that occurs on 170th kilometer of a transmission line from Area 1, and lasts for 80 ms (self-clearing fault),
- Case 3 – Temporary outage of a load in Area 1 which lasts for 2 seconds,
- Case 4 – Additional 20% load injection on a load bus in Area 1.

Observed system is modelled in MATLAB Simulink®. Simulation time is 25 seconds. All mentioned contingencies occur at 5th second of simulation time.

III. ANT LION OPTIMIZER ALGORITHM

Ant Lion Optimizer is a novel nature inspired algorithm for swarm intelligence optimization [7]. It mimics the intelligent behavior of ant lions during the larvae life cycle. In one iteration six phases are implemented which include random walk of prey, trapping in pits, building a trap, sliding of prey towards antlion, catching the prey/rebuilding the pit and defining a best antlion through elitism rule. Initial ant lion positions and prey positions are stochastically positioned through search space, as is common in all swarm intelligence methods.

A. Random walk of prey

Ants, as a favourite prey of ant lions, are here assumed to walk in random walks, which is described with cumulative sum function, as follows:

$$X(t) = [0, cumsum(2r(t_1)) - 1, \dots, cumsum(2r(t_n)) - 1] \quad (1)$$

where:

$$r(t) = \begin{cases} 1, & rand(0,1) > 0.5 \\ 0, & rand(0,1) \le 0.5 \end{cases}$$

and finally, a normalization of position in search space is defined as:

$$X_i^t = \frac{(X_i^t - a_i)\cdot(d_i^t - c_i^t)}{b_i - a_i} + c_i^t \quad (2)$$

In equation (2) X_i^t is a position of *i*-th variable in iteration *t*, a_i and b_i are minimum and maximum of random walk in *i*-th variable, and c_i^t and d_i^t are minimum and maximum of *i*-th variable at iteration *t*. This equation is applied at every iteration throughout the algorithm's duration.

B. Trapping in pits

Random walk of prey is affected by ant lions' pits. This assumption is mathematically defined as:

$$c_i^t = antlion_j^t + c^t, \quad d_i^t = antlion_j^t + d^t \quad (3)$$

where c^t and d^t are minimum and maximum of all variables at iteration *t*, and $antlion_j^t$ is a position of *j*-th selected antlion at iteration *t*.

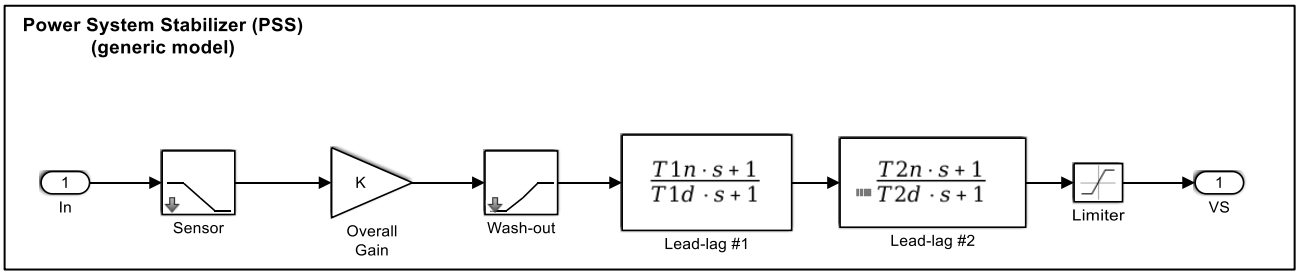

Figure 2. PSS1 model used in test system

C. Building a trap

Trap building is described as an ant lion's capability of hunting prey. In this algorithm, every ant is assumed to be trapped by one antlion. Fitness of an ant corresponds to a hunting capability/fitness of an antlion and therefore a roulette wheel selection function is here employed. This gives higher chances to fitter ant lions in catching better prey.

D. Sliding of prey in a trap

Ant lions are building traps whose quality corresponds to their fitness. In process of prey's sliding towards an ant lion, it shoots grains of sands out of center which helps to catch a prey. This process is modelled as adaptive decrease in a coned pit's limits:

$$c^t = {c^t}/{I}, \quad d^t = {d^t}/{I} \tag{4}$$

where I is a factor depending on a ratio of a current iteration and a number of iterations. This decrease in search space helps in achieving a better convergence towards optimum.

E. Catching a prey/rebuilding a trap

Final catching of a prey and ant lions reposition is described as:

$$f(ant_i^t) < f\left(antlion_j^t\right) \rightarrow antlion_j^t = ant_i^t \tag{5}$$

F. Elitism rule

By this rule fitness of a best ant lion is obtained and its position is assumed to affect every ant in a current search space. This is defined through next random walks of prey, as follows:

$$ant_i^t = \frac{R_A^t + R_E^t}{2} \tag{6}$$

where R_A^t is a random walk of prey around antlion selected through roulette wheel selection process, and R_E^t is a random walk of the same prey around elite ant lion at iteration t.

IV. Initializaton and Simulation Results of TAFM Model

All algorithms are repeated in 5 trials, with each trial having a maximum number of 50 iterations, and within each iteration a population of 25 agents (particles, salps, ants/ant lions) is tested with two objective functions. Dimension of each agent is equal to number of parameters to be tuned and is 28 (four PSSs with five parameters each, and four AVRs with two parameters each)

A. Proposed objective functions and parameter constraints

In this section, two objective functions are proposed. First objective function includes calculation of integral of time-absolute error (ITAE) with speed deviations, voltage deviations and tie line active power deviations:

$$f_1(t) = \int_{t=t_1}^{25\,s} t \cdot (|\Delta\omega(t)| + 0.005 \cdot |\Delta V_t(t)| + |\Delta P_{tie}(t)|) \tag{7}$$

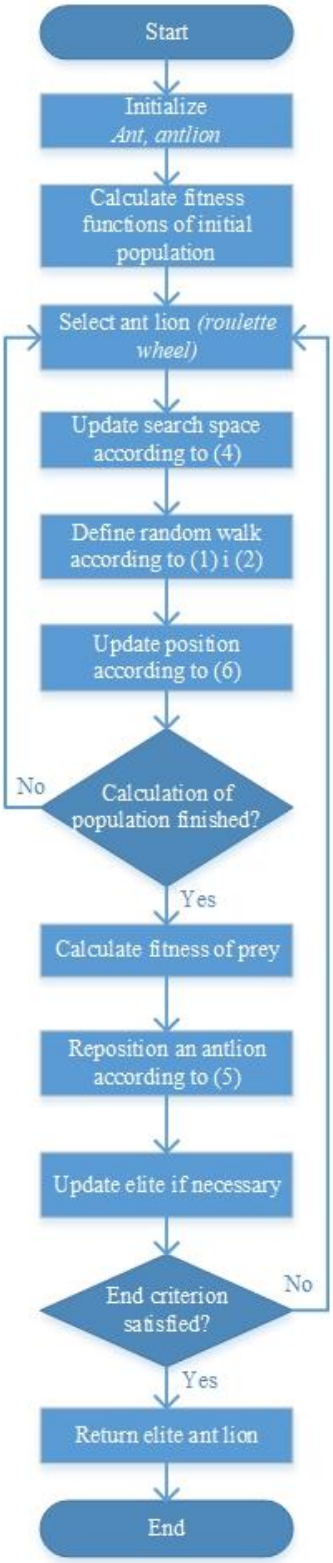

Figure 3. Flow chart of an Ant Lion optimizer

where:

$$|\Delta\omega(t)| = |\omega_1(t) - \omega_2(t)| + |\omega_1(t) - \omega_3(t)| + |\omega_1(t) - \omega_4(t)| + |\omega_3(t) - \omega_4(t)|$$

$$|\Delta V_t(t)| = 0.005 \cdot (|V_{t1}(t) - V_{t10}| + |V_{t2}(t) - V_{t20}| + |V_{t3}(t) - V_{t30}| + |V_{t4}(t) - V_{t40}|)$$

$$|\Delta P_{tie}(t)| = \frac{|P_{tie}(t) - P_{tie0}|}{10^5}$$

Second objective function used for evaluation takes into consideration rotor speed deviation responses from simulation. The quality indicators of these responses include mean overshoot, mean undershoot and mean settling time of four speed deviations. The second objective function is as follows [16]:

$$f_2(t) = 4000 \cdot \overline{os}^2 + 1000 \cdot \overline{us}^2 + \overline{ts}^2 \tag{8}$$

These two objective functions are to be minimized through algorithm's work flow. Parameters of *i*-th PSS and *i*-th AVR are constrained to values as follows:

$$1 \le K_{pss,i} \le 250$$
$$0.005 \le T_{1n,i} \le 5$$
$$0.005 \le T_{1d,i} \le 5$$
$$0.05 \le T_{2n,i} \le 15$$
$$0.05 \le T_{2d,i} \le 25$$

and

$$2 \le K_{a,i} \le 250$$
$$0 \le T_{a,i} \le 0.1$$

B. Algorithms used for testing and their initial settings

Model testing is done with four different algorithms: ALO, particle swarm optimization (PSO), velocity relaxed particle swarm optimization (VRPSO) and a salp swarm algorithm (SSA).

Initial settings for PSO and VRPSO include velocity factors according to personal and global best solution and weight factor for velocity of previous iteration $c_1 = 1.2$, $c_2 = 0.9$, $w = 0.9$, according to equation:

$$v_{j,d}^{i+1} = w \cdot v_{j,d}^{i} + c_1 \cdot rand(0,1) \cdot \left(pbest_{j,d}^{i} - x_{j,d}^{i}\right) + c_2 \cdot rand(0,1) \cdot \left(gbest_{d} - x_{j,d}^{i}\right)$$

where *j* is the particle, *d* is a dimension of a particle and *i* is iteration. VRPSO algorithm introduces adaptive speed for weight factor with constrained velocity: $w = w_{max} - a \cdot i$.

Adaptive speed factor is $a = 0.05$, and i is current iteration. Also, a novel algorithm called salp swarm algorithm (SSA) [17] is introduced for algorithm comparison purpose.

Initial setting for ALO includes defining of a factor *I* for decrease of a search space through iterations as follows:

$$I = \begin{cases} 1, & i \le \dfrac{max_iter}{3} \\ 1 + 10^{\frac{i}{max_iter}}, & i > \dfrac{max_iter}{3} \\ 1 + 10^{\frac{2i}{max_iter}}, & i > \dfrac{max_iter}{2} \\ 1 + 10^{\frac{3i}{max_iter}}, & i > 0.75 \cdot max_iter \\ 1 + 10^{\frac{4i}{max_iter}}, & i > 0.9 \cdot max_iter \\ 1 + 10^{\frac{5i}{max_iter}}, & i > 0.95 \cdot max_iter \end{cases}$$

where *i* is current iteration and *max_iter* is total number of iterations.

C. Algorithm evaluation indicators

Analytic comparison of algorithms is made with several factors regarding 5 trials of algorithm running. First three comparison factors are best fitness solution, mean value of fitness and standard deviation according to mean value:

$$f_{best} = min(f_1, \dots, f_5) \tag{9}$$

$$\mu = \frac{1}{5} \cdot \sum_{i=1}^{5} f_i \tag{10}$$

$$\sigma = \sqrt{\frac{1}{5} \cdot \sum_{i=1}^{5} (f_i - \mu)^2} \tag{11}$$

Next four factors are convergence quality indicators: convergence capability of an algorithm, mean value of convergence capability, best convergence capability and relative capability according to best one out of four algorithms.

$$C_A = \left(\int_{0.2 \cdot max_iter}^{max_iter} C(i)di\right)^{-1} \tag{12}$$

$$C_{A,mean} = \frac{1}{5} \cdot \sum_{i=1}^{5} C_{A,i} \tag{13}$$

$$C_{A.best} = max\left(C_{A,1}, \dots, C_{A,5}\right) \tag{14}$$

$$C_r = \frac{C_{A,best}}{C_{A,best,alg}} \cdot 100[\%] \tag{15}$$

D. Simulation results

In this section, analytical review is made through comparison of different algorithms along with some graphical responses that are shown as a result of testing and obtaining the best function. These responses include rotor speed deviation $\omega_1 - \omega_2$ as a representation of local mode of oscillations, rotor speed deviation $\omega_1 - \omega_3$ as a representation of inter-area mode of oscillations, terminal voltage V_{t2} on a swing type generator and a tie line power flow P_{tie}. Results are compared with the same scenarios on a system controlled with high gain proportional AVR regulator ($K_a = 200$, $T_a = 0\ s$), without attached PSS.

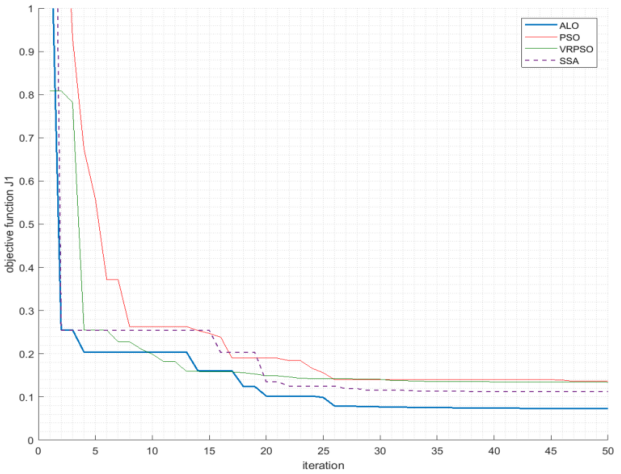

Figure 4. Convergence curve for objective function *J1*, 1 s tie line outage

Convergence curve for scenario 1 is shown in fig. 4. Here, four algorithm convergences are compared. Figures 5 to 8 show acquired responses for different algorithms in different scenarios. Table II shows algorithm quality indicators with the best algorithms highlighted. Table III has a list of parameters tuned by different algorithms.

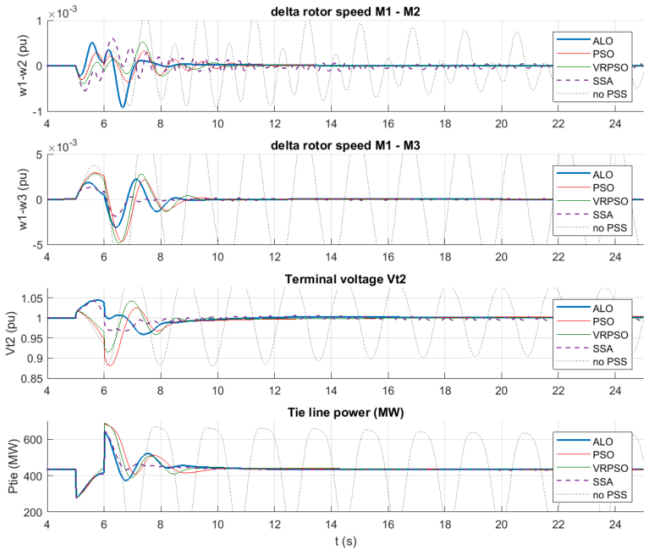

Figure 5. Testing results for 1 second line outage, objective function *J1*

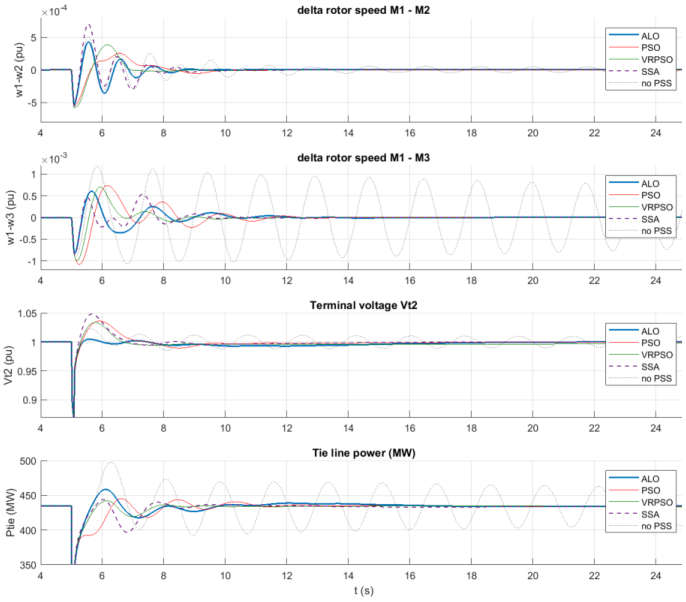

Figure 6. Testing results for 80 ms self-clearing fault, objective function *J1*

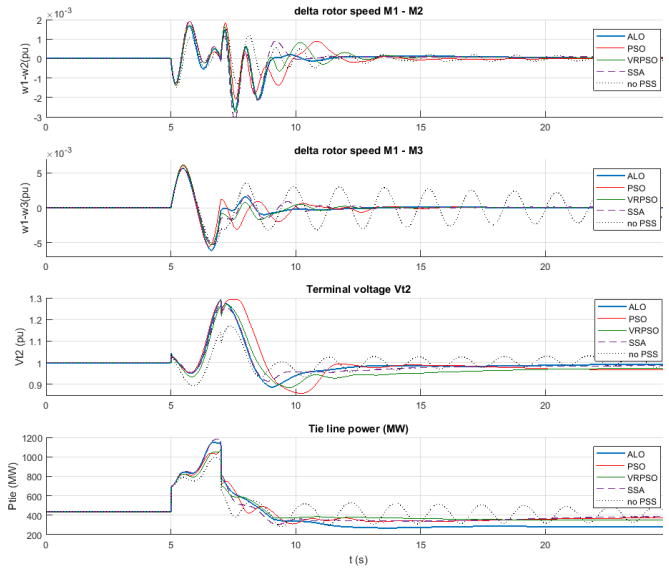

Figure 7. Testing results for 2 s area 1 load outage, objective function *J2*

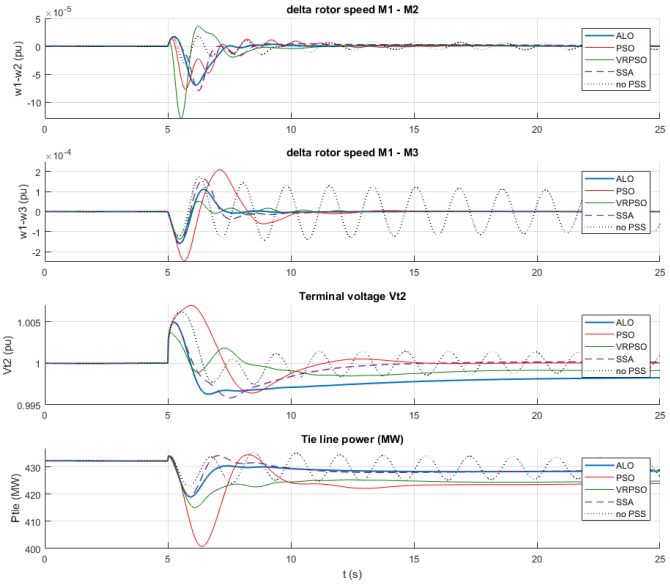

Figure 8. Testing results for 20% area 1 load injection, objective function *J2*

TABLE II. TECHNICAL DATA OF TESTED MODEL

Scenario	*Obj. function*	*Algorithm*	f_{best} (9)	μ (10)	σ (11)	$C_{A,best}$ (14)	$C_{A,mean}$ (13)	C_r (15)
Line outage 1s	J1	ALO	**0.0735**	**0.1339**	**0.0739**	**0.2597**	**0.1812**	**100**
		PSO	0.1363	0.2260	0.1085	0.1489	0.1080	57.35
		VRPSO	0.1339	0.1931	0.0766	0.1729	0.1300	66.60
		SSA	0.1120	0.1874	0.0966	0.1811	0.1345	69.74
	J2	ALO	**162.9440**	**217.8293**	75.22349	$\mathbf{1.0944 \cdot 10^{-4}}$	$\mathbf{1.0944 \cdot 10^{-4}}$	**100**
		PSO	269.8173	308.4391	**43.5255**	$7.3771 \cdot 10^{-5}$	$6.6284 \cdot 10^{-5}$	56.35
		VRPSO	234.5381	295.4364	70.3265	$1.0315 \cdot 10^{-4}$	$7.1943 \cdot 10^{-5}$	78.80
		SSA	199.0969	252.8005	78.3556	$1.2271 \cdot 10^{-4}$	$9.7629 \cdot 10^{-5}$	93.74
Self-clearing fault 80ms	J1	ALO	**0.0359**	**0.0428**	0.0124	0.5793	**0.5234**	89.91
		PSO	0.0453	0.0522	0.0111	0.5144	0.4138	79.83
		VRPSO	0.0367	0.0437	**0.0094**	**0.6443**	0.5215	**100**
		SSA	0.0426	0.0639	0.0261	0.5088	0.3849	78.97
	J2	ALO	83.1195	**114.8756**	**39.2521**	$2.5435 \cdot 10^{-4}$	$2.0661 \cdot 10^{-4}$	90.73
		PSO	125.8618	4084.9	6253.8	$1.3215 \cdot 10^{-4}$	$4.9845 \cdot 10^{-5}$	47.14
		VRPSO	112.8130	5370.5	6894.2	$2.1079 \cdot 10^{-4}$	$7.5774 \cdot 10^{-5}$	75.19
		SSA	**74.3044**	119.4744	59.7988	$\mathbf{2.8034 \cdot 10^{-4}}$	$\mathbf{2.0965 \cdot 10^{-4}}$	**100**
Load outage 2 s	J1	ALO	**0.2386**	**0.3224**	**0.1084**	**0.0898**	**0.0715**	**100**
		PSO	0.2676	0.3748	0.1327	0.0775	0.0605	86.28
		VRPSO	0.3101	0.5120	0.3108	0.0708	0.0529	78.77
		SSA	0.3061	0.4013	0.1438	0.0778	0.0638	86.58
	J2	ALO	**182.5300**	220.5101	45.8911	$\mathbf{1.1174 \cdot 10^{-4}}$	$9.7663 \cdot 10^{-5}$	**100**
		PSO	250.7516	327	108.1259	$8.1467 \cdot 10^{-5}$	$5.6787 \cdot 10^{-5}$	72.91
		VRPSO	257.1249	1091.1	1802.2	$8.2742 \cdot 10^{-5}$	$5.3311 \cdot 10^{-5}$	74.05
		SSA	184.4793	**213.3686**	**36.4869**	$1.1022 \cdot 10^{-4}$	$\mathbf{9.9767 \cdot 10^{-5}}$	98.64
Load injection 20%	J1	ALO	**0.0100**	**0.0110**	**0.0014**	**2.4026**	**2.2033**	**100**
		PSO	0.0111	0.0227	0.0183	2.0168	1.3873	83.94
		VRPSO	0.0139	0.0158	0.0025	1.5947	1.3748	66.38
		SSA	0.0103	0.0118	0.0021	2.3065	2.0748	96.00
	J2	ALO	**61.6440**	**72.9396**	**14.3459**	$\mathbf{3.4233 \cdot 10^{-4}}$	$\mathbf{3.0582 \cdot 10^{-4}}$	**100**
		PSO	102.3774	2084.1	4426.4	$2.4778 \cdot 10^{-5}$	$1.4661 \cdot 10^{-4}$	72.38
		VRPSO	87.1626	2078.1	4433.2	$2.3715 \cdot 10^{-5}$	$1.7828 \cdot 10^{-4}$	69.27
		SSA	88.1065	105.6882	20.5486	$2.3086 \cdot 10^{-4}$	$2.1416 \cdot 10^{-4}$	67.44

TABLE III. CONTROLLERS' PARAMETERS TUNED BY TESTING OF FOUR ALGORITHMS AND TWO OBJECTIVE FUNCTIONS

Algorithm + obj. function	*Scenario*	*PSS1-Kpss*	*PSS1-T1n*	*PSS1-T1d*	*PSS1-T2n*	*PSS1-T2d*	*PSS2-Kpss*	*PSS2-T1n*	*PSS2-T1d*	*PSS2-T2n*	*PSS2-T2d*	*PSS3-Kpss*	*PSS3-T1n*	*PSS3-T1d*	*PSS3-T2n*	*PSS3-T2d*	*PSS4-Kpss*	*PSS4-T1n*	*PSS4-T1d*	*PSS4-T2n*	*PSS4-T2d*	*AVR1-Ka*	*AVR1-Ta*	*AVR2-Ka*	*AVR2-Ta*	*AVR3-Ka*	*AVR3-Ta*	*AVR4-Ka*	*AVR4-Ta*
ALO-J1	Line outage 1s	155.065	1.19	0.014	1.913	2.488	75.07	0.69	0.9	1.439	0.05	92.686	0.744	0.024	8.588	7.091	57.889	0.352	0.008	2.918	0.905	53.076	0	151.829	0.006	87.376	0.01	82.834	0
ALO-J2		46.723	1.746	0.021	13.95	11.49	179.995	1.584	0.131	0.299	0.436	49.09	2.131	3.022	1.099	0.05	106.135	0.624	0.005	4.216	7.457	99.393	0.086	83.125	0.008	93.343	0.016	187.94	0.049
PSO-J1		250	5	4.954	6.795	0.05	1	0.005	5	0.05	25	10.348	5	0.005	0.05	0.05	1	5	2.104	15	0.05	2	0	2	0.1	68.156	0	165.939	0.1
PSO-J2		1	1.8	0.225	15	0.05	1	5	5	0.05	25	14.633	2.329	0.005	0.05	0.05	1	3.962	0.005	0.05	25	250	0.006	2	0	250	0.02	2	0.1
VRPSO-J1		67.501	3.195	0.005	9.402	23.548	1	1.25	0.215	1.275	9.045	11.619	3.241	0.005	11.568	7.325	1	5	1.15	11.772	0.967	22.647	0	2	0	139.845	0	186.709	0
VRPSO-J2		1	0.005	0.897	1.226	14.008	117.863	2.237	2.081	1.741	24.553	250	0.392	4.705	9.876	0.05	3.158	5	5	3.948	0.05	68.655	0.098	2	0.077	76.681	0	250	0.072
SSA-J1		139.293	1.732	0.167	14.995	9.182	215.544	2.08	0.005	8.267	15.845	98.22	0.813	1.384	14.273	0.05	181.335	3.756	0.015	11.232	24.938	240.562	0.003	68.665	0.081	224.174	0.084	220.644	0.092
SSA-J2		1.413	1.988	0.117	4.315	0.05	249.814	2.162	3.471	14.986	0.102	36.405	2.26	3.233	6.653	0.061	1.119	4.997	3.742	14.521	0.05	192.158	0	2.105	0.001	64.974	0.1	249.697	0.054
ALO-J1	Self-clearing fault 80ms	1.003	0.469	0.009	0.164	0.085	5.191	2.546	0.085	4.495	0.086	1	1.023	0.062	3.857	0.097	2.329	0.996	0.116	1.878	0.05	13.885	0.02	6.562	0.004	178.423	0.001	134.798	0.014
ALO-J2		4.997	1.039	0.593	0.699	0.236	55.54	1.403	0.194	0.442	0.05	6.692	1.252	0.301	3.978	0.05	1.67	0.937	1.032	4.82	4.899	13.844	0.014	40.302	0.03	38.122	0.009	202.829	0
PSO-J1		43.468	1.837	0.005	8.312	20.939	1	0.005	0.005	0.641	0.05	59.021	4.951	0.072	1.566	0.05	32.716	5	0.005	1.455	0.05	51.591	0.031	2	0.004	2	0	2	0.003
PSO-J2		83.275	2.315	0.005	1.411	7.55	250	5	4.922	6.004	25	22.108	3.245	4.428	0.849	0.05	1	5	4.999	4.245	15.462	137.382	0.1	2	0.043	54.247	0.085	250	0.1
VRPSO-J1		73.356	0.829	0.005	0.09	0.05	11.484	0.012	0.005	10.972	0.05	1	0.005	0.005	0.051	14.808	57.195	1.177	0.365	0.9	0.05	63.274	0	2	0.041	200	0.072	25.674	0
VRPSO-J2		1	0.005	0.525	0.05	17.315	1	2.123	4.076	0.05	21.943	1	1.95	0.005	0.05	0.05	1.092	0.742	0.005	14.363	0.05	184.928	0.1	125.992	0.016	2	0.023	166.65	0
SSA-J1		59.107	3.007	0.022	7.511	23.887	4.94	1.992	1.228	3.929	1.046	1	2.242	1.454	12.445	0.05	10.456	4.793	4.637	14.997	0.053	35.802	0.021	170.899	0.07	244.48	0.035	5.508	0.067
SSA-J2		11.97	1.399	2.474	14.965	0.062	5.947	0.961	2.139	9.621	0.084	135.933	3.971	0.651	1.662	0.112	1.983	4.764	1.711	12.779	0.05	24.551	0.059	53.601	0.049	3.511	0.023	35.978	0
ALO-J1	Load outage 2 s	1	1.954	0.35	9.907	4.367	1.259	1.42	0.375	0.487	0.064	1	0.137	0.312	3.92	3.274	7.919	1.333	0.085	5.342	0.051	33.656	0.003	118.512	0.021	2.594	0.001	13.079	0.007
ALO-J2		9.611	0.072	0.012	1.688	7.62	17.481	2.533	0.025	9.696	8.944	71.778	0.072	1.053	2.215	0.312	195.698	0.711	0.153	0.247	0.05	77.545	0.036	124.656	0.01	2.097	0.002	145.489	0.052
PSO-J1		12.302	5	0.01	0.05	14.562	4.63	0.58	0.315	11.589	24.186	141.594	3.461	0.005	1.144	0.05	1	4.999	0.07	0.366	8.412	243.784	0.095	77.605	0.098	2.821	0.029	16.832	0
PSO-J2		68.445	3.369	0.656	7.596	21.567	84.877	1.143	5	1.283	0.05	246.597	3.816	0.005	0.854	3.603	23.999	0.171	5	5.514	16.22	2	0.048	143.63	0.1	77.315	0.1	2	0.031
VRPSO-J1		1	0.005	0.005	8.789	0.05	1	4.043	0.005	15	20.756	5.303	1.378	0.005	4.604	11.481	1	0.005	2.096	7.404	0.05	3.764	0	128.44	0.064	164.761	0.1	2.065	0.1
VRPSO-J2		85.039	1.283	5	13.167	0.05	32.992	4.127	0.005	7.356	7.517	129.239	1.074	0.005	8.92	11.33	187.709	0.005	3.259	10.712	4.097	2	0	87.252	0.07	93.798	0	2	0.033
SSA-J1		1.016	0.04	0.011	7.436	0.804	1.224	4.984	0.212	9.973	24.977	1.512	0.89	0.006	13.786	0.156	1.099	1.717	4.846	1.258	1.266	2.694	0	249.841	0.096	2.685	0.005	2.82	0.1
SSA-J2		246.034	4.783	1.169	0.059	0.311	8.064	3.214	0.008	1.853	1.096	57.371	1.171	0.739	11.789	0.129	243.05	3.978	0.019	8.08	21.844	2.208	0.017	157.064	0	6.681	0.096	205.078	0.074
ALO-J1	Load injection 20%	1.771	1.379	1.231	3.327	0.063	131.586	1.094	0.006	2.393	0.2	1.004	3.154	0.163	3.621	0.072	1	0.416	0.696	2.076	8.89	37.586	0.004	6.998	0.001	89.346	0.022	57.273	0.036
ALO-J2		2.817	0.912	0.258	4.485	0.251	60.247	2.638	1.414	2.471	9.774	46.155	1.18	0.01	1.809	0.34	43.287	0.654	0.364	0.522	10.927	109.777	0.034	117.186	0.052	19.384	0.037	15.044	0.001
PSO-J1		1	3.419	0.548	15	0.05	230.712	5	5	4.945	13.955	1	3.987	2.775	15	25	1	0.608	0.167	15	0.05	34.902	0.1	174.77	0	2	0.073	250	0.063
PSO-J2		12.717	0.005	1.49	7.961	25	1	3.866	5	5.704	25	10.063	5	4.695	2.171	0.05	250	1.091	0.005	7.927	21.995	2	0.032	250	0.1	193.705	0	88.839	0.057
VRPSO-J1		10.449	5	3.296	15	5.505	1	0.005	4.323	0.05	4.68	1	3.626	1.54	0.05	15.404	1	5	0.005	2.221	0.05	2	0.061	116.273	0.065	24.572	0.1	91.419	0.1
VRPSO-J2		135.921	3.523	1.655	12.869	16.94	72.587	1.171	0.005	4.758	10.418	208.762	2.053	1.89	15	22.543	246.342	2.701	0.005	1.391	14.403	2.372	0.043	85.278	0.019	2	0.028	138.166	0.063
SSA-J1		1	1.89	4.632	1.504	23.269	1.39	1.923	2.341	8.14	15.403	1	4.998	4.974	14.926	0.05	1.093	4.073	3.961	12.481	0.05	130.528	0.1	205.729	0.037	207.162	0.012	103.034	0.095
SSA-J2		43.867	4.934	0.568	1.453	0.051	7.098	0.123	4.272	11.489	0.15	1.04	1.413	0.033	14.412	0.186	16.934	2.623	2.243	13.161	22.788	6.683	0.081	221.245	0.002	171.453	0.04	14.154	0.012

V. CONCLUSION

In this paper a new approach for control coordination by ALO algorithm is proposed. ALO algorithm has been applied for parameter tuning of control devices in generators' excitation systems in a TAFM model. A comparison between ALO, two standard PSO algorithms and a new SSA algorithm has been made for evaluation. ALO algorithm has been successful in majority of the investigated scenarios regarding best fitness achieved along with different convergence quality indicators. Testing was done with two different objective functions to see the algorithms' behaviour with two different approaches.

Further research of ALO algorithm for power system stability analysis may include a multi-objective approach with two functions. Through Pareto optimality this approach may yield even better results in achieving the best fitness solutions.

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Importance of Data Pre-processing in Credit Scoring Models Based on Data Mining Approaches

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***Abstract* - Data Mining has become essential tool for discovery of hidden patterns and information in databases. However, for a Data Mining model to be meaningful and effective, data pre-processing is one of the key factors in successful model preparation. In this paper, we have investigated how data pre-processing affects real dataset when applying Data Mining technique for the purpose of predicting default clients in a micro-financing institution. Therefore, several data pre-processing techniques have been described and applied to the dataset. Results are shown and compared for both of the cases with Generalized Linear Model and Decision Tree being the two Data Mining classification algorithms used for Credit Scoring model. It is concluded that Credit Scoring Model is much more accurate and efficient when it is executed on data that has been carefully prepared and pre-processed.**

Keywords - Classification, Credit Scoring, Data Mining, Data Pre-processing, Decision Tree, Generalized Linear Model

I. INTRODUCTION

As a tool for Knowledge Discovery in Databases (KDD), Data Mining has become very important in highly competitive business market for companies to extract some hidden information and patterns that can help them stay ahead of their competitors. It can help find unknown profitability, improve efficiency or help company's management make more correct decisions for the future. It is involved in different business domains, and so is in institutions and companies from Financial sector. They recognized that Data mining could be applied in the process of Credit Scoring that is used to predict default clients in order to decide whether to grant them a credit, especially classification algorithms such as Generalized Liner Model (GLM), Decision Trees, Support Vector Machines and Naive Bayes algorithm [1].

Extraction of hidden information and patterns requires implementation and appliance of advanced algorithms with careful analysis in order to choose technique that suits structure of given data sample the best. However, for the data mining model to be efficient and correct as much as possible, data pre-processing is of the crucial importance. It involves various tasks in order to prepare data so that data mining technique applied to it produces high-quality and accurate output patterns. Some of data pre-processing techniques are: data aggregation, feature selection and creation, data discretization and variable transformation [2].

II. RELATED WORK

Regarding investigation of data pre-processing techniques, their impact and appliance, several papers have been published.

Chandrasekar, Qian, Shahriar & Bhattacharya 2017 [3] investigated how data pre-processing methods can be used to improve the prediction accuracy of decision tree. Authors described decision tree algorithms J48 and C4.5 as data mining techniques used for classification. They used data from a real world leukemia microarray experiment and Weka as software for Data Mining for their research. Next, they described and applied supervised discretization filter on J48 algorithm to construct a decision tree in Weka. Finally, results were compared with J48 algorithm without discretization. Paper concluded that J48 algorithm shows much better accuracy and performance when appropriate data pre-processing is applied to it.

Huang, Li, Keung, Yu & Chan 2017 [4] analysed three-stage data pre-processing for analogy-based software effort estimation. Firstly, concept of analogy-based software was explained and how it can be used. Emphasis was put on data pre-processing as one of the key factors to ensure validity of the selected features. Therefore, three data pre-processing techniques were explained in detail: missing data imputation, data normalization, and feature selection for analogy-based effort estimation. Results of the research showed that those techniques have had significant impact on the accuracy of effort estimation. Authors proposed that experiments on more datasets should be conducted to verify the findings, more advanced estimation methods should be involved as well as more advanced missing imputation approaches.

Garcia, Marques and Sanchez 2012 [5] showed how data pre-processing on imbalanced credit data is used for improving risk predictions. Authors described dataset used for their research as well as concept of imbalanced credit data where class of defaulters is under-represented in comparison to the class of non-defaulters. They investigated if data resampling technique could be used to improve accuracy of learners built from imbalanced credit

datasets. Two resampling methods were described (over-sampling and under-sampling) with both of them applied in the experiment described in paper. Results showed that learning with resampled dataset provides much better performance and accuracy than the learning with the original one. Paper concluded that even a small improvement in accuracy and performance in credit scoring model can lead to future savings and affect commercial implications in a very positive way.

A. *Paper Contribution*

This paper compares results of Data Mining algorithm applied to the data that was not pre-processed against data that went through several data pre-processing techniques. It describes these techniques in detail with focus on real dataset provided by a micro-financing institution from Bosnia and Herzegovina. Furthermore, it analyses and thoroughly compares how the outcomes of applied Data Mining algorithm are affected by data pre-processing and verifies importance of appliance of such techniques.

III. RESEARCH METHODOLOGY

For our research, we used Oracle Data Miner (ODM), software package for data mining by Oracle company. For the given problem of classifying results in one of the two predefined categories, the best approach was usage of Classification algorithm. ODM uses four different algorithms for the classification: Support Vector Machine (SVM), Naive Bayes (NB), Generalized Linear Model (GLM) and Decision Tree (DT). All four algorithms were applied in our experiment, but the best results were shown by decision tree and generalized linear model, so these two data mining algorithms will be considered later in this paper.

In this research, two credit scoring model were built, both based on DT and GLM algorithms. The first model was trained and tested on real dataset before pre-processing and the second one on dataset after pre-processing. After that, the outcomes of the experiment were measured, compared and evaluated outcomes of the experiment.

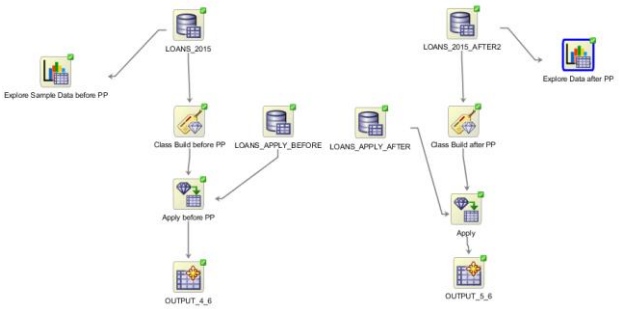

Figure 1. Credit Scoring models in ODM

Figure 1 depictures credit scoring models created in ODM. Credit scoring model applied on data before pre-processing is shown left in the picture and the right model is credit scoring model applied on the pre-processed dataset. After training of both models and evaluating the results, each of them were validated through applying on new dataset.

A. *Dataset Description*

In this paper a real dataset provided by a micro-financing institution from Bosnia and Herzegovina was used, which involved data about their clients, loans and repayment history. The original dataset consisted of 23615 records described with 33 attributes. These attributes are described in the following table:

TABLE I. DATASET DESCRIPTION

Name of Attribute	**Attribute Domain**	**Description**
UNIQUE_ID	Unique ID, Case Id	Unique id of loan request
SOC_STATUS	categorical	Social status of the client
DEMOG_STATUS	categorical	Demographic status of the client
QUALIFIACTION	categorical	Professional qualification of the client
GENDER	categorical	Client's gender (M/F)
TYPE_OF_CLIENT	Categorical	Type of client (F - individual, P - legal subject)
OWN_BUSINESS	categorical	Is client working in own business (Y/N)
OWNER_OF_BUSSINES	categorical	Is client owner of business (Y/N)
NATIONALITY	categorical	Client's nationality
URBAN_RURAL	categorical	Is client from urban or rural environment
MARTIAL_STATUS	categorical	Client's marital status
AGE	numerical	Client's age
DURATION_ON_ADDRESS	numerical	Duration of living on the same address in years
SOURCE_OF_INCOME	categorical	Client's source of income
TYPE_OF_CONTRACT	categorical	Client's type of contract with his/her employer (Unlimited time, Limited time, Seasonal etc.)
DURATION_OF_EMPLOYMENT	numerical	Duration of employment in years
LIVING_PLACE	categorical	Client's living place (Own, Rented, Parents, Others)
HH_NO_OF_INCOMES	numerical	Number of incomes in household
HH_NO_OF_NONADULTS	numerical	Number of non-adults in household
HH_NO_OF_ADULTS	numerical	Number of adults in household
HH_NO_OF_PETS	numerical	Number of pets in household
HH_NO_OF_DEPENDENT_MEMBERS	numerical	Number of dependent household members

AMOUNT_OF_LOAN	numerical	Amount of Loan
NUMBER_OF_INSTALMENT	numerical	Number of installments
TYPE_OF_LOAN	categorical	Purpose of taking loan (Agriculture, Trade, Production, etc.)
CLIENT_CYCLE	numerical	Ordinal number of client's loan request
COLLATERALS	categorical	Does client have collaterals (Y/N)
LOANS_IN_OTHER_BANKS	Categorical	Client has loan in other bank (Y/N)
CLIENTS_SEGMENT	categorical	Client's employment status (Employed, Unemployed, Family member is employed)
HH_INCOMES	numerical	Total amount of household income
HH_COSTS	numerical	Household costs
HH_AMOUNT_OF_INSTALMENT	numerical	Total amount of installments in household
DEFAULT_01	Target value	Is Client default (0 - Non-default / 1 - Default)

Original dataset consisted of loan requests that were submitted during one year period. Case Id of the dataset is unique id of loan request and the target attribute is classification attribute default_01. Clients are classified as bad or default if they have ever been late in paying loan obligations more than 30 days. Otherwise, they are classified as good or non-default. Since, our main target is recognizing default loans, positive class is the default one.

B. Data Mining Algorithms

Decision Tree is a supervised learning algorithm used to represent knowledge in intuitive and understandable form. It is based on recursion by selecting an attribute as a root node and making branches that represent an association between attributes and classes, as a result of attribute value test [6]. Furthermore, it uses historical data in form of training set to develop its decision rules in the form of binary trees and to enable classification of the cases [7]. This algorithm is able to generate clear structure that provides for easy interpretation of the rules which is its main advantage for credit scoring model.

ODM's generalized linear model uses logistic regression for classification. Logistic regression is a general linear model that models a binary outcome (0/1, good/bad, non-default/default etc.) on a certain number of predictors. It can be described with group of explanatory variables $X = \{X_i .. X_p\}$ and response variable of two categories, $Y = (y_1, y_2)$. This model can be represented by the following formula [7]:

$$\pi_i = \frac{\exp\{X_i\beta\}}{1-\exp\{X_i\beta\}}, \qquad (1)$$

where π_i is the probability of the i^{th} individual to belong to the certain category conditioned to X_i with β representing a vector that contains model's coefficients. Logistic regression is the most frequently used algorithm for credit scoring as it provides weighted linear sum of the attributes [8].

C. Data pre-processing

Various data pre-processing methods have been applied to the original dataset in order to produce improved version of it for our experiment. Firstly, we used data dimension reduction, as a method for reducing number of attributes for analysis by removing ones that are not relevant and important. High dimensionality of the dataset can make mined patterns more specific and less significant and at the same time make search space diverse. The consequence of such situation is dramatic increase of time consumption for the algorithm to find useful patterns [9]. After removing the attributes non-influential for the credit scoring, we decided to reduce dimension of the original data set by removing attributes type of client (all of the clients where of type F - individuals) and loans in other banks (all clients in the dataset had no loans in other banks or this information was incorrect). Also, the attribute amount of installment was removed due to redundancy, since it is highly related with attributes amount of loan and number of installments.

Next, we applied data aggregation as a technique for data summarization to solve a task of deriving the right level of data detail for Data Mining. It involves combining particular existing attributes into a new, single one to create more abstract dataset which will lead to a more compact dataset, better performance of the model and easier structure of the dataset for analysis [10]. We derived a new attribute *hh_incomes_real* by using the following formula: *hh_incomes_real = hh_incomes* - (*hh_costs +hh_amount_of_instalment*). The new attribute showed real amount of incomes in the household, and at the same time removed two unnecessary attributes from our data set. Previously described techniques directly affect data mining algorithm accuracy, since redundant or irrelevant attributes produce false results of algorithm applied.

When dealing with missing values, we identified that certain number of rows in the dataset (loans) have large number of attributes with null values such as: duration on address, duration of employment, source of income, type of contract, number of incomes in household, number of adults in household, number of non-adults in household, and number of pets in household. Since ODM offers two automatic methods for dealing with the problem of missing values: mean value and deleting rows, to avoid reducing number of rows for the training and thus having different size of dataset before and after pre-processing, we chose option mean value for missing values, while in pre-processed dataset with the

technique described previously we modified the original size of the dataset by replacing null values with meaningful data. We replaced null values of categorical attributes with the category "unknown", while numerical attributes with null values we replaced with the value of 0. This automatic option of ODM decreased our intent to improve importance of data pre-processing, but still, we were persistent in showing improvement by using other data pre-processing methods.

Next, we used equal interval binning, equal frequency binning and variable transformation as the methods for supervised discretization of our dataset. The main idea behind equal interval binning is to divide the domain of continuous attribute to a number of equal-length intervals (categories). The possible issue with this method is when category frequencies differ highly, and thus make the dataset skew towards certain categories. Therefore, on some attributes, we applied equal frequency binning also and compared results, as shown later in Results chapter. Variable transformation is a technique that transforms domain of an attribute to another for more efficient data usage and management. Furthermore, this method can make attribute values easier to compare [11]. The following table shows attributes from our dataset that were discretized:

TABLE II. DISCRETISED ATTRIBUTES

Name of Attribute	Attribute Domain	Description
QUALIFICATION	Categorical	Even though this attribute had registered value, many of these were duplicated or insufficient. We grouped then into four main groups: University degree, High School Education, Low education and Other. These are groups with approximate number of records belonging to the group.
DURATION_ON_ADDRESS	Numerical -> Categorical	We applied equal interval binning, but also equal frequency binning to categorize this attribute into four different groups.
SOURCE_OF_INCOME	Categorical	Same as with attribute qualification, we grouped these values into seven groups(Small private company, Big public company, Big private company etc.)
DURATION_OF_EMPLOYMENT	Numerical -> Categorical	Same as with attribute duration on address.
AMOUNT_OF_LOAN	Numerical -> Categorical	Same as with attribute duration on address.
NUMBER_OF_INSTALMENTS	Numerical -> Categorical	Same as with attribute duration on address.

IV. RESULTS

As mentioned earlier, the first credit scoring model was created based on a dataset without preprocessing where 60% of the dataset was used for training model and 40% for testing of it. Considering that many of the attributes with categorized, registry values were already discretized, even model trained on dataset without pre-processing has shown solid results. Predictive confidence for the decision tree algorithm was 45.6078% and for generalized linear model 39.7457%. Next figure shows model's results, including predictive confidence, average accuracy and overall accuracy.

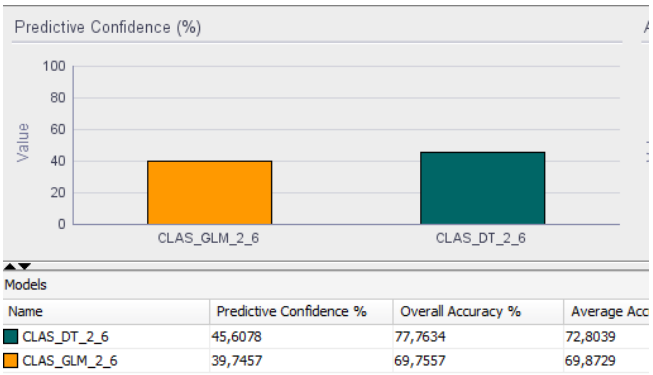

Figure 2. Results of classification credit scoring model before pre-processing

Next table represents performance matrix of DT credit scoring model built on original dataset before pre-processing.

TABLE III. PERFORMANCE MATRIX FOR DT MODEL BEFORE DATA PRE-PROCESSING

		PREDICTED			
		Non default	Default	Total	Correct (%)
ACTUAL	Non default	6046	1421	7467	80.9696
	Default	645	1179	1824	64.6382
	Total	6691	2600	9291	
	Correct (%)	90.3602	45.3462		

Out of 9291 records in the sample, model made 7225 right predictions, so the overall accuracy of the model before pre-processing is 77.7634%. Accordingly, error rate of the model before data pre-processing is 22.2366%.

TABLE IV. PERFORMANCE MATRIX FOR GLM MODEL BEFORE DATA PRE-PROCESSING

		PREDICTED			
		Non default	Default	Total	Correct (%)
ACTUAL	Non default	5203	2264	7467	70.2692
	Default	546	1278	1824	69.5175
	Total	5749	3542	9291	
	Correct (%)	90.5027	36.0813		

Performance matrix of GLM credit scoring model built on original dataset before pre-processing is shown in

previous table. Out of 9291 records in the sample, model made 6481 right predictions, so the overall accuracy of the model before pre-processing is 69.7557% and error rate is 30.2443%.

During pre-processing of the original dataset we applied pre-processing techniques described in previous chapter. Regarding discretization, two different techniques were applied: equal interval binning and binning with same frequency of values. The first technique showed better results for DT credit scoring model and the second one had better impact on results of GLM model. The following figures show results of applying equal interval and equal frequency binning on age attribute. The same techniques were applied on other discretized attributes.

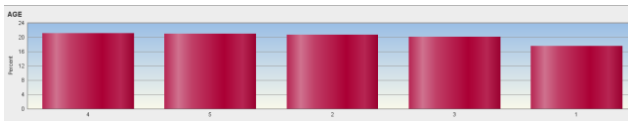

Figure 3. Histogram of attribute Age when equal frequency binning applied

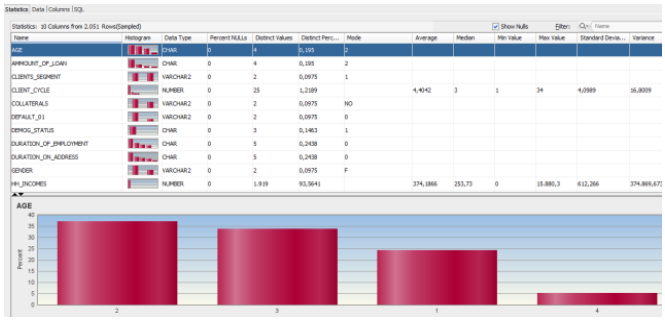

Figure 4. Histogram of attribute Age when equal interval binning applied

After applying described data pre-processing methods on original dataset, credit scoring model shown quite improvement for both of the trained algorithms. Next table compares actual data and predictions made with created DT and GLM credit scoring models before data pre-processing of dataset. Results of DT model are based on equal interval binning discretization and results of GLM model on equal frequency binning discretization.

TABLE V. COMPARISON OF PREDICTION BETWEEN DT AND GLM ALGORITHMS BEFORE DATA PRE-PROCESSING

	Measure	Before (%)	After (%)	Improvement (%)
DT algorithm	Predictive confidence	45.6078	62.5795	16.9717
	Overall accuracy	77.7634	91.3034	13.5400
	Average accuracy	72.8039	81.2892	8.4853
GLM algorithm	Predictive confidence	39.7457	43.2372	3.4915
	Overall accuracy	69.7557	72.2958	2.5401
	Average accuracy	69.8729	71.6189	1.7460

Thus, GLM model based on pre-processed dataset has shown 43.2372% of predictive confidence, 72.2958% overall accuracy and 71.6189% average accuracy, and DT model showed predictive confidence 62.5795%, overall accuracy 91.3034% and average accuracy 81.2892%. If compared with results of the credit scoring model based on the original set of data, we can see that data pre-processing improved results, but credit scoring model based on DT algorithm showed better improvement than the one based on GLM algorithm. It is excepted since discretized data enables DT to generate more precise rule sets. Performance matrix of this model is shown in the next table:

TABLE VI. PERFORMANCE MATRIX FOR DECISION TREE MODEL AFTER DATA PRE-PROCESSING

		PREDICTED			
		Non default	Default	Total	Correct (%)
ACTUAL	Non default	7301	166	7467	97.7769
	Default	642	1182	1824	64.8026
	Total	7943	1348	9291	
	Correct (%)	91.9174	87.6855		

As shown, out of 9291 approved loans, DT credit scoring model using pre-processed data correctly recognized 8484. That makes 1259 more correct prediction than DT model before pre-processing has predicted.

V. EVALUATION

Evaluation of results in this research is done by applying new real dataset on same, already built, credit scoring model. New dataset consisted of 21457 records and same set of attributes that were used for building the models. This dataset is applied on both credit scoring models, before and after pre-processing, but since it has shown greater improvement, only results given by DT algorithm are taken into consideration.

Next tables represent matrix of positive and negative classes for DT credit scoring model before and after data pre-processing.

TABLE VII. POSITIVE AND NEGATIVE CLASSES MATRIX FOR DECISION TREE MODEL BEFORE DATA PRE-PROCESSING

		PREDICTED		
		Non default	Default	Total
ACTUAL	Non default	13795	6472	20267
	Default	1001	189	1190
	Total	14796	6661	21457

TABLE VIII. POSITIVE AND NEGATIVE CLASSES MATRIX FOR DECISION TREE MODEL AFTER DATA PRE-PROCESSING

		PREDICTED		
		Non default	Default	Total
ACTUAL	Non default	18503	1764	20267
	Default	696	494	1190
	Total	19199	2258	21457

Model with applied data pre-processing techniques made 5013 correct predictions more than model without

application of these techniques. In relation with 21457 total predictions, it gives 23.3630% better predictions.

Out if 1190 loans that are really defaults, the first model recognized only 189 or 15.8823% loans as defaults and the second one recognized 41.5126% (494 loans). Therefore, the improvement of true positive rate is 25.6303%. As opposed to that, out of 20267 non-default loans, model built before data pre-processing, predicted 6472 as defaulters and the model built after pre-processing predicted only 1764 or 4708 mistakes less. According to that, false positive rate of first model is 31.9337% and of the second one is 8.7038% . This means improvement of 23.2299%.

When analyzing model predictions, the first model predicted 6661 loans as a default. Out of that number, only 189 loans were really defaulters, so the precision (positive) of this model is 2.8374%. The second model recognized 2258 loans as defaulters and 494 were really defaulters, so the positive precision of this model is 21.8778%.

Out of 21457 loans, credit scoring model before data pre-processing made 7473 wrong decisions and the one built after data pre-processing made 5013 wrong decisions less. So, the improvement of error rate is 23.3630%.

All mentioned measures of performance for both models are given in the table 9.

TABLE IX. MEASURES OF MODEL'S PERFORMANCES BEFORE AND AFTER PRE-PROCESSING

Measure	Before (%)	After (%)	Improvement (%)
Overall accuracy	65.1722	88.5352	23.3630
Average accuracy	41.9731	66.9403	24.9672
True positive rate	15.8823	41.5126	25.6303
False positive rate	31.9337	8.7038	23.2299
Precision(positive)	2.8374	21.8778	19.0404
Error rate	34.8278	11.4648	23.3630

Apart from improvement in accuracy, and in other showed measures, running time of applied algorithms has been reduced from 0.0833 minutes to 0.0467 minutes, which is also great improvement in algorithm execution time.

VI. CONCLUSION

This research showed impact of data pre-processing on results of credit scoring models based on data mining algorithms. Several data pre-processing techniques were applied on the real dataset and those are: dimension reduction, redundant attribute removing, data summarization (aggregation), dealing with missing values and supervised discretization (equal interval binning, equal frequency binning and variable transformation).

For the purpose of comparing results, two credit scoring models were built, one based on the data before data pre-processing and the other one based on data after pre-processing. Models were created using Oracle Data Miner application which uses different data mining algorithms for classification, so for both models decision tree and generalized linear algorithms were applied.

Even though the original dataset consisted of some already discretized data and the problem of dealing with missing values was automatically solved by Oracle Data Miner for both datasets, the improvement of the results for the model before and after applying pre-processing techniques is still notable. When validating both models improvement in overall, accuracy between model before and after data pre-processing is 23.3630% and improvement of positive precision is 19.0404%. All other measures of performances including running time also showed determined improvement, so we can conclude that detailed and comprehensive data preparation is of great importance for data mining approaches.

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Mining data of anti-corruption institutions to identify unusual growing trends of assets of individuals

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Abstract - **Identifying unusual grows of assets of a senior public officials can be done by analyzing their asset data such capital investments, cash, salaries, etc., which are usually declared at corresponding national institutions for anti-corruption. Usually, such agencies collect data for thousands of officials every year. Hence, manual analysis of such a relatively large of data, for a short computation time (i.e. in the range of seconds), is infeasible. Therefore, in this paper, we suggest a solution to this problem, which bases on two algorithms that arise from the field of artificial intelligence. First is the k-means algorithm, which, based on asset declaration data, groups the officials into clusters, where the two main clusters are: officials that have a normal asset grow (tagged as Best Clusters), and officials with unusual asset grow (aka. Bad Clusters). Second, by using the asset declaration data, as well as the demographic data of the existing officials, we train a Decision Tree algorithm to predict the group of the new officials, in order to place them into one of the existing groups/clusters. The experiments performed over a data set of 22300 assets declarations show that the proposed approach achieves an accuracy of 90% in comparison to the human expert analysis.**

Keywords - ***Assets Declaration; Clustering; k-means; Classifications; Decision Tree.***

I. INTRODUCTION

Assets Declaration (AD) process is a way of presenting and describing the richness of the senior public officials, where the declared data will be analyzed by anti-corruption institutions of corresponding countries [1]. When comparing the data of asset declarations in different countries, it can be noticed that the structure of these assets declarations includes components such as the domain of immovable property, movable property, cash, liabilities (credits), annual income, family annual income, etc. [2]. In each of these types of properties, it may have some declared property per person within the type (e.g., immovable property, may contain: house, land, flat, etc.). Then, each asset is described with some details (e.g.: name of the property, asset value in euro or the other currencies, year of profit, and its ownership) that outlines a given property. In general, each declaring person/declarant (i.e. senior public official) may have several statements of declarations that correspond individual years he/she has been holding a public position. Hence, the problem of analysis of assets declaration (AD) is to find and identify the officials who have unusual (abnormal) growth of their assets over the years, as well as classifying new declarants into potential declarants with unusual assets growing trends, or usual growing trends. Hereupon, this analysis aims to detect declarants who will be included in the anti-corruption investigation list to verify their assets and the way they are obtained (i.e. its origin).

The main contributions of this paper can be outlined as in the following: (1) presentation of a mathematical model for the problem of assets declaration at anti-corruption institutions, (2) application of the k-means algorithm for identifying senior public officials with unusual growing of assets, (3) application of the decision tree algorithm for prediction of assets growing trends for the new officials, and (4) an experimental study, using human experts, for evaluation of the proposed approach.

This paper is organized as in the following: Section II presents a literature review of approaches solving problems similar to AD problem; Section III presents the modelling of the problem and its mathematical definition; Section IV presents the proposed approach with representation of the solution; Section V presents the experiments and result interpretation; and Section VI concludes the paper.

II. LITERATURE REVIEW

In the literature, there is a large number of solutions to the problem of detection and finding of money laundering (ML) known as anti-money laundering solutions (AML). This type of problem is not the same as our problem of analysis of asset declaration of senior public officials, but it is somehow related. The AML problem has to do with controlling bank transfers to detect 'dirty' money, for the transfer of large amounts of money, whereas the problem tackled in this paper is about identifying senior public officials, whose assets (declared at anti-corruption institutions that include bank account information) have grown dramatically over the course of past coups of years. Klac et al. [3] solved the AML problem by using data mining (DM) methods to analyze huge datasets and build customer profiles of different groups, according to techniques: clustering (to group customers according to their properties), classification (to classify clients by predicting their behavior in the future). Gao and Ye [4] present a framework for DM based on the AML methodology, by using the concept of algorithmic classification, clustering, and searching, so the data is categorized in unusual/abnormal/anomalous, and detected

which persons are categorized as outliers. Further, the approach of Gao and Ye [4] detects and analysis the relation and interaction between members of the group, between groups and subgroups. Tang and Yin [5] present a solution for AML problem based on Statistical Learning Theory (SLT). They use methods based on Support Sector Machine (SVM) to filter transactions on database systems, by detecting the set of unusual transactions, and then classifying the data into two classes, where one of them would contain outlier data.

To the best of the author's knowledge, there is no any other approach in the literature that automatic analysis the data declared and accumulated at anti-corruption institutions, hence, in this aspect, our proposed approach is novel to this field.

III. PROBLEM DEFINITION

The problem of AD is defined in such a way that the declarations of assets, accumulated over the years, are compared by themselves, finding their growth rate, and based on this measure, it is decided which declarants have had an unusual increase in the property. Then, the new declarants are classified into the group of usual or unusual ones, according to their match to the existing declarants, by considering their previous declarations. And then, by processing the identified data in the same training set, we make the classification of new declarants into declarants with usual or unusual growth. For more information about this problem definition, see [2].

The mathematical definition of the AD problem can be done by using following notations:

D -*Assets declaration;*

s -*Number of senior;*

m -*Number of declarations;*

n -*Types of declaration attributes;*

A_i -*Attribute, where: i = 1, 2, ..., n;*

Z_i -*Declarants (Senior Official), where: i = 1, 2, ..., s;*

Declarations_1 – existing declarants (that have two or more assets declarations);

Declarations_2 – new declarants (that have only one assets declaration);

$$diff_{AVR} = (\sum_{i=0}^{m-1}\sum_{j=0}^{n}(d_{(i+1)j} - d_{ij}))/(m-1) \quad (1)$$

where: m - no. of declarations, n – no. of attributes

$$Z_{ij} = diff_{AVR}(D_{ij}),\ where\ 1 \le i \le m, dhe\ 1 \le j \le n \quad (2)$$

Equation (1) is used to calculate the average difference of the values of the attributes (i.e. d_{ij}) for multiple declarations of a given declarant. Then, based on these values, all declarants are represented in a matrix (Z_{ij}) of m rows and n columns, as denoted by Equation (2). Consequently, as property attributes, we use six categories, and we classify them into three groups: assets (Immovable Property - IP, Movable Property - MP, and Cash - C), Liabilities (debts) - L, and revenues (Annual Incomes - AI and the annual Family Income - FI). After finishing the process of grouping the declarants into clusters, we calculate the Total Property (P_T), Total Liabilities (L_T), and Total Income (I_T) for all members of each cluster (as specified by equations (3), (4), and (5)). Next, with the aim of identifying the best and bad clusters, for each group G, we calculate the difference between P_T, I_T, and L_T, as specified by Equation (6).

$$P_T = \frac{1}{m}\sum_{i=0}^{m}\sum_{j=0}^{n}(IP_{ij} + MP_{ij} + C_{ij}) \quad (3)$$

$$L_T = \frac{1}{m}\sum_{j=0}^{n} L_j \quad (4)$$

$$I_T = \frac{1}{m}\sum_{i=0}^{m}\sum_{j=0}^{n}(AI_{ij} + FI_{ij}) \quad (5)$$

$$diff_G = \sum_{i=0}^{k}(P_T - (I_T - |L_T|)) \quad (6)$$

where: m – No. of declarants, n - No. of attributes, k – No. of members in group G.

In order to calculate the average differences of growing asset values, the declarant must have at least two assets declarations. And declarants that meet this condition shall pass to the grouping process. On the other hand, the new declarants (those who have only one declaration, and that in the current year) will only be subject to the classification process. In order to realize the grouping, the average differences in asset growth should be first calculated. When the process of the grouping is finished (i.e. The group with the usual growing and unusual assets growing are determined), then it can be continued with the process of classifying the new declarants. These can also be considered as a constraint of the property declaration problem.

IV. SOLUTION APPROACH

The solution to the problem of analysis of asset declarations is made by undergoing several steps (see Figure 1), which are: (1) data pre-processing, where initially the declarants are separated into *existing* and *new* ones, and the calculation of changes of asset values over the years is made, (2) the k-means algorithm is applied for grouping declarants into specific clusters, (3) identification of the clusters with usual and unusual asset growing trends, where the data of this step are used as *Training Set* for the classification step, and (4) classification of new declarants (*aka Testing Set*) by predicting their class (usual or unusual) of the asset growing through a Decision Tree algorithm.

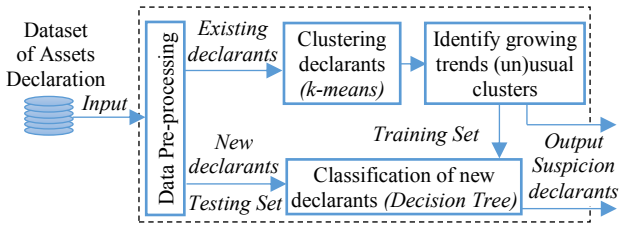


Figure 1 Block-diagram of solutions approach

A. Data pre-processing

Processing of data of assets declarations is obtained by calculating the total value of the property of an attribute, for example, declarant X, declared the declaration d_1, with the attribute A_1 = immovable property, such as: House 200,000.00 €, flat 80,000.00 €, land 30,000.00 €. Then, this attribute is represented as A_1= 310,000.00 € (200,000.00 + 80,000.00 + 30,000.00 = 310,000.00). In this way, we summarize the data of every attribute, so that it is included

in representing the total amount of assets. Thereafter, we calculate the average differences in the value of the growing asset of attributes for several years, according to the equation $diff_{AVR}$ (1), whereby all the declarants (which are part of the group tagged as Existing Declarants) are represented through the matrix Z_{mxn} (2), which contains the attribute values for all senior public officials. In the Z_{mxn} matrix, each row *i (1≤i≤m)* - represents an attribute of the declaration of a declarant, whereas each column *j* (1≤j≤n) - represents the values of asset declaration of a given attribute. The calculation of these average differences, and the representation of declarants through the matrix Z is described by the following pseudo-code (Algorithm 1).

Algorithm 1 The procedure for calculation of average difference

```
Get data of declarations (Import data from dataset);
Data = {data_ij | i← rows, j← columns} ← declarations;
Declarations_1 ← existing declarants;
Declarations_2 ← new declarants;
Z = {z_ij | i← rows, j← columns} (matrix with diff_AVR of
                                  all data Declarations_1);
rows ← 0, columns ← 0;
foreach declarations_1_ij ϵ Declarations_1 do

{
      m← max rows length;
      n← max columns length;
      while (rows <= m)
      {
         Difference = Get data declarations_1;
         while (columns <= n)
          {
           difference ← diff_AVR;
          }
         Z = difference;
       }
}
return Z;
```

B. Clustering declarants

The data of asset declaration represented through the **Z** matrix should be grouped into certain clusters according to the similarities of their attribute values, so that the declarants within the same cluster have similar values among themselves, and also have major differences with the other clusters of declarants. For this purpose, we use the *k-means* algorithm, which divides the data of dataset m into ***k*** clusters, whereby each declarant belongs to the nearby cluster, or to the nearest centroid ***c*** of cluster [6]. Simultaneously, the k-means algorithm moves the declarants from one group to another group that depends on the distance of members from the centroids of the respective groups, while the convergence of groups is achieved [7]. The determination of each declarant in which group he/she should be, is done by measuring the distance between the centroids and the declarants of each group, where the declarant will become part of the group whose centroid has the shortest distance with that declarant. The difference from a declarant and a centroid c_i is calculated by using the Euclidean distance as represented in [8]. After calculating the distance for each of the declarants of a cluster, as well as of the declarants that change the cluster, we calculate the value of new center *c'*, according to equation *C(xi)* [9], which represents a new average value over the given cluster. The following pseudo-code represents the actual method for clustering declarants into groups according to the similarities in the declared data.

Algorithm 2 Clustering method – based in *k-means*

```
Input:  Z = {z_ij | i ← rows, j ← columns} (set with data from
                                            Algorithm 1)
Get MaxIterations ← (maximal number of iterations)
Get k (k ← no. of clusters – input value, and k>=2)

Output: C = {c_ij | i = 1, 2, …, k; j = 1, 2, …, k} (set with data for
                                            saving value of centroids)
        L = {l(c) | c = 1, 2, ..., n} (set for labeling clusters)
        M = {m_ij | i ← rows, j ← columns} (gets data from Z and L )
        S_C = Create initial solution;
        S_B = S_C (value of centroids);
        Iterations = 0;
        While (Iteration <= MaxIterations)
        {
            Sc = Get K-means Clustering
            d_ij ← (Calculate a Euclidian distance);
            d^0 = d_ij;
            foreach z_i ϵ Z do
                        l(z_i) ← argminDistance (c_ij, d_ij), j ϵ
                                {1,2, …, k}(Eucledian distance)
            end;
            change false;
            g^0 ← (verifing true clusterings for every subject);
            S_C = d^0 (Current solution S_C = solution of d^0);
            Update clustering(S_C);
            Iterations ++;
            S_B=S_C (best solution S_B = current solution S_C);
            If (no declarants changet cluster)
                        {
                        g^0 = g^1;
                        S_C= g^1;
                        S_B=S_C;
                        }
                        return S_B;
            }
            return (C, M);
```

The presented approach can be used to group declarants into *k* clusters. After this, it is necessary to find the group (or groups) that have the highest discrepancy between incomes and capital investment's value over the years, which is a process described in the next subsection.

C. Identifying unusual asset growing trends

In this phase, we identify the group with the most usual trends of assets growing - *Best cluster*, and the group with the most unusual trend of assets growing - *Bad cluster*. The *"Bad"* cluster (group) contains the members that have the highest discrepancy of incomes and benefits, in terms of assets and capital investments growing, while the *"Best"* cluster is the one with the lowest such a discrepancy. This procedure is presented below by Algorithm 3.

The Bad Cluster list includes members with declarants that have unusual (abnormal) growing of assets. Hence, the members in this list should be part of the process for verification and investigation of their property by anti-corruption institutions. In cases, when we create more than two clusters, then, as part of the *Best* and *Bad Clusters*, we can have a range of groups, which could be selected between a predefined internal. From the practical point of view, this makes sense because there are occasions that a given group might contain only a single member (i.e. "Outlier"), who has a great difference from the other declarants (be it for bad or good context), but this does not mean that he/she is the only one who should be investigated, because it might happen that the next closer mean that he/she is the only one who should be

investigated, because it might happen that the next closer group might need to be part of investigation too. This process is explained in more details in [2] (p.48 and p.49).

Algorithm 3 The method for identifying unusual growing trends

```
Get Z, K;
Z = {z_ij | i ← rows, j ← columns} (set of data entries with
                                    clustering ← Algorithm 2);
K = {k |label value for each cluster} (Import from Algorithm 2);
m ← max Length rows;
n ← max length columns;
foreach k_j ϵ K do
{
    while (rows<= m)
        {
        while (columns<= n)
            {
                P_T = SUM(IP_ij, MP_ij, C_ij)/rows (length
                                                    of k);
                L_T = SUM(L_j)/rows(length of k);
                I_T = SUM(AI_ij, FI_ij)/rows(length of k);
            }
                Diff(G) = SUM (P_T – (I_T – abs(L_T)));
        }
        MIN(Diff(G)) ← Best Cluster
        MAX(Diff(G)) ← Bad Cluster
}
return (k, Best, Bad);
```

D. Classification of new declarants

For the case of the "new declarants", who declare assets for the first time, both, the calculation method - $diff_{AVR}$ and clustering method cannot be applied, because there are no existing data to compare with, so that their growing trend of assets over the years could be calculated. Hence, here, we apply the Decision Tree algorithm, which creates a tree model according to the data of the Training Set, which, in our case, is the data set created when the *k-means* algorithm is applied. The data of the Training Set enlists the existing declarants, who belong to either Bad or Best cluster, where each of them is annotated with a True or False mark. In order to predict the group of the new declarants, besides the three properties used for the existing declarants (immovable property-IP, movable property-MP, and cash-C), we consider properties such as birthplace, year of birth, name of the institution and job position, while liabilities are not taken into account [2]. In Algorithm 4, we present the pseudo-code of the actual decision tree algorithm that is implemented in this project, where details for calculation of metrics such as Entropy *H (S)* [10] and Information Gain *Gain(S, F)* [11] are outlined.

Algorithm 4 Classification method based on Decision Tree

```
Input:  Declarations_2 = {d_ij | i ← rows, j ← columns}
            (data to be "Testing Set" from Algorithm 1);
        Matrix_F = {f_ij | i ← rows, j ← columns}
            (data to be "Training Set" from Algorithm 1);
Ouput:  Tree;
        T;
Matrix_F = { f_ij | i ← rows, j ← columns} (a round
  attribute values "year of birth", "Property", "Incomes");
A ={a_i | i = (0, m), } (m = max number of attributes);
A ← Training Set;
T ← Testing Set;
Create a Tree Root (Select A_i, which is a best attribute)
Root ← A_k (Best attribute ← higher Gain(S, A), k ϵ i);
A' = {a'_i | (i= 0, m); m = number of current attributes}
        foreach a' ϵ A' do
            While (i ≤ m)
            {
                Calculate Entropy E(A') of attribute;
                Calculate Gain(S, A') – (S – simples
                            collection, A' - Attribute);
                }
                N' ← (Best attribute ← attribute with
                                high Gain(S, A'));
                N' ← be a Node of tree
                return (N');
        }
        return (Tree);
        T ← (Tree - this model applies for data of
                                    Testing Set);
        return T;
end;
```

This method measures the similarity (using the above mentioned attributes) between the new declarants and the existing ones, and, based on that, marks the new declarants either as usual or unusual declarants. Based on this, we predict whether there are new declarants that have prerequisite to become abusive, in terms of unusual growth of their assets.

V. EXPERIMENTAL RESULTS

In this section, we show the experimental results of the analysis of the data of assets declarations by using a real data set. In the following, we present the dataset structure that includes details about assets declarations, as well as the evaluation results about the proposed solution, which include comparative results, in terms of quality of analysis, computation time and user evaluation.

The algorithms are developed by using C# programming language that is part of Microsoft Visual Studio 2013 development environment. The experiments are done by means of a machine with CPU of type Intel Core i7-3770 3.4GHz with 8GB of RAM memory, while running on a Windows 10, 64-bit Operating System.

A. Dataset

The utilized dataset contains data about declarants, that are described by means of 15 attributes, such as: ordinal number (No), name and surname of the declarant, ID (this is an anonymized ID number that is assigned for the purpose of this research work), birthplace, year of birth, name of institution, name of the sub-institution, job position, date of declaration, immovable property, movable property, cash, liabilities, incomes, and family income. This dataset is composed of real declarants, whose data are available for public view, and it is obtained from the website of Kosovo Anti-Corruption Agency (ACA) [12]. This dataset contains about 22300 asset declarations, and it includes declarations for the period from 2011 to 2017.

B. Quality of prediction

In order to analyze the quality of the obtained solutions that are returned by the proposed approach, we have selected the data about 10 different declarants, who have a total of 20 property declarations. The experts from the Anti-Corruption Agency in Kosovo (ACAK) have been asked to manually analyze their declared data about the last two years. Their findings are that five out of ten of the declarants could be marked as suspicious. In Table 1, we present the complete details of this 10 declarants, where, for privacy reasons, their names and IDs are anonymized.

According to the findings of experts from ACAK, the declarants from 1 to 5 can be considered as public officials that belong the group with the most unusual growing of assets, hence they should be subject to the process of verification and investigation about the origin of their properties. On the other hand, when our approach is applied to analyze the data of these 10 declarants, the results are identical to the manual results produced by ACAK experts, when the *k-means* algorithm is applied to group declarants into five groups.

TABLE I THE DATA OF TWO LAST DECLARATIONS OF TEN DECLARANTS

No. of declarant	*No. of declaration*	*Name& Sur-name*	*ID*	*Date of declaration*	*IP (€)*	*MP (€)*	*C (€)*	*L (€)*	*AI (€)*	*FI (€)*
1	1	A	12345	3/30/2016	3,280,000.00	9,000.00	891.89	139,520.00	10,660.00	160,950.00
	2	A	12345	3/27/2017	3,908,000.00	9,000.00	2,400.00	626,962.00	11,152.00	160,800.00
2	1	B	23456	5/12/2016	120,000.00	0.00	0.00	0.00	3,500.00	5,860.00
	2	B	23456	3/30/2017	277,000.00	4,500.00	2,628.00	6,000.00	1,666.00	1,700.00
3	1	C	56789	3/22/2016	232,000.00	42,500.00	187,050.00	37,069.50	64,205.33	46,600.00
	2	C	56789	3/14/2017	2,482,000.00	37,500.00	234,000.00	24,607.50	61,334.00	46,600.00
4	1	D	67890	3/14/2016	685,000.00	5,000.00	800.00	0.00	9,678.00	10,800.00
	2	D	67890	3/29/2017	985,000.00	5,000.00	800.00	0.00	9,678.00	28,036.68
5	1	E	98765	3/17/2016	860,000.00	13,100.00	2,345.00	15,000.00	8,363.00	8,400.00
	2	E	98765	3/30/2017	902,610.00	3,700.00	0.00	42,700.00	5,241.00	8,500.00
6	1	F	09876	3/22/2016	350,000.00	4,000.00	40,000.00	53,000.00	20,908.00	7,200.00
	2	F	09876	3/29/2017	370,000.00	4,000.00	40,000.00	26,000.00	35,322.97	8,400.00
7	1	G	54321	3/31/2016	563,300.00	16,300.00	1,430.00	0.00	22,538.94	4,764.00
	2	G	54321	3/31/2017	484,500.00	7,000.00	9,932.14	0.00	21,813.28	5,916.00
8	1	H	65432	3/18/2016	122,000.00	4,000.00	42,000.00	0.00	3,076.23	620.34
	2	H	65432	3/29/2017	122,000.00	11,500.00	42,060.00	0.00	26,751.12	7,444.08
9	1	I	88880	3/31/2016	140,000.00	23,000.00	0.00	0.00	23,112.00	4,740.00
	2	I	88880	3/28/2017	140,000.00	23,000.00	0.00	0.00	29,426.64	4,939.80
10	1	J	99881	3/15/2016	204,000.00	4,000.00	0.00	0.00	682.00	75.00
	2	J	99881	3/30/2017	204,000.00	0.00	0.00	0.00	682.00	0.00

Nevertheless, the results of our approach are slightly different from the expert analysis, when the k-means algorithm groups the declarants into three or ten groups, where (in Table 2) it can be observed that person E is marked as a "suspected" declarant by ACAK experts, whereas our approach, in both cases, marks her/him as "unsuspected". In overall, based on these experiments with real users, it can be concluded that our approach can achieve at least 90% of accuracy in predicting whether a give declarant should be subject of further investigation of the origin of their properties. In addition, it should be noted down that the manual analysis done by ACAK experts includes the data of only last two years of declarations, whereas, our approach considers the data of all declarations of the officials that have been done in the past.

TABLE II. EVALUATION RESULTS FOR THE K-MEANS APPROACH

Name & Surname of Declarant	**Suspected Declarants**			
	ACAK Results	*Algorithm results*		
		K=3	*K=5*	*K=10*
A	Y	Y	Y	Y
B	Y	Y	Y	Y
C	Y	Y	Y	Y
D	Y	Y	Y	Y
E	Y	N	Y	N
F	N	N	N	N
G	N	N	N	N
H	N	N	N	N
I	N	N	N	N
J	N	N	N	N

TABLE III THE DATA OF DECLARANTS USED FOR CLASSIFICATION

	Declarants	*Birthplace*	*Year of birth*	*Institution*	*Job title*	*Total Property (€)*	*Total Income (€)*	*Output (Suspected)*
Training Set	A	Prishtina	1960	Kosovo Police	Director	200,000.00	20,000.00	FALSE
	B	Prishtina	1960	Kosovo Police	Manager	200,000.00	10,000.00	FALSE
	C	Ferizaj	1970	Kosovo Police	Secretary	200,000.00	10,000.00	TRUE
	D	Gjilan	1980	Government	Secretary	200,000.00	10,000.00	TRUE
	E	Gjilan	1980	Presidency	Secretary	100,000.00	20,000.00	TRUE
	F	Gjilan	1980	Presidency	Manager	100,000.00	20,000.00	FALSE
	G	Ferizaj	1970	Presidency	Director	100,000.00	20,000.00	TRUE
	H	Prishtina	1960	Government	Manager	200,000.00	30,000.00	FALSE
	I	Prishtina	1960	Presidency	Director	100,000.00	20,000.00	TRUE
	J	Gjilan	1980	Government	Secretary	100,000.00	32,000.00	TRUE
	K	Prishtina	1960	Government	Director	100,000.00	18,000.00	TRUE
	L	Ferizaj	1970	Government	Secretary	200,000.00	20,000.00	TRUE
	M	Ferizaj	1970	Kosovo Police	Manager	100,000.00	20,000.00	TRUE
	N	Gjilan	1980	Government	Director	200,000.00	20,000.00	FALSE
Testing Set	**X**	**Prishtina**	**1960**	**Government**	**Director**	**200,000.00**	**10,000.00**	**?**

In this regard, our approach in comparison to the manual one, besides being very quick in producing the results of the analysis, it can be more comprehensive, in terms of producing results that cover a wider period of declarations.

In Table 3, with the aim of didactic explanation, we present the details of a sample group of declarants (along with the corresponding attributes) that could be used as part of the training set. The aim is that based on attributes such as birthplace, year of birth, institution, job title, total property and total income, to predict whether a given new declarant can be associated with an existing declarant (i.e. one of the declarants from A to N in the training set) so that her/his class (suspected or not suspected) could be predicted as the class of the new declarant (i.e. declarant X). Based on the decision tree algorithm that was described earlier, the declarant X is classified to the class "FALSE", which means that she/he is predicated to be an unsuspected declarant, as presented in Figure 2.

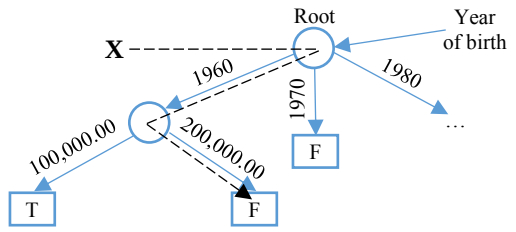
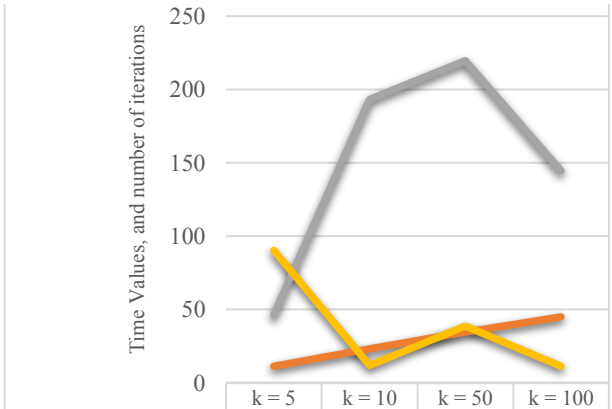


Figure 2 Decision Tree for classification of declarant X

C. Computation Time

By using a dataset of declarations with over 22,000 records, we extensively experimented with our proposed approach by analyzing the computation time for different algorithm settings, in regard to the number of clusters and the length of the identification interval. The computation results are presented in Figure 3, by outlining the number of iterations and clustering/classification time.



	k = 5	k = 10	k = 50	k = 100
Number of Iterations	11.34	23.34	34.67	45
Clustering Time /ms	46.33	193.33	219.67	144.67
Classification Time /ms	90.33	12	38.67	11.33

Figure 3 Computation time for different approach settings

The time for grouping declarants into clusters depends on the number of clusters utilized. The longest computation time observed from the experimentation is when the number of clusters is k = 50, which is 219.67ms, whereas the best case scenario is when the number of clusters is only 5, where the computation time is only 46.33ms.

D. User Evaluation

In order to measure the usability of the proposed approach, a prototype implementation is made and offered by the experts of ACAK to evaluate its features. Consequently, an only survey is made with them, where they were asking a number of questions regarding specific functionalities of the prototype system. In overall, the impression of the ACAK experts is that the prototype would facilitate to a great extent their daily duties, both, in terms of effectively and efficiently, towards a fast identification of the declarants that could be considered as "suspects". In Figure 4, we present the results of the five of the main questions asked in the survey, whereas the complete results of the survey can be found in [2].

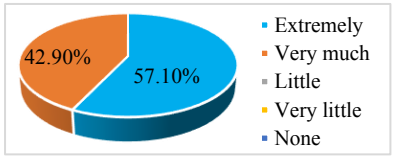
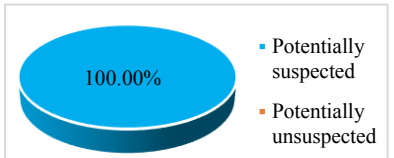
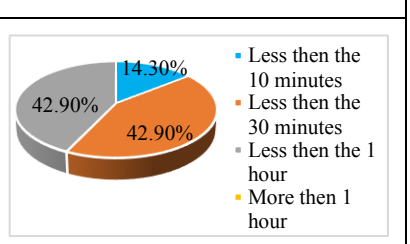
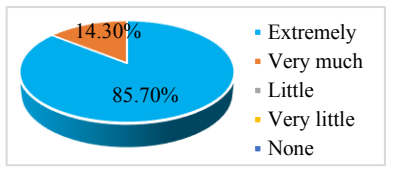
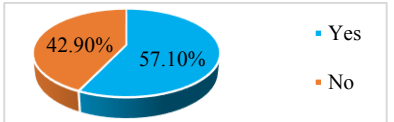
1. Is it helpful for your work to group declarants into clusters based on their declared assets over a range of years?	
2. Do you consider a declarant as a "suspect" when he/she has a substantial increase of property in comparison from the previous year, while his/her income or loans have not increased?	
3. How much time does it take for you to compare the declarations of the last two years for a given declarant?	
4. How much would it facilitate your day-to-day work a system like this if it would be able to generate a list of "suspected" declarants?	
5. Should a system like this compare the new declarants against the existing ones, in order to predict their potential behavior?	

Figure 4 User survey resulsts

VI. Conclusion

In this paper, we presented an approach for identifying unusual trends of growing of the assets of the public officials, who commonly declare their assets at anti-corruption agencies. Further, we presented a mathematical model for the problem of asset analysis, which is based on the practicalities of the anti-corruption institutions. Based

on the experimental study with real users, our *k-means* based approach achieves a 90% of accuracy, whereas our *decision tree algorithm* implementation can help in figuring out whether any new public official could have affinities for becoming a "suspected" declarant in the future.

As part of future work, we plan to extend our proposed approach by hybridizing (or partial substitution) of the *k-means* and *decision tree algorithm* with other grouping and prediction algorithms.

ACKNOWLEDGMENT

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Learning Diatom Ecological Models with Fuzzy Order Data Mining Algorithm

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***Abstract* - The data mining algorithms allow data scientist to extract useful knowledge from raw measured data. The fuzzy data mining algorithms have several advantages over crisp methods, and they have been used more often to obtain ecological knowledge from ecological data. In this paper, we aim to learn suitable habitat models of the ecological conditions where diatoms can exist in lake ecosystems by using a fuzzy data mining algorithm. The algorithm uses several different fuzzy concepts, namely, fuzzy membership functions, similarity metrics and order weighted geometric operator to build predictive ecological model that is able to reveal patterns in ecological data and thus find the suitable diatom ecological conditions. Additionally, we have made experimental evaluation of two similarity metrics that influence the accuracy for both descriptive and predictive models. Later, the results of the models are verified with the known ecological preferences found in the literature. Based on the obtained results, in future we plan to improve the fuzzy operators and similarity metrics and test other membership functions on new ecological data.**

Keywords - fuzzy data mining; diatom models; order weighted operator; indicating properties; similarity metrics.

I. INTRODUCTION

Ecological data contain a ton of useful information, the challenge is how to get the right information from the noise embedded in the data. Outside disturbances, bad sensors, bad weather etc., should not be taken into account. When the measured data is obtained from the environmental expert, there is not much for data scientist to do, in sense of improving the knowledge extraction and the quality of the knowledge itself. Techniques like pre-processing of data for noise removal can help in certain degree, but when we talk about crisp machine learning algorithms, they can hardly manage the uncertainty and data change. This is especially true for knowledge discovery in environmental data. One topic of this research area is discovering the connection between the diatom community in aquatic ecosystems and abiotic stress factors of the environment [1]. Ecological factors are vital because they show how water quality or trophic quality is influenced. In the literature, there are several different water or trophic classification systems (derived from different physical-chemical parameters) depending on what the index is used for. In the paper, we focus on water quality classification system represented with water quality classes based on three parameters (Conductivity, pH and Saturated Oxygen).

In order to discover the connection that exists between the biological and outside factors, and thus find the indicating properties of each diatom, various statically and data mining algorithms can be used to achieve this goal. Many of these tools have pros and cons, and algorithms exists that can provide better overcoming the analytical challenges of ecological data. Machine learning algorithms combine several statistical method that produce interpretable models and better tackle some of the problems that arise from individual usage. Methods like clustering, classification or regression are previously used for ecological modelling [2, 3]. More methods and procedures are presented in [4, 5, 6, 7, 8] where authors elaborate the advantages and disadvantages of decision trees like methods (CART, bagging, boosted trees and random forest) in terms of ecological studies. In area of finding suitable environmental conditions for certain organisms in their ecosystem, authors in [9, 10] presented models for environmental hydrological modelling and prediction of plant type abundance of wet habitat.

The well-known machine learning methods for building decision trees were previously used for modelling habitat suitability of the diatom community in Lake Prespa [11]. Obtained models were debated by the biological expert and he gave his opinion about the model results and discussed the obtained knowledge. After deeper analysis, some of the model knowledge has confirmed the correct indication of the diatom property, and some of the produced knowledge was new and yet to be tested by the biological diatom experts [11, 12]. Inspired by these results, we applied new method (multi-target predictive clustering trees) that modelled the influence of several physical-chemical parameters on the diatom community in a single model. This method improves the diatom model in general, but still the method was unable to cope with noise, data change and over-fitting problems. Furthermore, the data scientists need to dig deeper and obtain this knowledge from the measured data and more important, to understand the processes that drive the important variables, they must find adequate algorithm that is capable of dealing with a number of disadvantages that crisp machine learning algorithms carries with them.

In this paper, we apply the pattern tree method [13] by using the fuzzy theory concepts of membership functions, similarity metrics and aggregation operators. Furthermore, in this paper we investigate the influence of two similarity metrics to find the best model with highest accuracy. Another aspect which is evaluated in this paper is the influence of the order weighted geometric operator on

both similarity metrics. This should provide us with additional information based on experimental evaluation results before selecting the best model for ecological knowledge discovery. After this, the obtained fuzzy models can produce knowledge that can be compared with the known ecological preferences found in the literature [14].

The rest of the paper is structured as follows: Section 2 provides the definitions for method similarity and aggregations metrics used by the algorithm. Section 3 presents the measured evaluated dataset for Lake Prespa, the experimental setup, and the experimental results, while Section 4 present obtained models, interpretation and verification with the existing ecological knowledge. Finally, Section 5 concludes the paper and gives direction for future research.

II. METHOD METRICS

The fuzzy pattern tree algorithm used for ecological modelling uses three important concepts from fuzzy theory: membership functions, similarity metrics and aggregation operators.

Three membership functions are taken into account: trapezoidal, triangular and Gaussian functions. All these membership functions are widely used and provide decent performance for most fuzzy data mining algorithms. Two similarity metrics are considered for improving the model performance. Both similarity metrics are based on root mean squared error (RMSE) metric for error estimation. The first similarity metric is expressed with eq. 1 [13], for two fuzzy sets A and B:

$$RMSE(A;B) = 1 - \sqrt{\frac{\sum_{i=1}^{n}\left(\mu_A(x_i) - \mu_B(x_i)\right)^2}{n}} \quad (1)$$

Likewise, the RMSE^2 metric is defined as:

$$RMSE^2(A;B) = 1 - \sqrt{\frac{\sum_{i=1}^{n}\left(\mu_A{}^2(x_i) - \mu_B{}^2(x_i)\right)^2}{n}} \quad (2)$$

In both equations, x_i, represents the crisp discretized values. Variables $\mu_A(x_i)$ and $\mu_B(x_i)$ are the fuzzy membership values of x_i for A and B fuzzy sets, respectively. Metric RMSE^2 is similar with the other metric, but the influence of fuzzy membership values is reinforced by squaring, giving more importance to the organisms that are larger in number to be related with environmental factors. The aggregation operators are also important factor in building models with high prediction accuracy. The aggregation operators take input values from fuzzy sets and their membership values. In fuzzy set theory, there are many types of aggregation operators, and T-norms, T-conorms and averaging operators [15, 16] are mainly used. Since, T-norms and T-conorms are considered to output the min and max values of the fuzzy membership values of the both sets, the average operators produce values that consider average between the two fuzzy values. Some of them, like the average geometric weighted aggregation operator [15], take into account the property of ration values from the fuzzy membership values. This also could lead to performance improvement, since the particular ecological datasets incorporate these types of properties.

In out experimental evaluation, we focus not on comparison between different types of weighted aggregation operators, but on the use of different similarity metrics and membership functions (triangular, trapezoidal and Gaussian) with the same operator.

III. EXPERIMENTAL SETUP AND RESULTS

A. Experimental Setup

The dataset on which the experiments are made contains 13 input parameters. 10 most abundant diatoms are represented with the first 10 attributes with their relative abundance per sample, and the last three attributes

TABLE I. RESULTS FOR CLASSIFICATION ACCURACY USING THE TRAIN DATASET FOR TRAINING. BOLDED RESULTS SHOW THE BEST RESULT FOR EACH MEMBERSHIP FUNCTION BETWEEN THE TWO METRICS, WHILE UNDERLINED RESULTS SHOW THE BEST RESULT PER DATASET.

Similarity Metric	**RMSE**			**RMSE^2**		
Train	**Conductivity**	**pH**	**Saturated Oxygen**	**Conductivity**	**pH**	**Saturated Oxygen**
Triangular[1]	76.15	60.09	62.19	**76.61**	**60.55**	**62.69**
Trapezoidal[1]	74.31	61.01	60.20	**75.69**	**62.39**	**60.70**
Gaussian[1]	75.69	**63.30**	60.20	**76.15**	58.72	**62.69**
Triangular[2]	76.15	60.55	62.69	**76.61**	**61.01**	**63.68**
Trapezoidal[2]	74.31	61.47	61.19	**75.69**	**63.30**	**61.69**
Gaussian[2]	75.69	**63.76**	62.69	**76.61**	58.72	**62.69**
Triangular[3]	75.69	61.01	**63.68**	**76.61**	**61.93**	61.69
Trapezoidal[3]	**76.15**	**62.39**	**62.84**	75.69	61.93	59.20
Gaussian[3]	76.15	**61.93**	62.69	**76.61**	59.63	**62.69**
Triangular[4]	**75.69**	61.47	**64.68**	76.15	**62.39**	62.69
Trapezoidal[4]	**76.15**	62.84	**61.19**	75.69	**62.84**	60.70
Gaussian[4]	76.15	**62.39**	**63.68**	**77.52**	61.01	62.69

[1]SDM$_5$, [2]SDM$_{10}$, [3]DM$_5$, [4]DM$_{10}$

represent the water quality classes for conductivity, pH and Saturated Oxygen. These measurements are converted into one of the classes defined according to Saturated Oxygen [17], Conductivity [18] and pH [17, 18]. The number of classes for these attributes ranges from 4 to 6.

Due to the model accuracy investigation, we choose to build two types of models. The first type of model is the simple diatom model (SDM), which consists from zero candidate trees and one low-level tree with depth 5 (SDM_5) and 10 (SDM_{10}). About the concepts of candidate and low-level trees, the reader can get more information in [13]. The other type of experimental models, are models that contain 2 candidate trees, 3 low level trees and depth equal to 5 (DM_5) and 10 (DM_{10}). These four types of models in combination with two similarity metrics and the fuzzy order aggregation operator is used to provide inside look of experimental evaluation. We made the experiments by following two setup experiments. First, by using the fuzzification method based on three evenly distributed membership functions for each input variable, the input attributes transform the crisp values into fuzzy values and they are processed by the fuzzy pattern tree method on the entire dataset (Train). And second, the standard 10-fold cross validation is used for testing the prediction performance accuracy of the obtained models (Test).

TABLE II. RESULTS FOR CLASSIFICATION ACCURACY USING THE TRAIN DATASET FOR TESTING. BOLDED RESULTS SHOW THE BEST RESULT FOR EACH MEMBERSHIP FUNCTION BETWEEN THE TWO METRICS, WHILE UNDERLINED RESULTS SHOW THE BEST RESULT PER DATASET.

Similarity Metric	RMSE			$RMSE^2$		
Train	**Conductivity**	**pH**	**Saturated Oxygen**	**Conductivity**	**pH**	**Saturated Oxygen**
Triangular[1]	**72.77**	57.64	58.50	72.73	**54.87**	**58.50**
Trapezoidal[1]	69.52	54.91	55.00	**70.91**	**59.07**	**57.50**
Gaussian[1]	70.91	**56.75**	55.50	**72.75**	55.37	**60.00**
Triangular[2]	**72.32**	**58.12**	58.00	69.09	55.78	**59.00**
Trapezoidal[2]	69.52	56.73	54.50	**70.91**	**59.98**	**56.50**
Gaussian[2]	70.00	**58.14**	54.50	**72.77**	55.80	**59.50**
Triangular[3]	**73.70**	53.53	57.00	71.84	**54.39**	**59.00**
Trapezoidal[3]	**72.32**	56.32	55.50	72.75	**56.32**	**57.50**
Gaussian[3]	**73.25**	**56.73**	58.00	71.80	56.26	**58.50**
Triangular[4]	**73.25**	**54.89**	58.50	68.20	54.87	**58.50**
Trapezoidal[4]	71.86	**58.14**	55.50	**72.29**	57.68	**56.50**
Gaussian[4]	**72.32**	**56.28**	**59.00**	70.43	54.89	58.50

[1]SDM_5, [2]SDM_{10}, [3]DM_5, [4]DM_{10}

B. Experimental Results

The results from the experimental evaluation are presented in Table 1 and 2, and several conclusions can be drawn from them. Membership functions have influenced the model performance in various ways, for example, the trapezoidal membership function obtains best results related to the other functions in test procedure (Table 2). Furthermore, the triangular and trapezoidal functions accomplished better train results than the Gaussian function (Table 1). The analysis of the experimental results regarding the metric evaluation, presented results in which it is very hard to define strict rules. $RMSE^2$ metric showed to be superior over RMSE metric in the case of Conductivity for train, while for pH and Saturated Oxygen datasets in test evaluation experiments. Investigation of the model complexity revealed that the better performance with DM_5 and DM_{10} models is achieved with RMSE metric, while the models that are simpler have better results with the $RMSE^2$ metric. Overall, the Conductivity dataset achieved best prediction using triangular function, while trapezoidal function was effective metric for pH dataset, and last the Gaussian function was successful achieving best results for the Saturated Oxygen dataset. Based on these results, two models are selected for presentation and interpreted in the next section.

IV. ECOLOGICAL MODELS AND INTERPRETATION

In the previous section we discussed the performance evaluation of the models using various algorithm settings and based on these finding we got clear picture what method settings to select in order to get best predictive model. We have selected five fuzzy linguistic terms (Bad, Low, Good, Very Good and Excellent) to represent the indicating properties of each diatom for certain water quality class. The presented models are in hierarchical tree like form, where the top node or the root of the tree is the diatom which is the most similar with the output water quality class, while each branch of the tree reflect the indicator factor for that particular diatom.

A. Model Results and Interpretation

Presented pH model (Fig. 1), as well as rule from this model (Rule1), present interesting facts in which the classified diatoms can be used as bio-indicator for *alkalobiontic* pH water quality class. According to the model, the COCE diatom is an excellent indicator, as well as APED diatom which can be used as good indicator. These indicator properties are followed by the DMAU

diatom, which can be used as weak indicator, since weak indicating properties have higher similarity value related to the *alkalobiontic* pH water quality class (0.37).

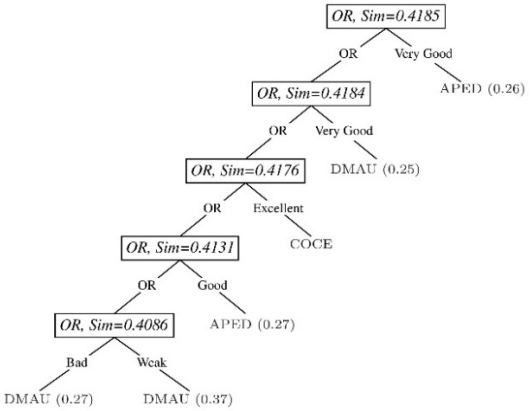

Figure 1. Diatom model for the *alkalobiontic* - pH WQC using SDM_{10} variant and Trapezoidal membership functions

The model presented in Fig. 1, is converted into rule Rule1 as follows:

Rule1: IF pH water quality class is *alkalobiontic* THEN *Amphora pediculus* (APED) is Very Good Indicator OR *Diploneis mauleri* (DMAU) is Very Good Indicator) OR Cyclotella ocellata (COCE) is Excellent Indicator OR APED is Good Indicator OR (DMAU is Bad Indicator OR DMAU is Weak Indicator). The model has similarity of 41.85%.

The other model predicts the indicating properties for the Saturated Oxygen water quality class represented with Rule2.

Rule2: IF Saturated Oxygen water quality class is *β-mesosaprobous* THEN DMAU is Excellent Indicator OR *Cyclotella juriljii* (CJUR) is Excellent Indicator) OR APED is Very Good Indicator OWG<0.16> *Cocconeis placentula* (CPLA) is Bad Indicator OWG<0.37> (*Staurosirella pinnata* (STPNN) is Weak Indicator AND CJUR is Weak Indicator).

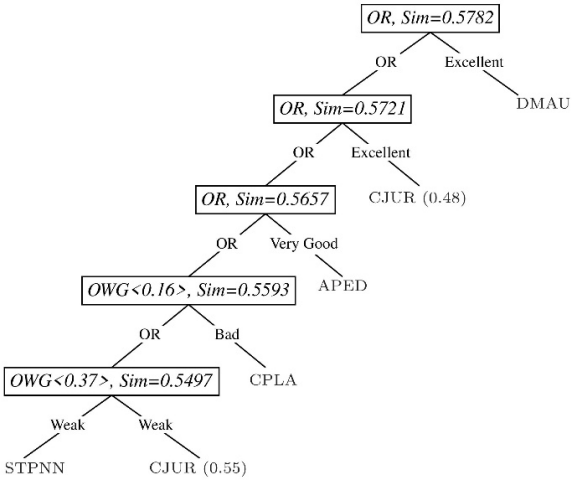

Figure 2. Diatom model obtained for the *β-mesosaprobous* Saturated Oxygen WQC using SDM_5 variant and Gaussian MF

The model has similarity of 57.82%. The presented model in Fig. 2, shows that the DMAU and APED diatoms can be used for indicating *β-mesosaprobous* waters. On the other hand, the CPLA, CJUR and STPNN diatoms cannot be used as indicators for such water.

B. Verification of the Models

Verification of the obtained knowledge is made using ecological references found in [14, 19]. Many of the diatoms have been recently added to the diatom library of Lake Prespa, therefore no ecological references exist for diatoms like the CJUR diatom. So, some of the results obtained from the predictive models for these diatoms can be the first to be known. According [16, 19], the APED diatom is known as *alkaliphilous*, *fresh-brackish*, *β-mesosaprobic* and *eutrophic* (because of organic nitrogen tolerance) indicators. The predictive diatom models have successfully verified the APED diatom ability to indicate *β-mesosaprobic* water, but not the *alkaliphilous* waters. Based on the known ecological preferences for CPLA diatom according [16, 19] is a *eutrophic* taxon with medium oxygen demand while the prediction models have found that is indicator for *β-mesosaprobic*. In the literature, the DMAU diatom is known to exist in slightly *brackish* waters [16, 19]. From the models presented in this paper, we can say that the DMAU diatom have a slight affinity to *alkalobiontic* environments and to be an excellent indicator for *β-mesosaprobic* waters. According to the prediction models, the COCE diatom is excellent indicator for *alkaliphilous* waters, while according the ecological preferences this diatom is found to be *meso-eutro* taxon [16, 19]. According [16, 19] the STPNN diatom, this diatom is known as hyper-eutrophic (*oligo-eutrophic*; *indifferent*) taxon frequently found on moist habitats, while the models have found that this diatom is weak indicator of *β-mesosaprobic* waters. The CJUR and NPRE diatoms have no ecological references in the literature, therefore before any conclusion is made, more experiments are needed to confirm found indicating properties.

V. CONCLUSION

Presented results in this paper, shows the influence of the three fuzzy metrics on the performance of the fuzzy pattern tree method used for learning diatom ecological models. We experimentally evaluated, the membership functions, similarity metrics, model complexity and fuzzy operators on both train and test models. The results show what model parameters were best to set to obtain the highest accurate predictive model, after that two ecological models were learned, presented and interpreted. The diatom models' results were verified with the known ecological preference in the literature, in which many of them were correctly identified. Some of the models added new knowledge that should be further investigate and before any firm conclusion is made for them.

Based on the presented results, we can conclude that the developing of more similarity metrics is important to increase the classification accuracy of the models. Additionally, novel MFs as well as implementation of other fuzzy based heuristic metric are also needed, which is focus of our future research.

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The software platform architecture for the component-oriented development of knowledge-based systems

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***Abstract* – The problem of creating a software platform for the automated iterative development of applied knowledge-based systems is considered in the article. Well-known component-based software engineering methodology is utilized as a general approach. The proposed architecture of the software platform includes the management sub-system and a set of problem-oriented components that, in addition to implementing the main functionality, should support the unified platform component interface. The management sub-system provides the ability to interactively define functions of the application based on the combination of the platform components methods via visual programming technique. The list of frequently used functions and features of knowledge-based systems and corresponding platform components is suggested in the article. The data control component implements methods for interacting with a data source. The next component provides the ability to create subject domain model in the ontology form. The rule-based reasoning component provides the ability to create a knowledge base on the top of the obtained domain ontology. The data representation component supplies an automatic creation of elements and forms of the user interface. As an illustrative example, the development process of the knowledge-based system for decision support in the infrastructure logistics domain is presented.**

Keywords - knowledge-based systems, software tool, component-based systems, automated software development

I. INTRODUCTION

Knowledge-based systems (KBS) are widely used in various problem and subject domains, such as diagnostics, classifications, planning, forecasting, finance and banking, engineering, medicine, transport. In comparison with other types of software, the main feature of KBS is the knowledge base that contains a set of systematized knowledge, describing the regularities of a particular area. KBS provides domain modeling, knowledge formalization and decision support based on various methods. Let's divide these methods into 3 groups.

1. Domain structure formalizing methods, including creating and storing concepts and instances.
2. Domain regularities formalization methods and related methods for supporting decision-making.
3. Other techniques of the decision-making support, such as application of the methods for numerical analysis and simulation modeling.

Methods for creating a conceptual models, ontologies, concept maps, etc. are frequently applied to define domain structure. Currently, a lot of software related to that problem are developed: Protege, OntoEdit, FreeMind, CmapTools, et.al. Traditionally, four groups of methods can be considered to solve the regularities formalization problem and related to them reasoning mechanisms: logical-based reasoning, including automatic theorems proving and logical programming; case-based reasoning; classifiers; rule-based reasoning. The last group of reasoning methods is in focus of this paper. The best-known and frequently used systems that implement rule-based reasoning are Clips, Jess, Drools, JRules, et.al. Note that the proposed in the article approach allows extending the platform by the addition of the other types of reasoning mechanisms. The third group of KBS methods includes various problem-oriented methods of decision-making that operate mostly with numerical information. For example, numerical methods for solving equations, formulas calculation, statistical quantities generation, and different types of computer simulation. These methods can be formalized as external procedures ("black boxes") for utilizing during the inference process.

One of the notable advantages of KBS is the ability to solve poorly formalized problems. However, during the creation and support processes of applied KBS developers frequently face the necessity of revising the current understanding of domain under consideration. In terms of described above groups of KBS methods it means the following: modification of conceptual model and related database; formalization of new and refinement of existing regularities of the domain, which in particular leads to a growth of the knowledge base and variations of the current set of problem-oriented methods. All these changes may also stipulate related transformations in the ways of interactions with the end user of KBS. So development and maintaining applied KBS in the up-to-date adequate state requires a lot of efforts devoted to solving problems of data model evolution, functionality expansion, and graphical user interface modification. To address the represented problems and, therefore, reduce the cost of creating, modifying and upgrading of applied KBS an automation of KBS development process is

required. Virtually it means that we need to develop the specialized software platform for KBS creation which originally includes methods and tools aimed at reconfiguring its architecture without significant efforts on rewriting the source code of applied KBS by utilizing a set of reusable components that implement considered groups of KBS methods.

So the basic components of KBS development platform, as well as the unified approach supporting their interrelations and data exchanging, are discussed in the article. The capabilities of the proposed platform were successfully tested during the development process of the knowledge-based system for decision support in the infrastructure logistics domain.

II. UNIFIED INTERFACE BASED APPROACH

A well-known component-based approach [1, 2] is utilized for specialized platform development. Within this approach, a component is an independent entity that implements at least one programming interface (a set of properties and methods) that is a formal description of one or more problem-oriented functions of the component. At the same time, to provide the possibility of extending the functionality of a deployed system, it is necessary to develop the tool for adding new components. Therefore, processes of component integration and intercomponent data exchange have to be unified. To solve the unification problem the basic metamodels of object-oriented programming have to be explicitly utilized as elements of the proposed platform software infrastructure. So, concepts of class, object, property, method and component are represented as a set of interfaces. Let's consider them in detail.

The *IClassDescription* interface has been proposed to handle the metamodel "Class" within the platform. So the interface allows utilizing data from the description of some class during operations execution of various type. The interface provides information of the following type: class name, description, class type, description of the base class, a list of derived classes. Also, properties and methods can be retrieved by name or as a list with the ability to filter (for example, only properties with a single value, object properties, collection properties, etc.), while for the metamodels "Property", "Method" and "Method parameter", the *IPropertyDescription*, *IMethodDescription*, and *IMethodParameterDescription* interfaces are used, respectively. In addition, the *IClassDescription* interface can act as object factory, i.e. provides instantiation of the described class, while the *IObjectDataController* interface is used as the return value (its description will be given later).

```
interface IClassDescription
{
 public String Name();
 public String Description();
 public TKindsOfDataTypes Kind();
 public Boolean IsAbstract();
 public IPropertyDescription
        PropertyDescription(String Name);
 public IMethodDescription
        MethodDescription(String NameOfMethod);
 public IList Properties(ISearchCriteria
        SearchCriteria);
 public IList Methods(ISearchCriteria
        SearchCriteria);
 public IClassDescription
        DescriptionOfParentClass();
 public IClassDescription
        DerivedClassDescriptions();
 public IObjectDataController CreateNewObject();
}

interface IPropertyDescription
{
 public String Name();
 public String Caption();
 public String Description();
 public TKindsOfDataTypes KindOfProperty();
 public IClassDescription DescriptionOfClass();
 public IClassDescription Owner();
 public Boolean Collection();
 public Boolean Required();
}

interface IMethodDescription
{
 public String Name();
 public String Description();
 public IClassDescription Owner();
 public IList InputParameters();
 public IList OutputParameters();
}

interface IMethodParameterDescription
{
 public String Name();
 public String Caption();
 public String Description();
 public TKindsOfDataTypes KindOfParameter ();
 public IClassDescription DescriptionOfClass();
 public IMethodDescription Owner();
 public Boolean Collection();
}
```

Supported data types are formalized as the TKindsOfDataTypes set with the following elements.

- Persistent – a class that provides the object state storage between software system sessions, each object has its own identifier.
- Serial – a class that provides the object state storage between software system sessions within an "Persistent" type object, object of this type has no own identifier.
- Transient – objects of this type exist only during software system session.
- Text - a generalized representation of the text data type (string, widestring, varchar, text, etc.).
- Integer – generalized representation of an integer (byte, integer, long, word, etc.).
- RealNumber – generalized representation of a real number (real, float, double, numeric, etc.).
- Date – the standard date representation in the form of a day/month/year structure.
- Time – the generalized representation of time (time, time with time zone, time without time zone, etc.).
- DateTime – the generalized representation of the date and time (datetime, timestamp with time zone, timestamp without time zone, etc.).
- Boolean – boolean true/false.
- BinaryStream – large amount of binary data.

- CharacterStream – large amount of character data.
- Unsupported – data types not covered by the previous list, and therefore not processed.

In accordance with the responsibilities separation principle for the metamodel "Object", the following interfaces have been developed. *IObjectClassDescriptionController* provides the ability to obtain a description of an object in the form of a class name, a class type, and a full description in the form of a link to the IClassDescription interface.

```
interface IObjectClassDescriptionController
{
 public String NameOfClass();
 public TKindsOfDataTypes KindOfClass();
 public IClassDescription ClassDescription();
}
```

IObjectDataController allows to control an arbitrary object state. The interface supply methods that allows to retrieve the textual representation of the current state, as well as obtaining the current value and setting a new value of the object property by name. In addition, the interface defines a method for copying the current state of an object to a new object of a similar class.

```
interface IObjectDataController
{
 public Boolean SetValueOfProperty(String
        NameOfProperty, Value);
 public String LiteralProperty(String
        NameOfProperty);
 public IObjectDataController
        ObjectProperty(String NameOfProperty);
 public IList CollectionProperty(String
        NameOfProperty);
 public String ObjectDataAsText();
 public IObjectDataController Copy(Boolean
        DeepCopy);
}
```

IObjectActivityContololler is designed to control the behavior of an arbitrary object, while working with a particular method is implemented according to the "Command" pattern, when the method is interpreted as an object whose state is described by the method signature. For method processing, it is proposed to use the interface *IMethodDataController* to extend the functionality of the *IObjectDataController* interface, using the following methods: checking the readiness for execution, directly running for execution, checking for execution. Thus, the *IObjectActivityContololler* interface provides a method controller by name or a full list of methods, and the *IMethodDataController* interface responds directly to the method.

```
interface IObjectActivityContololler
{
 public IList ListOfMethods();
 public IMethodDataController
        MethodDataController(NameOfMethod)
}

interface IMethodDataController extends
IObjectDataController
{
 public Boolean IsReady();
 public Boolean IsExecuted();
 public Boolean Execute();
}
```

The *IComponent* interface is proposed to represent the component metamodel, providing the ability to control the state and behavior of the component using *State*, *Behavior* methods that return links to the *IObjectDataController* interfaces, and *IObjectActivityContololler*, respectively. The *DescriptionOfComponent* method provides a description of the component as a reference to the interface *IDescriptionOfInterfaceImplementor*, which is an *IClassDescription* extension and provides additional information about the list of interfaces implemented in this component. Interactive facilities of the component can be accessed via the *ContolPanel* method.

The interfaces *IObjectClassDescriptionController*, *IObjectDataController*, *IObjectActivityContololler* form the unified interface of the platform object. While the *IComponent* interface is a unified interface for the platform component. This set of unified interfaces makes it possible to implement the open architecture of KBS development platform. In other words, it is possible at any time to extend the list of solved problem-oriented tasks by adding a new component, without changes in the source code of the platform.

III. THE PLATFORM ARCHITECTURE

The proposed concept of the unified interface of the component makes it possible to represent the platform architecture as a collection of elements of only two types: management sub-system and the set of components. Each component, in addition to the problem-oriented functions, must ensure the implementation of the *IComponent* interface. The management sub-system is an element of the platform architecture that exists as a single instance and is responsible for the direct creation of applied KBS in accordance with the following generalized algorithm:

1. Adding information to describe the general characteristics of KBS (name, description, purpose, etc.).
2. Creation of a formal model of the KBS domain structure.
3. Creating a formal decision-making model for KBS.
4. Create a user interface for accessing KBS data and functions.

To perform each of the steps, except for the first one, it can be used a lot of different methods and approaches, but for the approbation purposes only one of the possible implementations was chosen. Thus, the formalization of the domain structure will be implemented as a conceptual model of the following kind:

CM=<*Concept*, *Attribute*, *Relation*, *Concept Instance*>,

<*Concept*>=<*Name*> <*Description*> {<*Attribute*>},

<*Attribute*>=<*Name*> <*Attribute type*> <*Default value*>,

<*Attribute type*>= *Literal* | *Concept*,

<Relation>=<Concept> <Name> <Relation type> <Concept>,

<Relation type>=Literal.

To support decision-making, a rule-based reasoning will be exploited and related knowledge base (KB) model has the following form:

KB=<Template, Rule, Initial Condition>,

<Template>=<Concept>|<Relation>,

*<Rule>=***IF** *<Condition>* **THEN** *<Action>*,

<Initial Condition>=<Concept Instance>.

According to proposed rule model, the left side of the rule can contain the following conditions: the presence of the fact of the specified template, the restriction on the value of the fact slot, comparison of the value of the slot with the existing fact, comparison with the slot value of another fact. And the following types of actions can be used to form the right part of the rule: creating a new fact, modifying an existing fact, deleting a fact, invoking an external method.

Since KBS is also a subclass of information systems, the implementation process includes tasks related to the data definition and the implementation of standard functions for data manipulation (browse, read, edit, add, delete operations). Currently, these tasks are solved using different types of database management system (DBMS). To solve the problem of centralized storage of domain data and access to them, it is suggested to implement interaction with the DBMS on the basis of the following interfaces. *IDBControlInterface* provides the formalization of the general operations with the DBMS, including the tasks of connecting, supporting transactions, accessing database controllers and its elements, as well as implementing service-diagnostic functions, for example, the execution of user requests; obtaining a list of supported data types in the *TKindsOfDataTypes* set format; information about run-time errors. *IDBObjectDataProvider* provides a formalization of the functionality to retrieve the data of the base element, including the definition of the query structure, the creation of criteria for searching and sorting data. In general, the structure of the search criterion can be complex: from a simple grouping of constraints of the field value and to a combination of other complex criteria with an arbitrary nesting. Logical operators (AND, OR) are used for grouping. Interfaces *IConditionsOfSearching* and *ISearchCondition* are proposed for representation both complex and single search criteria as well.

```
interface IConditionsOfSearching
{
 public String GroupOperator();
 public IList Conditions();
}
interface ISearchCondition
{
 public String Name();
 public String CompareOperator();
 public String Value();
}
```

IControllerOfDataModifications provides the formalization of tasks for adding, editing and deleting data of a database element. In most cases, these tasks require the ability to uniquely identify certain information (a row in a relational table, a file, an object). To obtain the description of the ID of the database element, as well as other unique indexes, *IDescriptionOfDatabaseObject* is proposed as the descendant of the *IClassDescription*.

Based on the analysis of user interfaces of the popular systems for KBS development (Protege, etc.), the standard set of graphical controls for the platform is suggested. At first, this set provides support for all simple data types from the set of *TKindsOfDataTypes* (single/multi-line input fields, date and time elements, checkbox for representing a logical type). In addition, more complex user interface elements have been added to the resulting set for implementing frequently occurring tasks: displaying data in a table form, including nested tables, selecting one or more options from the list, displaying the data as a network. The suggested set of controls is utilized to automatically create browsing and editing forms based on the functionality of the *IClassDescription* and *IDescriptionOfDatabaseObject* interfaces. When due to the lack of information such kind of) automatic creation is impossible, users can exploit techniques of visual design for UI development.

IV. THE IMPLEMENTATION ISSUES

In accordance with modern trends in the development of software systems, the implementation of the management sub-system and the functional components of the proposed platform is implemented in the form of web-applications. Proposed software platform exploits FreeBSD, Apache software bundle in order to create server-side part platform, as well as PHP and Java languages for developing the components. The data storage functionality uses well-known DBMS PostgreSQL. Component interaction is based on HTTP / HTTPS, SOAP and Websocket protocols. The GUI and *ControlPanel* method of the *IComponent* interface (if necessary) are built on the top of the HTML, CSS and JavaScript languages and popular JavaScript libraries such as jQuery and jQueryUI. Next, we will take a closer look at the implementation of the basic components.

The data control component provides the implementation of the interface set *IDescriptionOfDatabaseObject*, *IDBObjectDataProvider*, *IDBControlInterface*, *IControllerOfDataModifications*, for the PostgreSQL 9+ database. The main functions of this component are the following: connection to the server, obtaining a list of the database server and the tables related to them, performing operations with the selected table. These operations are extracting a meta description, modifying and retrieving data, within which the *IConditionsOfSearching* interface can be used to formulate search criteria. SQL code for all data operations is generated automatically. In the data control component, the implementation of the *ContolPanel* method of the *IComponent* interface provides a user

interface that allows one to display the table data with the ability to filter, view the logical structure of the database and execute an arbitrary SQL query in the terminal.

The data representation and editing component provides the implementation of standard platform controls based on the jQuery, jQueryUI, jQueryGrid, jsPlumb libraries. The component implements a data model that stores information about the developed forms of the user interface, containing: name, description, list of used UI controls. The processing of this model is based on the functionality of the data control component. The data control component also exploits the functionality of the data representation component to implement its UI. The component provides the ability to visually design problem-oriented user interfaces.

The subject domain model design component is implemented as a web application and has the following functionality: the formation of a hierarchical structure of concepts from abstract to more concrete ones; the definition of the properties and relations; creation of instances of concepts (by implementing interfaces for interaction with the DBMS). The description of relations is carried out by constructing a semantic network, where the vertices are concepts and the relationships are edges.

Rule-based reasoning component is implemented as a web application and has the following functionality: creating knowledge bases on top of the selected conceptual model; the formation fact templates list based on concepts of the conceptual model; visual construction of the rules in the form of "IF conditions THEN actions"; creating initial conditions; generation of knowledge base code in Jess and Clips format and its inference; creation the concept instances from inference results. A visual scheme for constructing the rules is exploited in the component. The code generation can be carried out both for the knowledge base in a whole and for its individual elements (a fact template, a rule, a description of the initial conditions). To test the knowledge base code, a terminal is proposed. It provides the facilities to edit the generated code and execute it using the Jess or Clips inference engines. The terminal display the inference results: the state of the working memory, the list of fired rules and error messages.

V. AN ILLUSTRATIVE EXAMPLE

Let's consider an illustrative example of the development process of the knowledge-based system for decision support in the infrastructure logistics domain (KBS4IL). The main objective of KBS4IL is to support research of the functioning and allocation of interrelated, multi-scale infrastructure facilities utilizing a variety of analytical tools. The research process is carried out in the form of a multivariate scenario analysis and is defined by the original methodology [3]. These methodology defines the sequence of steps for complex assessment of the transport and logistics infrastructure in some region. The KBS4IL system has to implement methodology and was built on the top of the proposed platform. KBS4IL exploits a conceptual model consisting of three parts: infrastructure logistics domain (vehicle, terminal, stakeholder, route, etc.), description of applied methods and tools (problem statement descriptions, solvers), and concepts related to specific of research session implementation (scenario, initial and final state of survey, survey stage et.al.). The existing ontologies of city logistics [4] and multimodal transportation [5] were adopted for creating KBS4IL conceptual model. The initial information and the results of decision making are stored as instances of concepts. According to applied research methodology [3] KBS4IL can solve the following types of tasks:

- creation of a transport and logistics assessment of the current region state;
- identification of problem situations in the region;
- solution searching for the identified problems;
- the assessment of the decision-making results and forming the recommendation.

KBS4IL utilizes the platform ability for rule-based reasoning. Also externally defined problem-oriented

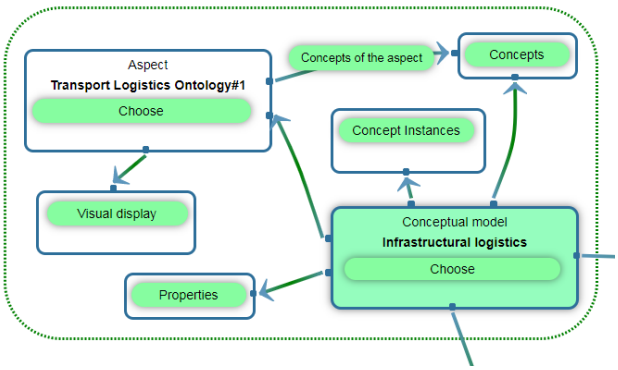

Figure 1. Main KBS4IL UI form of the subject domain model design component

methods can be included to the reasoning process via the platform facilities. For example, special tools for the pathfinding [6] , the problem of location [7], the problem of organizing communications [8] can be invoked by HTTP request. The process of interaction with the user is implemented on the basis of the platform components functionality. Main UI form of the subject domain model design component displays schema where each element provide access to related function (Fig.1). For example, "Conceptual model" element shows UI form with the list of created conceptual models; "Concepts" element runs UI form with the concepts hierarchy of selected conceptual model along with their properties (Fig.2); "Aspect" element provides access to the user interface for setting a relationships between concepts, where the single concept is displayed as the vertex of a net while the relationship is represented as an edge (Fig. 3).

Inspired by KBS4IL the current future plans are the application of platform to develop a KBS in the engineering domain (diagnostics of reliability and safety

of unique technical systems [9]), and the ecology domain (assessment of environmental impacts based on ecological-economic model of the region [10]).

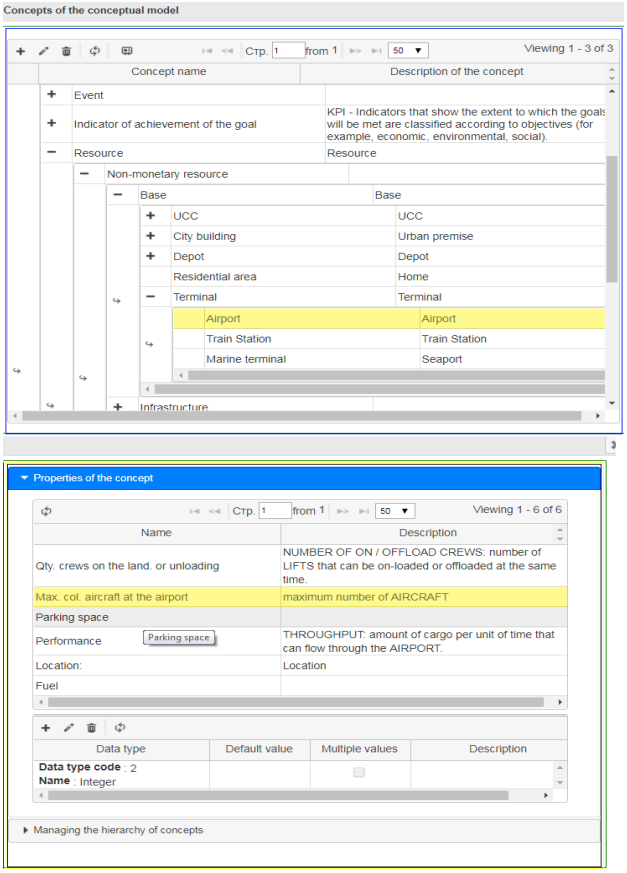

Figure 2. The fragment of infrastructure logistics domain conceptual model: concepts and properties

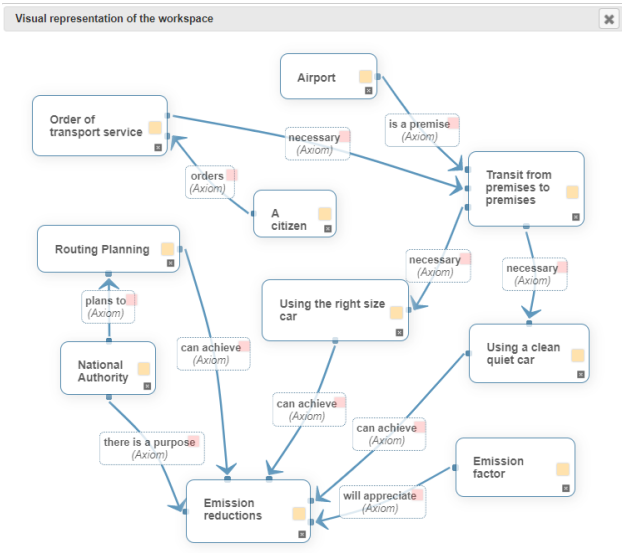

Figure 3. The fragment of infrastructure logistics domain conceptual model: relations

VI. CONLUSION

Specialized software platform for KBS creation based on component-based approach is discussed in the article. The problem of unification the process of components integration and intercomponent data exchange is considered. The suggested approach allows representing KBS architecture development process as a declarative description of the interrelations between the components while information exchange is governed by the data transformation rules. The ability to obtain the structure description of the data about to process at the start of the method execution within the platform components allows creating a generalized implementation of information processing algorithm related to some problem-oriented task. So platform component function can cover a set of particular cases. This platform component feature significantly improves the efficiency of code reuse as the same component can solve many tasks of a certain class without any changes in source code. The platform was tested for the development of KBS for decision support in the infrastructure logistics domain (KBS4IL). Experience in application and maintaining of KBS4IL has demonstrated the operability of proposed platform.

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Countywide Natural Gas Consumption Forecast, a Machine Learning Approach

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***Abstract*—This paper proposes several machine learning models for gas consumption forecast. The consumption data used is for a county in Croatia, and the considered models are decision trees, linear regressors, support vector regression, and neural networks. Most of the models show promising results when compared to similar research. The criterion used to identify the forecast quality is the root of the mean squared error, error being the forecast difference from the expected value. The findings presented in this paper can be used to better understand the way natural gas is consumed in the county and to create a more sophisticated regressor in the future.**

***Index Terms*—Natural gas, forecasting, regression, machine learning, optimization, intelligent systems, time series**

I. Introduction

Natural gas consumption forecast is a common problem in the field of energetics. Knowing the volume of gas that is going to be consumed on a given day can be useful for market analysis and resource management. A model that can successfully forecast these consumptions can save money and increase infrastructural efficiency.

The task of forecasting gas consumption can be interpreted as time series regression. Several fields of mathematics and computer science have attempted to solve this task. In this paper we analyze the machine learning approach through application of various models. This approach is used because other studies have shown that it works, but, to author's knowledge, none of them have applied it to the data set used in this research.

A. Related work

In 2012 research was conducted by HEP Plin Ltd., where an overview of the most common natural gas consumption forecast methods was given [1]. Later, in 2014, they have conducted research of the ways solar radiation influences gas consumption in residential buildings, and proposed models like various linear regressors, neural networks and support vector regressors (SVR) for gas consumption forecast, using the weather data and metered measurements [2].

Research in 2014 by Bianco et al. [3] has shown how climactic factors, gas price and GDP affect the consumption of gas in residential buildings. A linear regression model in combination with genetic algorithms was used on these features to build models for long-term gas consumption forecast . This research shows how economical conditions of a country affect the gas consumption and how they can be used to forecast future consumptions.

A study similar to this research was conducted in 2015 by Szoplik [4] where a multilayer perceptron was used for short-term, hourly gas consumption forecasts. The results shown there are comparable to results of this research, which will be discussed in the later sections.

A paper by Yu et al. [5] proposes the usage of decision trees for a similar type of problem, forecast of energy consumptions in buildings. The results show forecast precision of 92%, which may indicate that decision trees could also be used for a county-wide forecast.

Some more recent studies analyse more advanced models like the one by the University of Piraeus, Greece, where a combination of wavelet transform, ANFIS and genetic algorithms was used to improve forecasts for various Greek cities [6]. Similarily, in Turkey, a hybrid of genetic algorithm and simulated annealing was used to improve forecasts of more basic models [7].

B. Hypothesis

We can conclude several things from the results the studies from the related work – linear models and models like neural networks are viable for gas consumption forecast. Also, there is always room for improvement of these models with more sophisticated ones (hybrids, usage of heuristic optimizations, fuzzy computing, etc).

The approach we choose for solving the problem of gas consumption forecast is, like in the previously stated studies, supervised learning; concretely, neural networks, ordinary linear regression, lasso linear regression, support vector regression (SVR) and decision trees.

We assume that the experiment is successful if its results are comparable to the ones from the previously stated studies and normalized root of the mean squared error is within 5% of the total span of the gas consumptions. Another used error indicator is the mean absolute percentage error, which should be around 5% like in some of the mentioned related work [4], [8].

II. Data set

One data set was used, containing metered daily consumptions expressed in m^3, related to a county in Croatia. To author's knowledge, this set wasn't used in any prior research.

The time interval for which the data is available is from 23 February 2013 to 30 September 2017, containing a total of 1496 samples. When talking about daily consumptions, one day counts as time interval from 6:00 AM of the current day to 6:00 AM of the next day, which is defined as a single gas day [9]. Other than consumptions themselves, the set contains temperature (daily average value) and timestamps of the consumption measurements. Prior to being processed by the machine learning techniques, consumptions and timestamps were preprocessed in ways that will be explained in this section.

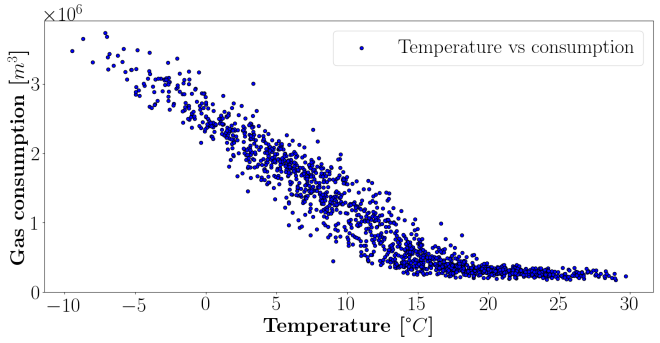

Fig. 1. Daily consumption of natural gas related to mean temperature.

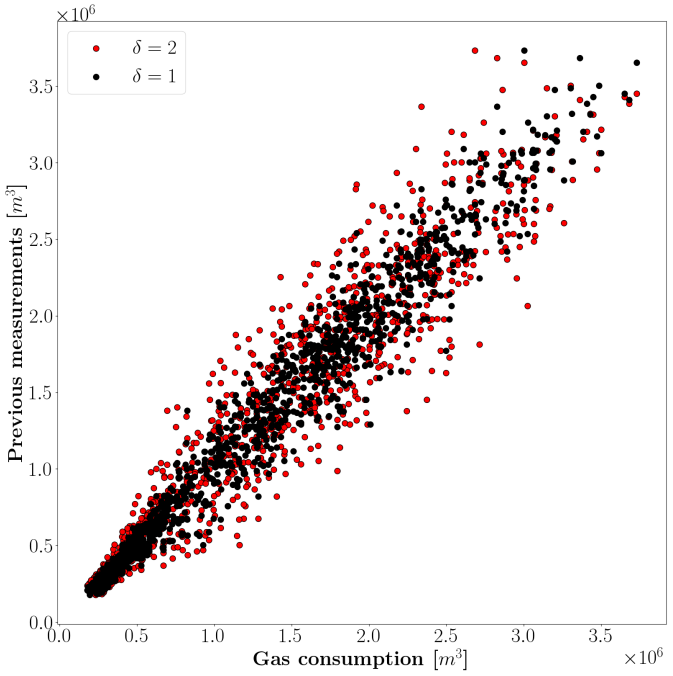

Fig. 2. Daily conumptions in relation to the consumptions measured δ days earlier. Shows autocorrelation of the gas consumptions.

Figure 1 shows the way temperatures and gas consumptions correlate to each other on the daily data set. There is a clear correspondence between these two values, consumption being negatively correlated to the temperature. It's also shown how gas consumption behaves during the warmer parts of the year, dropping until temperatures reach approximately $17°C$, then dropping at a much slower rate. Concretely, the correlation coefficient of the temperatures and consumptions for days when the temperature was above $17°C$ is -0.5163, whereas it is -0.9545 for the samples where temperature is below $17°C$.

Since the data sets are time series, another set of useful features are consumption values of the earlier measurements. Figure 2 shows how daily consumptions vary from the previous measurements in relation to the day difference. These values and expected outputs were normalized during the preprocessing to simplify the gradient descent of the models that use it and to fit the outputs in the interval $[0, 1]$ (since the neural networks used the sigmoid activation function).

The last used feature was the timestamp of the measurement. Information extracted from the timestamp was type of the day, differentiating days of the week, holidays and connected days (days between two non-working days). As preprocessing, the timestamps were converted to integers corresponding to their type where holidays were treated the same as Sundays and connected days were treated the same as Saturdays, having seven types in total. The integer types were later one-hot encoded since they are a categorical variable. This feature is useful because it attempts to model consumer behaviour by expecting them to consume gas in different amounts if they're home (which depends on the type of the day).

III. Model Forecast Estimation Methodology

For model estimation, the data sets were split in two groups. The first, fitting data set, contained the data from 23 February 2013 to 30 September 2016, and the second, test data set, from 1 October 2016 to 30 September 2017 (the last complete gas year) [9]. The fitting set is used to train and validate various models and the test set represents the unknown data. Error on unknown data is the test result.

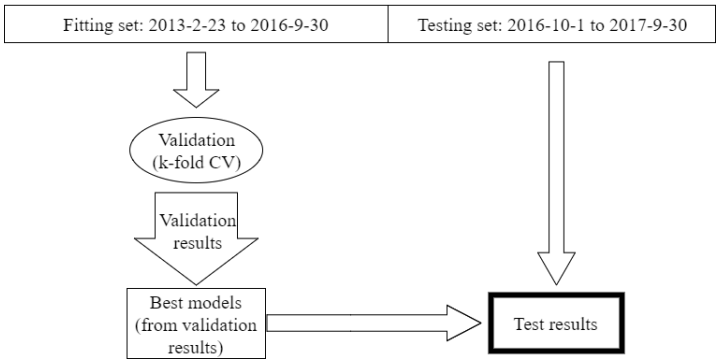

Fig. 3. Overview of the experiment methodology.

The fitting set was used for model training and validation. It was shuffled and split in 5 parts. These 5 parts were then used for a 5-fold cross validation on all combinations of models and their hyperparameters. This process was then repeated $0.01 \times N$ times (where N is the number of samples in the fitting data set) and the averages of the model performances on the validation sets were used as the criterion of the model quality. The best models were then trained on the whole fitting

set (without shuffling or splitting it) and their performance was estimated on the test set, yielding the final results. This workflow is illustrated at figure 3.

IV. Results

Models used for the research were ordinary linear regression, lasso regression, feed-forward neural networks, support vector regressors (SVR) and decision trees. We used the previously described validation algorithm to optimize hyperparameters for these models, and then tested them on the testing set. The hyperparameters stated in the result tables represent:

- α – L1 regularization factor.
- d – Polynomial degree to which the inputs are mapped.
- a – Neural network architecture, first value is the number of inputs, last value is the number of outputs and values in between are numbers of neurons in the hidden layers.
- μ – Neural network learning rate.
- ϵ – SVR soft margin.
- C – SVR error penalty.
- mf – Maximal number of features in the decision tree.
- md – Maximal depth of the decision tree.

The results of the multiple averaged 5-fold cross validations are written in the table I. The hyperparameters are written in the brackets next to the model name.

TABLE I
A sample of validation results on the daily consumption dataset. Contains estimated best models and some lower rated models, to show how they compare.

Model	RMSE ($\times 10^4$) [m^3]	MAPE
Lasso ($\alpha = 2, d = 3$)	6.956	4.93%
Lasso ($\alpha = 3.51, d = 2$)	7.314	5.731%
Linear regression ($d = 2$)	7.289	5.993%
NN ($a = [9, 60, 40, 1], \mu = 0.001$)	7.133	4.665%
NN ($a = [9, 10, 40, 1], \mu = 0.05$)	7.868	4.595%
SVR ($\epsilon = 0.001, d = 3, C = 1500$)	7.396	5.343%
Decision tree ($mf = 9, md = 10$)	7.397	6.496%

When the best models from the table I are trained on the fitting set and applied to the data in the testing set, the results from the table II are achieved. The linear regression isn't included because it is basically lasso where α is zero, which has given inferior results.

TABLE II
Forecast results of the best validated models on the testing set (consumptions of 2017). The selected models are the ones with the best validation results of each model type.

Model	RMSE ($\times 10^5$) [m^3]	MAPE
Lasso ($\alpha = 2, d = 3$)	1.22	5.987%
NN ($a = [9, 60, 40, 1], \mu = 0.001$)	1.231	5.644%
SVR ($\epsilon = 0.001, d = 3, C = 1500$)	1.401	6.452%
Decision tree ($mf = 10, md = 9$)	1.95	7.551%

V. Discussion

As stated in the introduction, the errors should be within 5% of the difference between the lowest and largest consumption. Since the consumptions span from $1.75 \times 10^5 m^3$ to $3.731 \times 10^6 m^3$, the errors below 1.778×10^5 are considered acceptable. Almost all error fall within that margin, except for the decision trees, which was partially expected, due to the simplicity of that model. Also, the MAPE error is approximately similar to other research, indicating that the models were used at a similar level of efficiency [4], [8].

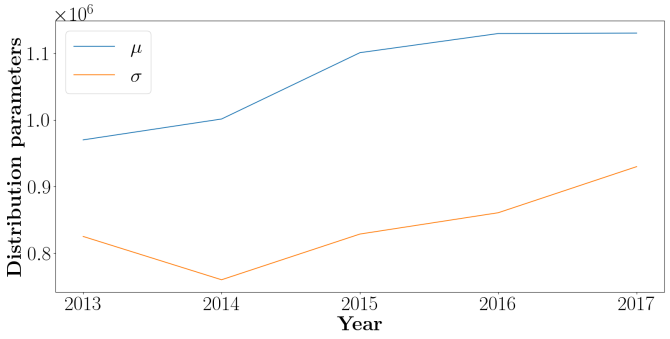

Fig. 4. Consumption (normal) distribution parameter variation from 2013 to 2017. The mean consumption of the year 2017 has stayed similar to 2016, but the standard deviation has increased.

It can immediately be noticed that there is a large difference between the validation errors and the test errors (RMSE). The test errors are approximately as twice as large as the validation errors. One explanation is that the models get biased during the validation towards the validation sets. As a result, the models selected during the validation could possibly be inferior to other models that generalize better [10]. This, however, is not very likely as the step where the cross validation is repeated multiple times on shuffled samples was introduced as a counter measure against this. Another explanation for this large difference is in the properties of the year 2017. It is possible a certain social, climatological or economical factor has made the year 2017 somewhat deviant (as shown on figure 4). This could indicate that the used models weren't robust enough to adapt to these deviations. In that case, identifying this factor should also be a priority in future research. Despite that, most of the errors are still within the acceptable interval, making the results valid.

Potential problem with forecasting gas consumption is the variability of climate in various areas of a county. Since the county spans across a relatively large area and it's near a hill, it's expected that the temperatures will vary in different subareas. Because of this, temperature measurement becomes a less credible feature for the machine learning models. Potential improvements could be usage of temperature measurements for different neighborhoods, addition of new weather variables like solar radiation or wind speed, or even economical variables like GDP or natural gas price to the data sets [2], [3].

Another potential improvement is the usage of a more sophisticated model. The results could be improved using heuristic optimizations, ensemble regressors or recurrent neural networks, methods that have shown to be capable of

improving the robustness of basic machine learning models [11]. This could be a potential focus point of future research, finding a more sophisticated model that could improve upon the results presented in this paper.

VI. Conclusion

This paper has presented information on how certain machine learning models can be used to forecast natural gas consumptions for the county area, based on previous consumptions, temperatures and times the measurements were taken. The models that were used for the research could be considered simple since no hybrids were used, but they have given results comparable to similar studies.

Despite these upsides of the stated results, certain inaccuracies were noticed, as stated in the discussion section, that could be improved upon in future research. If we're to learn from related work, one of the potential improvements is addition of new parameters to the data set. Concretely, this would include addition of new weather variables, or even economical ones. Another potential focus point is creation of a more robust, sophisticated model, that would be a hybrid of multiple models presented here. With this, we can determine that the topic of gas consumption forecast for the used data set remains open for further improvements.

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Cuisine classification using recipe's ingredients

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***Abstract* – The purpose of this paper is to explore the linkage between recipe's ingredients and identification of a cuisine. This has been tackled as a problem of cuisine classification. We will examine various approaches (different machine learning algorithms) for recipes classification based on the recipe's ingredients. The output will be the recommendation of the classification methodology, i.e. what kind of preprocessing can be done to improve the classification and the performance of several classifiers on the dataset we will be using.**

Keywords - cuisine classification, recipe ingredients, preprocessing, POS tagging, Levenshtein distance, support vector machines, neural networks

I. INTRODUCTION

Every person who wants to live a healthy lifestyle needs good nutrition in combination with physical activity. These factors could be taken as most contributing to maintain a healthy weight, reduce the risk of chronic diseases (like heart disease and cancer), and promote the overall health. Nowadays, human diet is not only influenced by the food's nutritional values or the body's energy needs, but also by other factors, such as climate (terrain, the soil quality, the robustness and the availability of the crops and livestock) and culture (beliefs, religion, and socio-economic status). For example, the usage of spices in the hot climate regions comes from the need of keeping the food resistant to bacteria for longer time [1].

In cooking, a set of ingredients composes a particular dish. Ingredients are the main substances that determine the taste or flavor of the dish. A recipe on the other hand is a set of instructions that describes how, by using some collections of ingredients, one can prepare a specific culinary dish. The culinary dishes are organized into cuisines. Furthermore, a cuisine can be defined as a style of cooking characterized by distinctive ingredients, techniques, and dishes, and is usually associated with a specific culture or geographic region. Although the combination of spices and ingredients could be taken as unique for specific cuisines, regions, and cultures, there are situations where this is not the case. There are cases where the same combination of ingredients tastes differently if they are cooked from ingredients produced in different world regions, while the slight modification of the quantity of ingredients and the preparation steps could lead to different categorization of the given recipe.

So, if we are given the list of ingredients, estimating a cuisine type is not an easy task. Since we are living in an Internet era we are overcrowded with an enormous number of different recipes spread throughout many web sites with no particular geographic order among them.

Using the information, we threw above we can address the problem as follows: *Can we assign each dish to a particular cuisine if we are given only recipe's ingredient data*? This problem could be addressed by standard machine learning approaches (we only need a good and reliable training set of recipes annotated with the cuisine label). The produced model(s) could deal with categorizing unknown recipes into previously known cuisines. We will explore several machine learning classifiers, like Naive Bayes, Feed Forward Neural Networks and Support Vector Machines. Using the listed classifiers will propose common methodology for classifying recipes.

A. Related Work

If we translate the problem of cuisine classification into multi-class document classification, then we are able to come up with dozens of related papers. To do that, lets change the notations first.

- Recipe = Document
- Ingredients = Words in the document
- Cuisine = Document class

One approach towards tackling this problem is the solution proposed by Rennie and Rifkin [2]. They conclude that the Support Vector Machine (SVM) can effectively perform multi-class text classification when used as part of an Error-Correcting Output Coding (ECOC) scheme. By reducing the problems to binary classification, one can apply many well-known machine learning algorithms, such as Naive Bayes and SVM. But, the disadvantage of this method is training of independent classifiers, by not taking into the account the correlation between classes. They also show that Support Vector Machines outperforms Naive Bayes in multi-class classification, which is the same as our conclusion for multi-class cuisine classification.

One of the most common obstacles when performing text classification is the length of the feature vectors. Very long and sparse vectors can slow down the learning of the classification model. Therefore, algorithms for feature selection should be applied. The work presented in [3] provides comparative study of several feature selection methods in statistical learning of text categorization, based on aggressive dimensionality reduction. To reduce dimension of feature space, document frequency thresholding, Information gain, Mutual Information and Term Strength are compared. In information retrieval, TF-

IDF (term frequency–inverse document frequency), is a numerical statistic that is intended to reflect how important a word is to a document in a collection or corpus. In text mining it is often used as a weighting factor. The paper [4] discusses in detail about the TF-IDF. In our approach we will examine both the reduced and non-reduced feature vectors provided from the recipes collection. In addition, we use TF-IDF to create a more representative feature vectors for better classification.

There are many attempts to classify dishes to cuisines by using ingredients. In the [5] the authors build several feature sets and train them with different classification algorithms. However, we deploy unconventional methods for making the naming conventions of the ingredients consistent throughout all cuisines, as well as an improved feature selection method based on the frequency of the ingredients. Moreover, we used Naive Bayes and Support Vector Machines to establish lower and upper boundaries for the classification accuracy, and we did most of the work with Neural Networks. Very similar to our approach is the work conducted by the Su, Lin, Li and others [6]. They perform automatic cuisine classification on the dataset taken from Food.com. Compared to our dataset, their dataset has many more features, like recipe names along with ingredients and cuisines data. For training purposes, we use ingredients and cuisine data only, which makes our task more challenging and interesting.

In [7] the idea of attribute-based classification was applied in order to classify plates of food to the correct cuisine by the country, using the ingredients as attributes for a plate of food. Although they apply the classification on the images taken from the plate of food, they conclude that every cuisine could be categorized by unraveling its distinct features encoded by the used ingredients.

However, in our approach we practice unconventional methods mostly focused on preprocessing the ingredients to improve the classifier's accuracy. Our motivation is to reach a conclusion that even though using the same classifiers, the way the data is preprocessed plays a huge role in whether the classifier's accuracy will increase or decrease.

The rest of the paper is organized as follows. The section 2 describes the problem and the dataset used in our experiments. Further, in section 3 we will dive into the preprocessing methodologies that we practice in this paper. In addition, we will give directions for proper preprocessing of the dataset to tackle the problem. In section 4, we will examine the classification methods applied to the dataset(s). In the next section, we will provide experimental results obtained by using different classifiers, feature vectors and libraries. The last section, section 6, concludes the paper.

II. DATASET

The dataset we are using is publicly available on Kaggle, and was part of a past competition named "*What's cooking?*" hosted by Yummly[1].

[1] Yummly is a popular service that provides recipe recommendations, semantic recipe search and a digital recipe box.

TABLE I. SEVERAL STATISTIC MEASURES FOR THE RECIPE'S DATASET WE WILL BE USING THROUGHOUT THIS PAPER

Cuisine	#recipes	MAXI	MINI	AVGI	MFUI
Brazilian	467	59	2	9.52	onions
British	804	30	2	9.7	milk
Cajun Creole	1546	31	2	12.61	garlic
Chinese	2673	38	2	11.98	sesame oil
Filipino	755	38	2	10	pepper
French	2646	31	1	9.81	all-purpose flour
Greek	1175	27	1	10.18	dried oregano
Indian	3003	49	1	12.7	garam masala
Irish	667	27	2	9.29	salt
Italian	7838	65	1	9.9	olive oil
Jamaican	526	35	2	12.21	ground allspice
Japanese	1423	34	1	9.73	mirin
Korean	830	29	2	11.28	soy sauce
Mexican	6438	52	1	10.87	chili powder
Moroccan	821	31	2	12.9	ground cumin
Russian	489	25	2	10.22	sugar
Southern US	4320	40	1	9.63	butter
Spanish	989	35	1	10.42	garlic cloves
Thai	1539	40	1	12.54	fish sauce
Vietnamese	825	31	1	12.67	water

The dataset is consisted of 39774 recipes in total. Each recipe contains several ingredients and belongs to a specific cuisine. A recipe can belong to only one cuisine meaning that the class attributes are mutually exclusive. There are a total of 6714 distinct ingredients in the entire training dataset, while the number of unique classes (cuisines) is 20. Some interesting statistics about the dataset, like number of recipes per cuisine, maximum (MAXI), minimum (MINI) and average (AVGI) ingredients per recipe per cuisine, and most frequent unique ingredient (MFUI) per cuisine are given on table 1.

What is specific about the training dataset is that the data is exceptionally skewed (as shown on figure 1). We provide this info because later on we will propose a solution where by reducing the number of distinct ingredients we can improve the accuracy of the classifiers. A sample of one recipe from the training set looks like:

```
{
    "id": 3735,
    "cuisine": "french",
    "ingredients": [
        "sugar", "pistachio nuts", "white almond bark",
        "flour", "vanilla extract", "olive oil",
        "almond extract", "eggs", "baking powder",
        "dried cranberries" ]
}
```

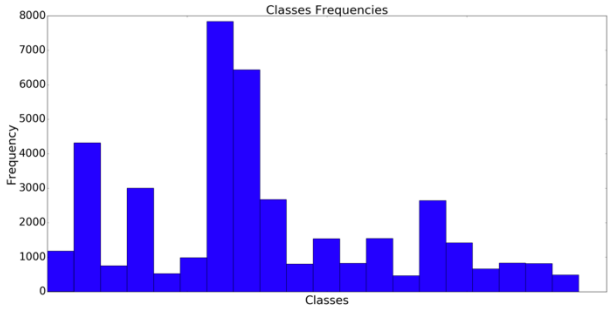

Figure 1. Histogram of class distribution. The total number of distinct ingredients is 6714 spread across 428275 occurrences among the recipes. The prevalence of some classes (cuisines) is dominant in comparison to the others.

If we take a closer look at this recipe's JSON format, it is easily to conclude that if we combine sugar, pistachio nuts, white almond bark, flour, vanilla extract, olive oil, almond extract, eggs, baking powder and dried cranberries, then this combination will probably taste as the most deserts of the French cuisine.

Besides the training dataset, an additional test set of 9944 instances has been provided. In test set recipes, the cuisine label is missing, and the task at hand was to predict the cuisine value for each given sample.

III. PREPROCESSING OF THE DATA

Bearing in mind that the real-world data is noisy and inconsistent, we had to have a way to preprocess the data in order to eliminate such irregularities. There are multiple data preprocessing techniques, but we will focus on two. First is the data cleaning, that is applied to remove noise and inconsistencies from the data. As a methodology for data cleaning we used Levenshtein distance. The second is data reduction. Data reduction is the task where we reduce the data size in terms of excluding redundant attributes that only lead to increased dimensionality of the data, and yet they do not hold any information that will help us achieve better classification. Since we are working with text, there is a blurry boundary between data cleaning and reduced dimensionality of the data. With that said, the methods we propose cohesively clean the data and reduce its dimensionality as well.

A. *Levenshtein distance*

As we described above, the dataset consists of 6714 unique ingredients and each of the recipes is described using this set of ingredients. Our first approach was to determine whether this is the true number of unique ingredients. We took on this problem using Levenshtein distance or Edit distance, as it is commonly referred to.

The Levenshtein distance algorithm [8] returns a single integer as a measure of similarity between two strings. Using this knowledge, we ran this algorithm on the whole dataset with the intent to measure the similarity between each of the ingredients. With this approach, we narrowed down the results even further: the algorithm only returns the string (ingredient) pairs that have Levenshtein distance less than or equal to 2. This means that only 2 single character edits are required to switch one of the strings (ingredients) to the other. Three examples of such pairs are provided below.

lemon grass = lemongrass
groundnut = ground nuts
low sodium soy sauce = lower sodium soy sauce

As an output we got 287 pairs of ingredients whose Levenshtein distance is less than or equal to 2. From that set we extracted 108 ingredient pairs, who were essentially the same ingredient with some minor typing error. As a result, the filtered dataset was lowered down to 6662 unique ingredients.

B. *Outliers analysis*

Since we are dealing with textual ingredients, we need to determine which ingredients can be considered as outliers. One way to determine the outlier-ingredients is based on their frequency of occurrence. After computing the frequency of each ingredient and sorting that array in an increasing order, we proceed towards estimating if an ingredient is considered as an outlier or not. Now let's suppose that we pick certain elements from the list such that we split the list into equal size consecutive sets. These elements are called Quantiles [9]. The 2-quantile is the element that is dividing the upper and lower halves of the array. The 4-quantiles are the three elements that split the array of ingredients frequencies into four equal parts; where each part represents one-fourth of the array. They are more commonly referred to as *Quartiles*. The first quartile denoted by Q1, is the 25th percentile. It cuts off the lowest 25% of the data. The third quartile, denoted by Q3, is the 75th percentile. It cuts off the lowest 75% of the data. The distance between the first and the third quartile is called the interquartile range (1) and it measures the spread of the data:

$$IQR = Q3 - Q1. \quad (1)$$

Using the interquartile range, we can label an ingredient as an outlier if it's frequency is $1.5 \cdot IQR$ above the third quartile or $1.5 \cdot IQR$ below the first quartile. However, due to the skewed distribution of the data, if we use this methodology in the default form, we will completely eliminate the most frequent ingredients, resulting in recipes containing 0 ingredients. To avoid this, we preformed the outlier filtering to only eliminate the ingredients whose frequency is $1.5 \cdot IQR$ below the first quartile, which resulted in a feature vector of 1383 unique ingredients. Figure 2 and Figure 3 show a plot of frequencies of the ingredients.

C. *Part of speech tagging (POS)*

The last preprocessing step we applied on the dataset was POS tagging [10]. Our intention was to use POS to filter out the preparation procedure of the ingredients (chopped, grilled, fried and etc.). Several examples are provided below:

unsmoked bacon = bacon
smoked bacon = bacon
diced mushrooms = mushrooms
fried mushrooms = mushrooms

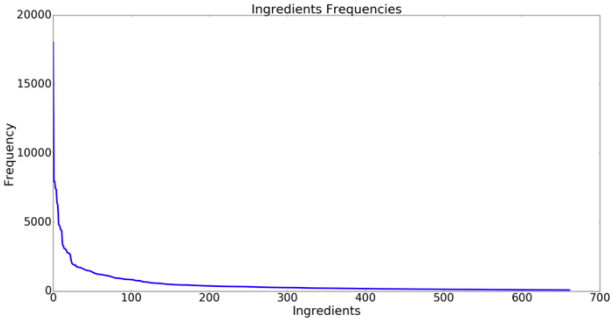

Figure 2. Frequencies plot for the most frequent 662 ingredients.

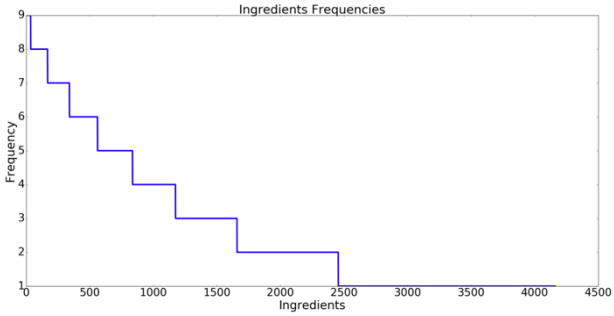

Figure 3. Frequencies plot from the 2500 most frequent ingredient till the end.

To achieve this, each line of text (ingredient) was POS-tagged, and we filter out only nouns. This approach yielded lower yet interesting results (4793 ingredients).

IV. Classification

The central part of our methodology is the learned classification model. We will explore several machine learning classifiers, like Naive Bayes, Feed Forward Neural Networks and Support Vector Machines. We will dive into the distinctive characteristics of all these classifiers, and we will choose one of them as the most promising for our recipes classification problem.

A. Naive Bayes

Naive Bayes (NB) is a probabilistic classifier which is based on a naive assumption that each of the features are independent. NB works towards selecting the class label that maximizes the posterior probability:

$$P(C_k|x) = P(C_k)*P(x|C_k) / P(x). \quad (2)$$

while the naive assumption is:

$$P(x_i|x_{i+1},\ldots,x_n,C_k) = P(X_i|C_k). \quad (3)$$

Although the naive assumption is false most of the time, this classifier gave extremely competitive results.

B. Neural Networks

Neural Network (NN) is a supervised learning algorithm that learns a function:

$$f(\cdot) : R^m \rightarrow R^o. \quad (4)$$

by training on a dataset, where m is the number of dimensions for input and o is the number of dimensions for output. Given a set of features: $X = x_1, x_2, \ldots, x_m$ and a target y it can learn a non-linear function approximator for the classification task.

Each NN consists of several layers of neurons. The first layer, known as the input layer, consists of a set of neurons $\{x_i|x_1,x_2,\ldots,x_m\}$ representing the input features. Each neuron in the hidden layer transforms the values from the previous layer with a weighted linear summation $w_1x_1 + w_2x_2 + w_3x_3 + \ldots + w_mx_m$ followed by a non-linear activation function $g(\cdot) : R \rightarrow R$, which in our case is the hyperbolic tan function. The output layer receives the values from the last hidden layer and transforms them into output values. The output layer is a Softmax activation function over the 20 class attributes.

$$y_i = \exp(z_i)/\sum_{j=1}^{K}\exp(z_j), \quad \text{for } j = 1, \ldots, 20. \quad (5)$$

C. Support Vector Machines (SVMs)

The hard margin Support Vector Machines (SVMs) are proven method to achieve better classification accuracy when working with textual data [2]. In order to perform the classification task, the SVMs must translate the problem of multi-class classification into binary classification. To solve the problem, we use the One-vs-All approach. We train a single classifier per class, with the samples of that class as positive samples and all other samples as negatives. This strategy requires the base classifiers to produce a real-valued confidence score for its decision, rather than just a class label [11]. Then the model searches for two parallel hyperplanes that separate each of the two classes of data, so that the distance between them is as large as possible. The region bounded by these two hyperplanes is called the ”margin”, and the maximum-margin hyperplane is the hyperplane that lies halfway between them. These hyperplanes can be described by:

$$\boldsymbol{w} \cdot \boldsymbol{x} - b = 1, \quad \boldsymbol{w} \cdot \boldsymbol{x} - b = -1. \quad (6)$$

The distance between these two hyperplanes is $2 \cdot \|\boldsymbol{w}\|^{-1}$ so, the model learns to maximize that distance based on the samples from the training set. In order to maximize the distance between the planes we want to minimize $\|\boldsymbol{w}\|$.

V. Results

In this section we will present the results from all the classification models. These results are shown on table 2. We will make several tests with different sized feature vectors. This is necessary because it does not always mean that the most frequent X ingredients are going to be evenly distributed between the different classes. In fact, that would be possible, but it is not probable. So, an improved bag of words approach should be used for a more balanced feature vector.

The feature selection methods that were implemented to create the feature vector which is used as input for learning the classifiers are:

a) TF-IDF vectorization of the text (ingredients).

b) Bag of words approach. In this test, instead of taking the total number of unique ingredients, we are taking the most frequent 3500 ingredients and we build the feature vector from them.

c) Bag of words per class approach. In this test we are taking the most frequent 450 ingredients for each class separately.

For the Naïve Bayes classifier, we used bag of words (NB 3500mf) and bag of words per class (NB 450mf*), for the Neural Network classifier, we have used bag of words (NN 3500mf), bag of words per class (NN 450mf*) and TF-IDF (NN tfidf), while for the Support Vector Machines classifier, only TF-IDF feature selection method is used (SVM tfidf).

The NN architecture setting we used for all conducted tests is:

1 hidden layer with 100 neurons
Mini-batch gradient decent with batch size of 200 samples
Ridge regularization of 0.0001
Constant learning rate of 0.001
Early stopping criterion[2]

while the setting that we use for the SVM model is:

Radial Basis Functions kernel
Penalty term: 100
Gamma: 1

All the methods are evaluated with the holdout method. In this method, the given data are randomly partitioned into two independent sets, a training set and a test set. In our case, 75% of the data are allocated to the training set, and the remaining 25% is allocated to the test set. The training set is used to derive the model. The model's accuracy is then estimated with the test set. The estimate is pessimistic because only a portion of the initial data is used to derive the model [12].

The evaluation metric we used is accuracy. The accuracy of a classifier on a given test set is the percentage of test set tuples that are correctly classified by the classifier. That is:

$$accuracy = \sum_{i=1}^{20} (M_i/T_i). \quad (7)$$

where M_i indicates the correctly classified samples of class i and T_i indicates the total number of samples of class i in the test set.

We used *Pycharm* as main development environment and *Python* as the main programming language. We used the *scikit-learn* library [13] for the implementations of our classifiers, the *nltk* library [14] for the text processing and *matplotlib* for visualization.

A. Results for the original dataset

As can be seen from the results obtained from the original dataset provided by Kaggle, the data is especially prone to noise since it is written by humans. There are lots of typos and naming conventions that refer to the same ingredient but are written in a different format. All these errors can be treated as noise and decrease the accuracy of the proposed classification models.

TABLE II. THE ACCURACY FOR EACH OF THE CLASSIFICATION MODELS, WITH THE CORRESPONDING FEATURE SELECTION METHOD, ON ALL 4 DATASETS (ORIGINAL + 3 PRODUCED)

	NB 3500mf	**NB 450mf***	**NN 3500mf**	**NN 450mf***	**NN tfidf**	**SVM tfidf**
Original dataset	0.736	0.739	0.782	0.777	0.78	0.802
Levensh. distance	0.748	0.744	0.787	0.776	0.791	**0.809**
Outliers filter.	0.725	0.722	0.761	0.759	0.761	0.784
POS tagged	0.732	0.736	0.779	0.767	0.777	0.794

B. Results for the filtered dataset with LD

The Levenshtein distance can filter out the mistakes in the original dataset, resulting in 6662 unique ingredients. As can be seen from the results shown on Table 2, we can came to conclusion that even though we are using the same models with exactly the same feature selection methods, the accuracy of the classifiers is improving on this "filtered" dataset. This preprocessing step can be taken as "naive", but it leads to increased accuracy of the classification models compared to the results obtained from the original dataset.

C. Results for the dataset with excluded outliers

By using the formula that outliers the ingredient if it's frequency is 1.5·IQR below the first quartile, we decreased the number of distinct ingredients to 1378. What is special about this dataset is that even though the filtered dataset contains only 20% of the original dataset, the accuracy of the models using the same feature selection methods have decreased insignificantly.

D. Results for the filtered dataset with POS tagging

After applying the POS tagging to the ingredient list, and extracting only the nouns from the ingredient phrases, we generated the dataset of 4793 distinct ingredients. The part of speech tagging is definitely the most interesting preprocessing step. Although the number of unique ingredients is lowered, the accuracy did not decrease significantly. If it is taken into consideration that we applied this approach in the naivest fashion, it can be concluded that if this step is done carefully and further tests and analysis are done, the above-mentioned approach might yield best results.

VI. CONCLUSION

The purpose of this paper was to explore the problem of cuisine classification. Cuisine classification can be used in different purposes, like diet planning, nutritional analysis, cuisine similarity detection etc. Based on the results we have obtained from training and testing the models on different datasets, with different feature selection methods, we can conclude the following:

[2] if the loss on the validation set (15%) does not improve for 2 iterations

Naive Bayes models when trained on a proper dataset with an informative feature vector per sample (450 most frequent ingredients per class) show extremely competitive results. Even though it fails to catch the important relations in the data, this model serves as a baseline for the other classification methods.

Neural Networks models show ability to catch the signal that is present within the data, but they either suffer from underfitting or overfitting. Although the results we got by using Neural Networks are pretty good, it is likely that an improved approach with regards to selecting better features will yield excellent results.

Support Vector Machines models achieve best results among all models (when trained and tested on the Levenshtein distance processed dataset). Even if trained and tested on a noisy dataset (the original dataset provided by Kaggle), they manage to find separating hyperplane between the classes (cuisines).

As we can see from the confusion matrix (Table 3), most of the misclassification errors occur when a recipe that belongs to a less frequent class is mistakenly classified as a recipe from one of the most frequent classes. An obvious indicator for this is class 9 (Italian cuisine) with highest occurrence among all classes. A contrary example is class 1 (Brazilian cuisine) as a class with roughly 20x less recipe members, where very few recipes are mistakenly classified as belonging to the Brazilian cuisine.

In future we would try to overcome this problem with either oversampling of the less frequent classes, or undersampling of the most frequent classes. In terms of undersampling, one allegedly good approach is stratified sampling, where the instances from each of the most frequent classes are split into clusters called stratas, and the sampling is performed by taking a number of instances of each cluster. This will ensure that we have a representative optimal sample of each class.

TABLE III. THE CONFUSION MATRIX FOR THE CLASSIFIER THAT ACHIEVED THE BEST ACCURACY. THE GREEN CELLS ACCENT THE SITUATIONS WHERE THE CLASSIFIER MAKES SIGNIFICANT ERROR - MORE THAN 30 FALSE CLASSIFIED INSTANCES.

csn	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
0	67	1	2	1	2	4	0	5	0	10	1	0	0	10	0	0	13	2	0	0
1	1	91	1	1	2	25	1	5	20	10	2	1	0	4	0	2	28	1	0	0
2	0	1	283	1	0	13	0	0	0	11	2	0	0	8	0	1	62	1	0	0
3	1	3	2	603	4	4	0	2	0	8	0	17	15	2	0	1	5	0	14	6
4	3	1	1	15	121	4	2	3	2	3	1	1	2	8	0	0	7	1	8	5
5	0	8	6	3	1	447	4	2	7	113	0	1	0	7	1	3	34	6	1	0
6	0	0	0	0	0	7	221	4	0	40	1	0	0	2	7	2	3	4	0	0
7	0	1	1	5	1	2	8	677	0	5	0	1	2	12	15	1	4	1	8	1
8	0	19	1	0	0	15	2	0	102	7	1	0	0	3	0	2	21	2	0	0
9	1	5	4	5	2	75	25	5	3	1777	0	2	0	17	1	6	39	15	1	0
10	0	3	1	0	3	3	0	6	1	0	101	0	0	4	0	0	9	0	0	0
11	1	0	0	34	2	5	0	27	0	5	1	257	5	7	0	0	2	0	9	3
12	0	0	1	26	1	2	0	0	0	1	0	13	154	0	0	1	2	1	1	1
13	3	0	2	2	3	9	2	4	2	34	0	1	1	1463	2	1	27	11	0	2
14	0	0	1	0	0	5	4	18	0	13	1	0	0	5	155	1	2	2	0	1
15	0	6	3	0	0	11	1	3	3	9	1	1	1	4	1	66	5	3	0	0
16	2	7	45	4	1	40	6	4	14	36	1	2	0	30	2	1	851	3	0	0
17	2	1	5	1	1	24	4	1	2	41	0	0	0	30	2	2	7	124	0	2
18	2	0	0	22	3	0	2	15	0	6	0	5	1	2	0	0	5	0	314	20
19	1	0	1	25	6	1	1	0	0	3	0	1	3	2	0	0	4	0	59	145

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Application for The Analysis and Browsing of Images – Use Case: A Public Photo Archive

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***Abstract* - Automatic tagging and content-based image retrieval have been studied extensively in the past decades, although for a long time there were very few practical implementations targeted at end-users. Today, there are several commercial products for automatic image annotation, but still, in many cases, the applications have remained closed source, and no comprehensive open source solution exists. This paper presents a real-life use case of the analysis of a publicly available photo archive. The use case is used to illustrate the data format utilized in the indexing and searching of the analysis results. Furthermore, the user interface of the designed web application used for browsing the photo content is presented in this paper.**

Keywords - Image Processing; Application; Data Format; Use Case

I. INTRODUCTION

Automatic tagging and content-based image retrieval (CBIR) have been studied extensively in the past decades. Nevertheless, for a long time there were only a very few practical implementations targeted at end-users despite the advancements achieved in the development of various image recognition algorithms and prototype systems presented in research publications. In recent years, this has begun to change. The automatic gates used in airports at passport security control are one of the many example applications. Recently, both Google and Flickr published photo services which take advantage of image analysis. Flickr has implemented a feature which allows automatic generation of tags for photos that the user has uploaded to the service. Google has a similar feature in its Photos application, and the company also offers the "search by image" function in its image search. Unfortunately, the implementations for commercial applications are often kept out of the public domain. Sometimes the implementation has been hidden behind a public application programming interface (API), sometimes the feature is limited to the company's own applications without developer access. Fortunately, this opens the door to research on open implementations for image analysis. Most of the current research is related to semantics, algorithm, and machine learning studies – user interface design and the API specifications are given less weight [1][2][3]. There has been some research on the design of user interfaces [4], but often this is mainly related to the grouping of search results, and not on the overall design of the client. This paper proposes a data representation format for search queries, and presents the user interface designed for a practical use case. The work presented in this paper is part of a large national research project called Data to Intelligence (D2I) [5]. D2I was a four-year Finnish Strategic Research and Innovation Agenda (SRIA) program that aims to study and develop methods and tools for the management, processing, and utilization of large amounts of data captured from the environment, Internet, and many other sources. This study is related to the previous research – mainly, the description of the overall system architecture [6], the first user interface prototype [7], and the publications of the content analysis engines [8][9]. Additionally, the background framework used to implement the use case presented in this paper has been published as open source [10].

The structure of this paper is as follows. Section 2 briefly explains the overall architecture used for the developed system, and presents the basics of the object data model used. Section 3 presents the use case in more detail, illustrates the user interface, explains how the query operations are created based on user actions, and shows examples of API usage. Section 4 discusses the challenges met during our research and proposes topics for future studies. And finally, Section 5 summarizes this paper.

II. OBJECT GENERATION

A diagram of the simplified system architecture is shown in Fig. 1. The system uses third party content storage for storing the image files. In our case we use Google's Picasa or its successor Google Photos, both of which can be accessed by utilizing the Picasa Web Albums Data API [11]. The user account on the storage service is synchronized with the front-end service, which generates analysis tasks for pre-defined analysis back-ends based on the retrieved metadata. The task-based analysis functionality is explained in more depth in [6].

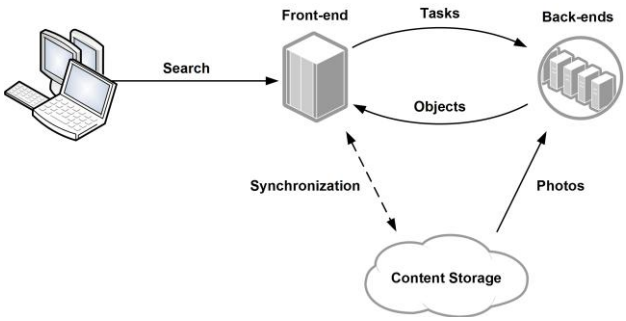

Figure 1. Simplified system architecture.

The back-ends analyze the submitted tasks and the related content, and attempt to extract additional metadata, which in our case is called *objects*. Objects can consist of any kind of metadata, although internally the objects are categorized into four primary types: *faces*, *keywords*, *metadata*, and *objects*. *Faces* represent facial recognition data, or the people detected in the content. *Keywords* are

recognized tags, classes, or concepts. *Metadata* are basic key-value pairs, which can represent, for example, Exchangeable image file format (Exif) data extracted from the photos. *Objects* are a generalized container for all objects that do not fit in the first three categories. In general, objects of type *object* are not used in the search queries unless especially requested by the user. An example of an extracted object in Extensible Markup Language (XML) format is presented in Section 3 (see Fig. 3 and Fig. 5). The choice of format is up to the developer, as both of the commonly used formats – XML and JavaScript Object Notation (JSON) – can be easily serialized from object presentations [12][13].

An object can be associated with one or more photos, and it could also represent content retrieved from other user accounts or from other third party content storage services. The extracted objects are stored on the front-end database, and can be modified by the user – or by the back-ends. However, it should be noted that the back-ends can only modify the objects submitted by themselves, and if the objects have not been manually modified by the user. The latter condition is placed to ensure that the analysis back-ends do not undo any user modifications. There is currently no versioning support for object modifications in our service. The support for version control was not deemed important in our current use case and would have complicated the database structure requiring more design and implementation work. Based on the extracted objects, an index is generated on the front-end, which is used for search operations. This means that as a general rule the back-ends are not used for the search functionality after the initial analysis phase.

There is one important exception to this rule, which is the case of content-based search. In content-based search the user provides the reference content to be used in the query. This content may be, for example, an uploaded photo, a URL link to a file located on the Internet or an internal content identifier known by the service. If content is provided through upload or link it needs to be delivered to the back-ends for analysis. The actual analysis of the content is relatively fast and in an optimal case the operation takes less than a couple of seconds. For this reason for larger files the deciding factor becomes the content download/upload speed. Even though connection speeds have increased considerably in recent years, uploading a large image of several megabytes can still take a lengthy time, especially when using a mobile connection or an asymmetric consumer connection with a limited upload bandwidth.

If the content is provided using a known identifier, there are two possible scenarios the front-end can perform. It can use the metadata associated with content referenced by the identifier, and use this data to perform a local index search. Another option is to pass the identifier to the back-ends for further analysis. The second option is for photos that do not have metadata associated with them or where the metadata is very limited. The back-ends could execute analysis for the photo based on the features and characteristics of the photo (such as shapes and color), and return a list of known identifiers for similar photos. In our service this search functionality is called *similarity search*, and in CBIR terminology the feature is often called query-by-examples. The disadvantage of this method when compared to metadata-based queries is the slight increase in the query time caused by the back-end analysis. Also, if the photos have well-defined and validated metadata, such as keyword tags, the metadata search may result in more accurate results, especially if the material contains blurry or otherwise challenging content.

III. USE CASE: PHOTO BROWSER

The use case is simple (although the practical implementation might be complex): we have a very specific collection of photos, which should be tagged automatically and easily. In our case the collection consists of photos taken in various activities in our university, and of promotional material. Currently, the photo repository itself is private, and only selected photos are listed on public channels, such as the university's Instagram page [14] and on the public web page [15]. The photo repository is quite large, consisting of thousands of images, with some of the photos being old enough not to have any usable metadata in them.

For this use case, we created a simple HTML-based photo browser, called UCPoriBrowser, focused on search and visualization needs. The photo browser retrieves the synchronized photo metadata from the front-end service, and illustrates it in combination with the user's photo collection. In this case the "user" is a common user account used by the university staff member who selects photos to be shown on the university's public media. Thus, the staff members also constitute the test group for the use case. The users of the web page or the readers of the material are not directly the target of the test case.

Compared to the Smart Photo Service test application used in an earlier user study [7][16], this version of the photo browser has certain features omitted, which are not important for this use case, such as tag modification and direct user feedback. In any case, both test applications utilize the same representational state transfer (REST) API of the front-end service.

A. Photo view and search

The photo browser consists of two views: the photo browse and photo details view. In the photo browse view the user is shown the photo thumbnails of the currently selected album, or alternatively the whole photo set. The photo browse view is also used for visualizing the search results (shown in Fig. 4) but without the object clustering features (i.e., grouping). The photo browse view has buttons (left/right arrow) for navigating through larger albums, an album selector, and a Home button for returning to the initial state of showing all user photos.

By clicking any of the thumbnail photos, the photo browser goes into the photo details view, showing the scaled up photo (shown in Fig. 2). In this view, the associated tags are also shown at the bottom of the screen. Any number of these tags can be selected (highlighted) and used as search terms by pressing the *Search* button. In Fig. 2 the user has selected the tags *Vegetation*, *City*, and *Streets*. These tags are used in the example of search results shown in Fig. 5.

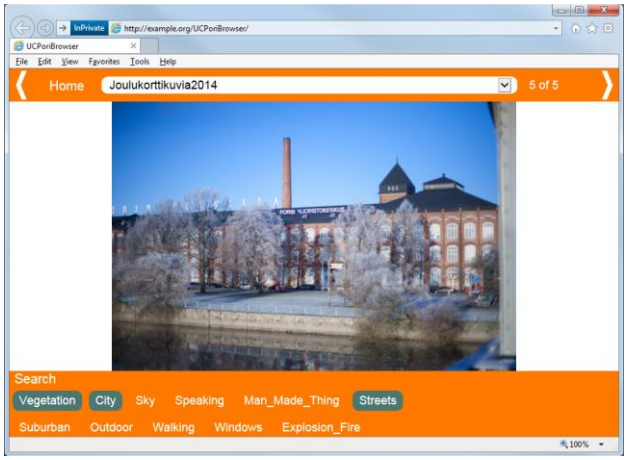

Figure 2. Photo in a slideshow view with detected keywords.

The photo details view offers the same navigation features as the photo browser view with buttons for moving to the previous/next photo.

B. *Search query generation for object-based search*

When the user selects any number of search terms from the slideshow view shown in Fig. 2, the JavaScript code on the web page will construct a query, which will be sent to a REST API method on the front-end. A simple example of the query – in XML format – can be seen in Fig. 3 (query) and Fig. 5 (result). In this case the user has selected two keywords, *Vegetation* and *City*. If more keywords are selected, a new object element with a new value element is added containing the selected keyword. The *objectType* element in both objects describes that the search should be targeted only at objects of the given type. The given objects are processed as having an OR relation, meaning that any photo with any of the given objects is returned, although photos with multiple matches of the given search terms are ranked higher in the returned result set. If several object types with the same value need to be targeted, this can be achieved by creating a duplicate of the object element with identical values, but replacing the object type with a different value. A similar logic of duplication can be used to provide all the required variations. The advantage of this method is that it keeps the format simple and easy to extend. The downside is the increased size of the request. In our use case the queries remain relatively small, and the majority of the data transfer consists of the download of media files on the client side, and even with a larger amount of objects, the request sizes are not extreme. One thing to keep in mind is that the object presentation is not perhaps the most optimal way for very simple search cases, such as searching by a single keyword. In simple queries the ratio of overhead to the actual content can be quite high, although even then the transferred data amounts are not especially high considering modern day standards. Also, it is quite simple to provide convenience methods in the REST API for simple use cases.

It is also possible to directly use any identifiers (e.g., user, back-end, object, or content identifiers) known by the service to filter the query results. The same object can be associated with multiple photos, and using identifiers can help to generate more exact results. Whether identifiers can be used or not depends largely on the user's tagging practices. If the user creates new objects each time, for example by not selecting a previously existing keyword tag in the tagging view, or by creating tags with slight variations (e.g., *car* vs. *cars*), the identifiers cannot be used and the search must be targeted to a more fuzzy text-based search. The identifier-based search can also help in cases where one search term has multiple meanings. An example would be the word *beetle*, which can mean both the car, and the insect – a use case illustrated by [19]. The identifiers are globally unique within the context of the service, and use the universally unique identifier (UUID) syntax [18], although in the example figures of this paper all identifiers have been simplified to integer values to keep the examples more readable. One exception is the optional *objectId*, which can be assigned by the object creator; it can be of any (textual) format, and is only guaranteed to be unique when used in combination with the creator identifier (user or back-end identifier). The purpose of the *objectId* is to facilitate use cases where the creator wants to include an internal identifier for the object. The identifier can also be a category, description, or other use case specific value.

```
POST /rest/ca/searchSimilarByObject

<objectList>
 <object>
  <value>Vegetation</value>
  <objectType>KEYWORD</objectType>
 </object>
 <object>
  <value>City</value>
  <objectType>KEYWORD</objectType>
 </object>
</objectList>
```

Figure 3. Example object-based search.

In addition to the basic value, *objectType*, and identifiers there are several other elements that can be included in the objects. A fully defined object can be seen in the response example in Fig. 5. Every element seen in the response example can also be used in the query as a filter. Any search criteria can be omitted, which will cause the default value to be used. In general, the default value is a wild card, i.e., any value will be matched.

The other elements shown in Fig. 5 are:

- *Status*, which can be *CANDIDATE* (back-end created object), *USER_CONFIRMED* (accepted or created by a user), USER_REMOVED (hidden or deleted by a user), or BACKEND_REMOVED (hidden or deleted by a back-end).
- *Rank* contains the ranking value of the object as defined by the user, for example, based on thumbs down/up or star-based user feedback.
- *Confidence* value shows the back-end's estimate of how well the object in question represents the related media content.

- *MediaType* describes what kind of content the object is meant to be associated with. The relation is not strictly enforced and any content could be associated with any type(s) of objects (e.g., video could be associated with a picture and/or audio objects/keywords). It is also possible to create objects without a specific mediaType.
- *Visibility* is the privacy value for the object. The objects can have the visibility of *PUBLIC*, *PRIVATE*, or *GROUP*, depending on who has access to the objects.

In addition to the search terms provided in the Hypertext Transfer Protocol (HTTP) body, the REST APIs accept URI parameters as part of the query URI, but these are primarily meant for selecting the response format (XML/JSON), paging the results (*limits*), or selecting what data should be included in the response (*data_groups*). The use of data groups is briefly explained in subsection III D.

C. Search query generation for similarity search

The query generation for the similarity search is quite simple. The browser does not contain any content that has not been previously analyzed, which means that all identifiers required for an identifier-based similarity search are available. The similarity search is in essence a simple REST API call, as shown in Fig. 4.

```
GET /rest/ca/searchSimilarById?id=1
```

Figure 4. Example similarity search.

The identifier (or identifiers) for the photos used for searching similar content are sent to the service REST API by the photo browser client and the front-end will pass the identifiers to the back-ends for further analysis. How the back-ends perform the actual similarity comparison and search is irrelevant from the client's and the front-end's perspective. In general, the back-ends will compare the data structures extracted from the content during the initial analysis for resolving matching content. The data is often back-end specific and comparing data of one back-end to data of another back-end could be challenging – this is also the primary reason why the similarity search utilizes back-ends directly instead of performing the search entirely on the front-end. The approach also mitigates the need to transfer back-end specific data to the front-end or into a shared database. The disadvantage is the one extra call to the back-end (or back-ends) during the search phase.

Additionally, and most importantly, synchronizing the back-end data to the front-end would violate the loose coupling interface contract between the front-end and the back-ends. The front-end is not – and should not be – interested in the inner workings of the back-ends. Implementing the vector comparison on the front-end would clutter the front-end code with back-end specific functionality and it would make it more difficult to extend the service by adding more back-ends.

D. Query results

Fig. 5 shows an example response for a search query. The format and output are identical for both the object-based search and the similarity search – only the value of the *method* attribute changes to reflect which method was called. The content depends on the search results and the *data_groups* parameter given in the original query. In our case the output contents are grouped into several data group values, which define what elements are present in the response. For example, *data_groups=basic* would return only the basic details of the media, such as identifiers, URL, and file name, but no object listings or additional metadata. The value *all* would return everything known about the media. It is also possible to define intermediate data groups, such as *keywords*, which could include only keyword metadata. The data groups can be freely combined and the data group combinations are the unions of the given groups. Another approach would be to allow the user to individually specify every element (or JSON field) required to be present in the response. An example of this approach is the use of the *fields* parameter in the Facebook Graph API [19]. The choice between the two approaches is mainly a question of the preference of the developer and the requirements of the use case – that is, how specific the filtering is required to be. The actual implementation is not necessarily any more complicated in one approach than in the other.

```
<?xml version="1.0" encoding="UTF-8"?>
<response
   method="similarPhotosByObject"
   service="ca">
 <mediaList>
  <media>
   <UID>1</UID>
    ...
   <objectList>
    <object>
     <backendId>1</backendId>
     <confidence>0.969</confidence>
     <rank>1</rank>
     <mediaObjectId>1</mediaObjectId>
     <mediaType>PHOTO</mediaType>
     <objectId>backend-1</objectId>
     <status>CANDIDATE</status>
     <objectType>KEYWORD</objectType>
     <value>Vegetation</value>
     <visibility>PRIVATE</visibility>
     <userId>1</userId>
    </object>
      ...
   </objectList>
  </media>
 </mediaList>
 <status>OK</status>
</response>
```

Figure 5. Example of object's XML format.

Fig. 6 shows the results of an object-based search in the UCPoriBrowser's browse view. The search results are shown similarly to the initial browsing mode but more

emphasis is given to the objects that were used in the search query. To improve the search quality, a number of proposed techniques were listed in [20] and [4]. We chose to utilize the search clustering (or grouping) technique to display the search results. The clusters are sorted in descending order based on the number of hits (i.e., the number of query objects matching the photo's objects). Each cluster is titled with the object names present in the cluster, and is outlined to separate them from each other. The result view is also inspired by the faceted result view [21], although in our case the user interface is much simpler, and retains the possibility to see the result grouped by the search terms.

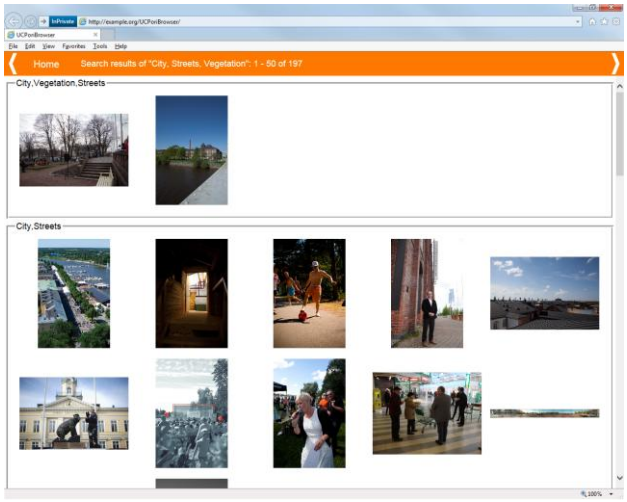

Figure 6. Search results arranged with clustering feature.

For this example query, the same objects (*City*, *Streets*, *Vegetation*) were used as those selected in Fig. 2. The user may return to the initial view by pressing the Home button, or do more searches in the same manner as was done in the example case of Fig. 2.

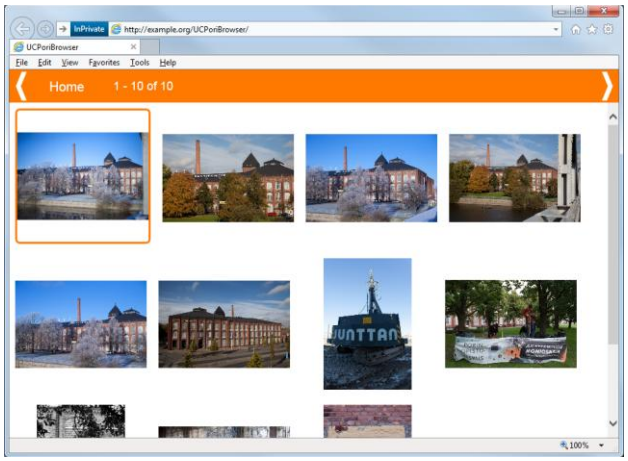

Figure 7. Similarity search results.

Fig. 7 illustrates the search results for a similarity search. The photo chosen for the reference image is shown in the figure as the first image of the result set, highlighted with borders, and is the same photo as shown in Fig. 2. The browse and slideshow features are identical to the object-based search results, and the main difference is that the results are not categorized by the metadata values – for example, the keywords seen in Fig. 6, but are ordered by similarity to the given reference photo in the opinion of the analysis back-ends with the best matching photo first. The reason for not showing the categories is simple: for similarity search, no metadata terms are given, thus making it difficult to re-order the photos by metadata. Also, in the case of the similarity search, it is possible that some of the returned photos do not even have any associated metadata.

In the search result view – by long-clicking a photo – it is possible to invoke the similarity search in the same way as from the slideshow view. The functionality is available both for the results of an object-based search, and for a previously executed similarity search.

IV. DISCUSSION

The photo browser was met with positive feedback and the results were thought to be generally good, although some of the generated keywords were thought to be not so useful. The usability of certain keywords is a well-known issue. This is caused by the nature of the keywords, which are based on about 350 back-end defined tag categories (classes). The challenge is in the selection of categories, as we do not have a clear idea of what keywords the users prefer, and there is no easy way to generate new categories dynamically. In principle it would be possible to use pre-annotated photos for generating new classes. In practice, creating an exceedingly large number of categories would cause two problems. Firstly, it would decrease the analysis performance as there would be more classes to compare against. Secondly, it may also decrease the quality of the results if there is only a minor difference between the generated classes, increasing the possibility of incorrect classes appearing in the analysis results. Thus, it would be better to find an optimal set of categories to use for analysis, despite the difficulties associated with category selection. In the photo browser use case the classes can be discussed with the university staff members, but there is currently no easy way for the users to create new classes by themselves.

One of the features requested in the user feedback was the ability to download the original full version of the uploaded photo. In our use case the photo browser uses the scaled down images provided by the content storage service to improve the performance of the web client. The same lower resolution images are also used by the analysis back-ends because the higher resolution does not offer noticeably improved analysis results, but would decrease the analysis performance. Adding the feature is a simple matter of adding a link to the full-sized picture in the search results.

One issue, not directly addressed by the feedback, is the limitation in face detection. The problem is inherently the same as with many other photo services. The service needs a set of reference pictures with manually associated persons for the analysis process. This can be done relatively easily for university personnel, because the university already has a staff listing on its web page. For other people, facial tagging becomes a tedious manual process. Thousands of unknown persons are recognized – students, general public, visiting teachers, etc. - in the

university's photo collection. Additionally, automatically detecting people might cause privacy issues in some cases.

Another minor issue is the ranking of the results for the similarity search. In cases where multiple back-ends are used, there is no well-defined way to sort the results. The results are sorted by back-end specific normalized confidence score, but because of the inherent differences in the analysis methods used by different back-ends, there is no guarantee that the values are directly comparable. One back-end's confidence of 0.5 does not necessarily equal another back-end's confidence of 0.5. This becomes problematic especially when there is very little difference in the confidence values between the back-ends and in cases when one back-end gives more optimistic confidence values than another back-end, resulting in discrimination in the search results. In our current implementation we assume that the user will not notice the slight difference in the sorting order, although we realize that the sorting principles require further study.

In the current implementation the similarity search and the object-based search are separate, and it is not possible to utilize objects in the similarity search. The search results could be compared on the client to improve the search accuracy further, but no combined search functionality is currently supported in the service. How to implement the combined search, and how the user interface should be designed to make this potential feature usable, are some of the relevant and interesting research topics for the future.

V. SUMMARY

This paper presented a structured format for describing media objects detected from multimedia content. The use of the format was illustrated through a real-life use case of an analysis of the public photo archive of a Finnish university consortium. The purpose of the use case was both to test the designed format and to receive feedback about the usability of the generated tags. The format was considered flexible enough to implement the photo browser use case. The functionality of the browser and the generated tags was found to be good in general, although the users felt that some of the tags were of no particular benefit**.** The selection of tags for automatic generation was seen as a possible future direction for research, and that is clearly the area that requires improvements and therefore more detailed study.

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A System for Monitoring and Visualization of Big Mobility Data

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***Abstract* - Efficient real-time monitoring and tracking of mobile objects has recently been a focus of a relatively intense research. Mobile objects produce a huge volume of mobility data arriving in the form of continuous data streams that need to be processed, analyzed and visualized in different information flow processing (IFP) applications. In most cases, this visualization is concerned about redrawing mobile objects locations that represent the result of a continuous query on the map. In this paper, we present a system architecture that enables you to write, construct and pose continuous query in our MobyDick framework prototype for processing big mobility data as spatio-temporal data streams in a cluster computing and to visualize their results on the map. System components are based on the Scala programming language and open source software tools for connection and communication with Apache Flink stream processor which is core of our framework prototype. The system is intended for experienced users familiar with Apache Flink paradigm as well for the beginners who can construct queries from their portions and visualize current locations and trajectories of mobile objects on the map.**

Keywords - mobile objects; mobile data; big data; spatio-temporal data streams

I. INTRODUCTION

A new information flow processing (IFP) applications such as real-time intelligent transportation systems, traffic monitoring and mobile objects tracking or network and infrastructure monitoring, need to process huge volume of mobility data arriving in the form of data streams with very low latency, i.e. in near real-time. Real-time processing of big mobility data requires push-based paradigm which means that the same, static, persistent queries are processed continuously over transient, dynamic, frequently changing streaming data. These requirements for real-time responses to posed spatio-temporal queries in addition with frequent updates of mobile objects' positions and fluctuations in the data volume have been pushed data processing from database management systems (DBMS) and cluster computing frameworks towards data stream management systems (DSMS). In fact, a streaming computation framework that supports spatio-temporal mobility data types and operations, and scales data processing transparently to large clusters is needed to efficiently support processing of big mobility data as spatio-temporal data streams in a cluster computing.

In our previous work [1] we have presented the design and implementation of a novel, in-memory parallel and distributed system prototype called MobyDick that supports real-time processing and analysis of big mobility data derived from spatio-temporal data streams. We have built this prototype on the top of Apache Flink [2], a distributed streaming dataflow engine that has an efficient, parallel fault recovery mechanism, and an unique ability to combine nearly real-time and batch in-memory processing in an unified programming framework, by extending it with a type system consisting of the set of spatio-temporal data types and corresponding operations. This work presents our effort towards real-time distributed processing and analyzing big spatio-temporal mobility data within cluster computing framework, using a set of high-level operators and without having to concern about work parallelization and fault tolerance.

To fully support modeling, analyzing and monitoring big mobility data, we extend this prototype with ability to visualize results of spatio-temporal continuous queries by redrawing a mobile object's position on the map with each new arriving data stream element. Proposed system architecture enables processing incremental results of continuous queries which are refreshed with the most recently received positional information generated at data source (mobile object), as well as map background for their appropriate presentation.

II. RELATED WORK

In order to analyze, monitor and visualize big mobility data, a suitable interactive and user-friendly on-line tools, capable of displaying and animating mobile objects on maps, are needed. Visualization tools are crucial to enrich user's perception, so that complex spatio-temporal continuous queries over mobile objects can be performed and comprehended intuitively. Hence, this research area has been very active in the last years and a number of helpful monitoring and visualization systems are available today, with a growing demand for more advanced strategies and approaches. Each approach consider various technologies appropriate to the nature of mobility data and

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suitable for the spatio-temporal DBMS, cluster computing frameworks or spatio-temporal DSMS.

A visual analytics platform in data intensive computation environment that supports large-scale spatio-temporal data is presented in [3]. This platform uses distributed storage, data reorganization, distributed queries, spatial indices, and segmented fetch for processing and visualizing Big Data with spatio-temporal attributes. The processing and visualizing is achieved by redefining task model, data model, and visual mapping strategies.

Y. Wang et al. present [4] an algorithm that can find patterns from massive trajectory data stream by batch processes and visualization of gained spatio-temporal information. An algorithm attempts to discover and visualize the places at which people often stop when they are walking or driving, or the places which are becoming crowded by analyzing massive trajectory data streams.

David et al. describe [5] how to use D3Js as an open source JavaScript library for manipulating documents based data, which encompasses HTML, SVG and CSS technologies, to provide an abstract interface which enables to effectively visualize large complex sets of spatio-temporal data. This approach enables a more intuitive, user focused, tactile navigation and selection for specific analysis of large set of spatio-temporal data which is illustrated on a spatio-temporal database of the Edison electric company using the Visual technique called chloropleth.

B. Mao et al. propose [6] a framework for online visualization of spatio-temporal data stored in database and linked to spatio-temporal data server implemented with Jetty WebServer, from which browser acquire spatio-temporal data using WebSocket with JavaScript program. The animation in the browser is implemented by canvas object defined in the HTML5 specification with JavaScript. One of the most popular online digital maps, Google Maps that contain rich data sets and useful APIs for the development is used for spatial data visualization.

M.G. de Oliveira et al. present [7] a domain independent web-based spatio-temporal viewer and analyzer, which deals with the temporal variation and includes data mining clustering algorithms, providing an intuitive visual analysis of the results. This approach promotes interoperability since it may be connected to any map server that implements the Web Map Service and Web Feature Service, specified by the Open Geospatial Consortium (OGC).

Visualization tool which includes an animated map that enables the user to visualize and compare trajectory data, find patterns, comprehend behaviors, and discover knowledge from the observable mobile objects, simply through the tracking of the objects movement is presented in [8]. Visualization tool is developed in an online environment by using only open source libraries like SVG, D3.js, Leaflet.js and Crossfilter, where a user would be able to visualize his data just by using a simple browser and without having to install any kind of third-party software.

III. OVERVIEW OF CONCEPTUAL SYSTEM ARCHITECTURE

In order to monitor and visualize big mobility data derived from spatio-temporal data streams, we need a system architecture that is capable of presenting continuously produced results of posed continuous queries in a real-time or with very low latency. Such system architecture has a modular schema design simplified presented in Fig. 1 in which each component is responsible for a particular task in big mobility data analysis process.

The core of this system architecture is a distributed stream processing engine with embedded support for spatio-temporal data types and operations that ingests a big mobility data from outer sources (base streams), applies transformations to model, analyze and transform spatio-temporal streaming data, and continuously produces results to be visualized (derived streams). Due to big mobility data nature, this data stream processor has to provide data distribution, communication and fault tolerance for distributed computations over data streams and also to execute programs in a data-parallel and pipelined manner. Support for spatio-temporal data types and corresponding operations within this data stream engine is crucial for processing and monitoring big spatio-temporal mobility data.

After the results of continuous queries are produced, system needs to ensure an appropriate visual exploration technique with low latency read access to a distributed stream processing engine. Two dimensional maps are particularly useful visual exploration techniques to present spatio-temporal data in a specific moment. Due to their static property the maps are mostly embedded with web technologies and supported by a various APIs so they have an ability to present geographical information whose location and/or shape change over time.

The third component of system architecture presents effective approach for construction and posing continuous queries over big mobility data in a form of user-friendly graphical interface, which any type of user could understand and operate. This means, any type of user should be able to define various conditions for continuous query, even conditions that combine dynamic big mobility data with static spatial entities, and to immediately suspend a query execution and to start a new one.

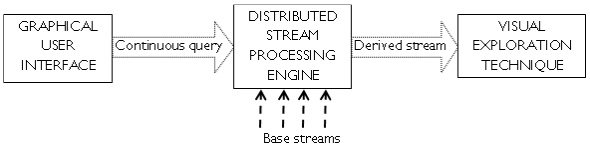

Figure 1. Conceptual schema of system architecture

IV. SYSTEM IMPLEMENTATION

In this section we present our system developed according to modular design approach proposed in previous section, that offers possibility of querying, monitoring and visualizing big mobility data. As we have already pointed out in the paper introduction, core of our system is Apache Flink distributed streaming dataflow

engine extended with our MobyDick library for spatio-temporal data types and operations support. The remaining two modules of system architecture[1] we have realized through a common system component that brings together user-friendly GUI and maps for visualization as shown in Fig. 2.

A. *GUI for defining and posing continuos queries*

User-friendly GUI allows even beginners to construct and pose various spatio-temporal continuous queries which incremental results will be later visualized on the map. GUI is developed using ScalaFX programming language, which is a user interface domain specific language (UI DSL) written within the Scala language that sits on top of JavaFX 2 and JavaFX 8. Every ScalaFX application is also a valid Scala application, which is the main reason why we chose ScalaFX for implementing GUI, since our MobyDick prototype built on top of Apache Flink distributed data stream engine is also developed using Scala.

Defining spatio-temporal continuous query over big mobility data is enabled by simply choosing the operation and parameters from the offered subset of functions and operations on mobile objects implemented within MobyDick prototype according to the data model described in [1]. Based on the selected operation, user will have a possibility to enter only certain parameters that would result in proper definition of spatio-temporal query. This is the main reason why even the beginners could use our system to extract the information they require, without knowing much about data streams technologies and spatio-temporal operations in the background. The list of currently implemented operations includes a most commonly used subset of operations defined in our data model: *within*, *disjoint*, *passes*, *trajectory length*, *distance*, *min distance*, *max distance* and *direction*, while the rest is yet to be implemented in this system.

Before selecting the operation, user must determine a time window for the query, by choosing `NOW` or `PAST` window from the interface. Apache Flink offers two different types of time windows, tumbling and sliding windows. Both window types are used to discretized the stream into windows, i.e. a finite group of elements. For tumbling windows, those elements are non-overlapping (system collects data over some period of time defined by user input, e.g. we can compute number of cars passed in the last minute). On the other hand, for certain applications it is important that windows are not disjoint because an application might require smoothed aggregates. For example, we can compute every 30 seconds the number of cars passed in the last minute. Such windows are called sliding windows. By selecting `PAST` window, user can basically choose one of the two window types and enter collect and result time for the window.

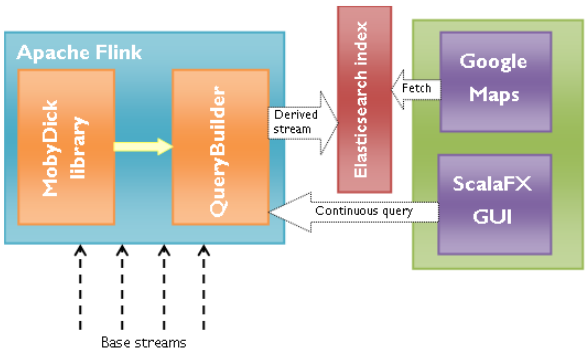

Figure 2. System implementation

When user selects an operation that involves interaction with static spatial object, one must be defined with its coordinates. User first chooses a type of spatial object (point, linestring or polygon) and then defines one by one points it consists of by entering their coordinates. Since the data model uses JTS library for defining spatial objects, user has to input coordinates in UTM coordinate system, which are later transformed into latitude and longitude used by Google maps.

After user chooses query parameters, they are wrapped inside QueryBuilder component, an object of a Scala class we have created just for this purpose. It is responsible both for spatio-temporal query creation and execution. Based on query parameters passed from GUI of our system, QueryBuilder component constructs a query using spatio-temporal data types and operations from MobyDick library and invoke Apache Flink *execute* method that transforms base data stream into derived stream which is result of designed spatio-temporal query.

B. *Maps for presenting position and trajectory of mobile objects*

To present results of spatio-temporal continuous query produced incrementally by the data stream processor, we use Google Maps v3 API that enables showing current positions of mobile objects, as well as their trajectories. Since the Google Maps use the WGS84 spatial reference system used by the Global Positioning System (GPS) (geographic coordinates between -180° and 180° longitude and -90° and 90° latitude) our system also offers possibility to convert coordinates from Universal Transverse Mercator (UTM) projected coordinate system, in which user defines query parameters, to WGS84.

One of the most important system requirements is possibility to fetch results from data stream processor in a real time or with very low latency. Since this is not possible to accomplish by directly connecting Google Maps to Apache Flink, in our system we use a data store with low latency read/write access as an intermediary layer between these two components. After execution of the query, the resulting derived stream is written into an Elasticsearch index [9]. Elasticsearch is chosen as it offers possibility of retrieving and working with big data in a nearly real-time scenario, which our system is designed for and since ApacheFlink has connector for Elasticsearch, which allows us to create custom sink that can request actions to an Elasticsearch index (actions like insert, update, delete). Custom Elasticsearch sink is also defined with a Scala class. Adding sink to the already defined spatio-temporal query takes place inside the QueryBuilder component simply by calling `.addSink()` method on the derived stream.

[1]The source code of a system for visualizing big mobility data is available at Bitbucket: https://bitbucket.org/DarioOsm/visualisation/src

Elasticsearch index is defined with the following structure:

```
{
 "locations" : {
   "properties" : {
      "location": {"type": "geo_point"},
      "time": {"type": "date"},
      "driverId": {"type": "integer"},
    }
 }
}
```

It holds information about mobile object (expressed with ID of the driver), its current location, and timestamp when the result is written (event time, not the time of processing). Once the data is written into Elasticsearch, which happens as soon as query created by QueryBuilder is defined and executed, we retrieve the query results from the Elasticsearch in a form defined by Elasticsearch index mentioned above. Usually it has to be done by defining query using Elasticsearch Query DSL, which is based on JSON, but since we use Elasticsearch only as a connector we just fetch data from index by sending AJAX request to Elasticsearch. The resulting data containing location of the mobile objects, that meet query condition, are then visualized on the map in a form of extending trajectories or moving markers depending on the users selection.

V. QUERY EXAMPLES AND VISUALIZATION

Users can define various spatio-temporal queries over big mobility data by using GUI component of our system and by following instructions for constructing query condition presented in previous section. Query examples in this section are run over the streaming mobility data defined with an id of the mobile object (driver), location (defined by `Point` from JTS library) and event time (timestamp when the source generated the object) which are derived from Infati data set [10].

Q1: *Continuously every half minute, show location of all mobile objects who travelled more than 2 km in past 10 minutes.*

If the user wants to pose this query, he would choose "*PAST*" for window type and select "*Sliding Window*" type, after which he would enter 600 seconds (equivalent of 10 minutes) as a "*Collect Time*" and 30 seconds for "*Result Time*". He will have to choose operation "*Trajectory length*", operator ">", and value "*5000*".

Such user selection would result with following query:

```
val queryQ1 = geoLifeStream
.assignAscendingTimestamps( geolife =>
 geolife.timestamp.getTime )
.keyBy(0)
.timeWindow(Time.of(600, TimeUnit.SECONDS),
 Time.of(30, TimeUnit.SECONDS))
.apply { MobyDick.mobilePoint _ }
.filter( mo => mo.location.lengthAtTime
            (mo.location.endTime) > 2000 )
.map( mo => (mo.location.atFinal().geom,
 System.currentTimeMillis / 1000, mo.id))
```

Q2: *Continuously report current locations (or trajectories) of all mobile objects within particular region of interest.*

If the user wants to pose this query, he would choose "*NOW*" for window type, "*Within*" for operation, then he would choose "*Polygon*" as the geometry type, after which he would input several coordinates in UTM coordinate system that forms polygon, i.e. the region of interest.

This would result with following query:

```
val queryQ2 = geoLifeStream
.assignAscendingTimestamps( tuple =>
 tuple.timestamp.getTime )
.filter( geolife =>
geolife.position.within(polygonOfInterest))
.map( geolife =>
(geolife.location.atFinal().geom,
System.currentTimeMillis / 1000,
geolife.id))
```

Q3: *Continuously, each minute, report current locations (or trajectories) of all mobile objects that were within 300 meters from a point of interest within last 15 minutes.*

If the user wants to pose this query, he would choose "*PAST*" for window type and select "*Sliding Window*" type, after which he would enter 900 seconds (equivalent of 15 minutes) as a "*Collect Time*" and 60 seconds for "*Result Time*". He would choose "*Distance*" operation, operator "<" and value "*300*". He would choose "*Point*" as the geometry type and entered UTM coordinates for the point, i.e. the geometry of interest.

This would result with the following query:

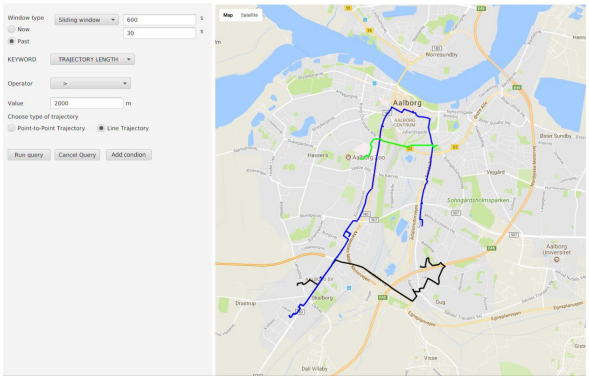

Figure 3. Definition and visualization of query Q1

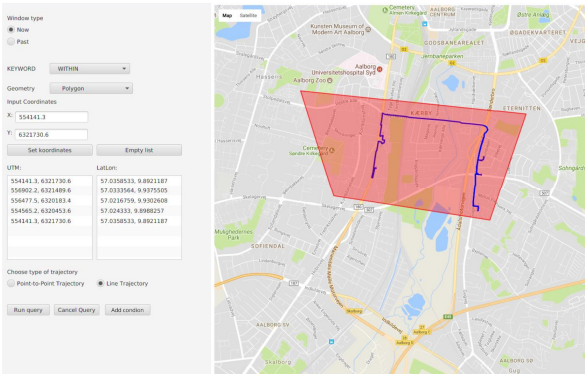

Figure 4. Definition and visualization of query Q2

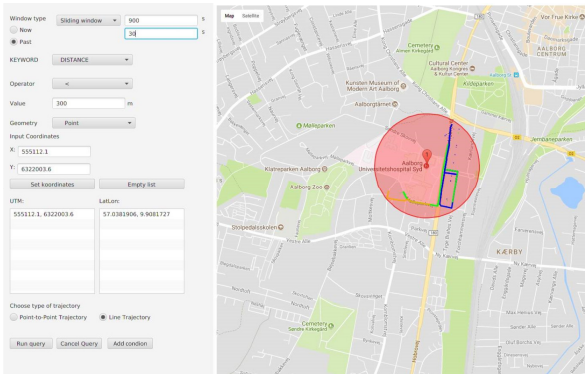

Figure 5. Definition and visualization of query Q3

```
val queryQ3 = geoLifeStream
.assignAscendingTimestamps( tuple =>
 tuple.timestamp.getTime )
.keyBy(0)
.timeWindow(Time.of(900, TimeUnit.SECONDS),
 Time.of(60, TimeUnit.SECONDS))
.apply { MobyDick.mobilePoint _ }
.filter( mo =>
 mo.location.distance(pointOfInterest,
 mo.location.endTime).asInstanceOf[Double]
 < 300 )
.map( mo => (mo.location.atFinal().geom,
 System.currentTimeMillis / 1000, mo.id) )
```

Q4: *Continuously, each second, report current locations of all mobile objects who passed over particular road (line object) of interest.*

If the user wants to pose this query, he would choose "*PAST*" for window type and select "*Tumbling window*" type with 1 seconds result time. He would then choose "*PASSES*" for operation and "*Linestring*" as the geometry type, after which he would enter several UTM coordinates that form the line of interest. This would result with the following query:

```
val queryQ4 = geoLifeStream
.assignAscendingTimestamps( tuple =>
 tuple.timestamp.getTime )
.keyBy(0)
.timeWindow(Time.of(1, TimeUnit.SECONDS))
.apply { MobyDick.mobilePoint _ }
.filter(mo =>
 mo.location.passes(linestringOfInterest))
.map(mo => (mo.location.atFinal().geom,
 System.currentTimeMillis / 1000, mo.id))
```

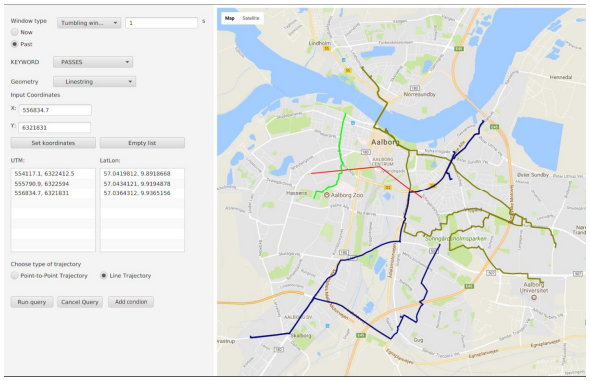

Figure 6. Definition and visualization of query Q4

In previous examples we have presented a most commonly used queries over mobility data that involve only one criteria for mobile objects selection. However, our system also allows a possibility of posing even more complex queries, by combining multiple different conditions over mobility data.

Q5: *Continuously, each minute, report current locations (or trajectories) of all mobile objects that were within 1 kilometer from a point of interest within last 15 minutes, having traveled more than 800 meters.*

If the user wants to pose this query, he would choose "PAST" for window type and select "Sliding Window" type, after which he would enter 900 seconds (equivalent of 15 minutes) as a "Collect Time" and 60 seconds for "Result Time". He would choose "Distance" operation, operator "<" and value "1000". He would choose "Point" as the geometry type and entered UTM coordinates for the point, i.e. the geometry of interest. After defining the first condition, user has to click on "Add another condition" button, which would add a possibility of choosing operation "Trajectory length", operator ">", and value "800".

This would result with the following query:

```
val queryQ5 = geoLifeStream
.assignAscendingTimestamps( tuple =>
 tuple.timestamp.getTime )
.keyBy(0)
.timeWindow(Time.of(900, TimeUnit.SECONDS),
 Time.of(60, TimeUnit.SECONDS))
.apply { MobyDick.mobilePoint _ }
.filter( mo => mo.location.lengthAtTime
 (mo.location.endTime) > 800 &&
 mo.location.distance(pointOfInterest,
 mo.location.endTime).asInstanceOf[Double]
 < 1000 )
.map( mo => (mo.location.atFinal().geom,
 System.currentTimeMillis / 1000, mo.id) )
```

Continuous queries over base streams, i.e. big mobility data from outer sources, as a result produce derived streams that need to be visualized on maps. The response time than represents the time elapsed from the moment the first element of derived stream was produced up to the moment it was visualized on map, which in case of proposed system includes the time of writing data stream element to Elasticsearch index and the time of fetching data from index and presenting on map. For each of the queries previously presented this response time is approximately 10 milliseconds which confirms that the

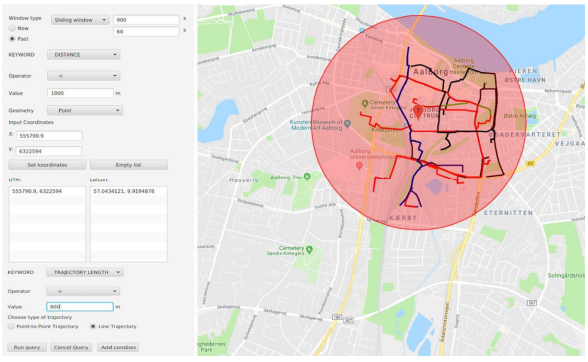

Figure 7. Definition and visualization of query Q5

designed system visualizes mobility data in nearly real time

VI. CONLUSIONS AND FUTURE WORK

This paper presents conceptual design and implementation of a system that enables monitoring and visualization of big mobility data derived from spatio-temporal data streams. The system is based on our previously developed MobyDick prototype for real-time processing of big mobility data within cluster computing framework which is extended with user-friendly GUI developed in ScalaFX and Google Maps API for representing results of continuous queries on maps. To ensure nearly real-time fetching results from data stream processor we use Elasticsearch index in combination with AJAX requests from Google Maps API. We illustrated and validated our proposed approach through different representative spatio-temporal queries over big mobility data presented in the last section. With possibility to define and pose continuous queries by simply clicking mouse and choosing various operations and window types, the system is proved to be appropriate for any type of users, for the beginners and advanced ones as well.

However, there are still some open issues within this system that will be focus of our future work: (i) implementation of full set of operations and predicates on big mobility data from our data model, (ii) more suitable approach for defining spatial objects used in spatio-temporal continuous queries condition and (iii) combining multiple conditions for more complex continuous queries which also includes objects from persistent storage.

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Pavement Crack Detection Using Otsu Thresholding for Image Segmentation

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***Abstract*—Pavement cracks are the first signs of structural damage in the asphalt pavement surfaces. The oldest method for detection and estimation of the pavement cracks is human visual inspection, also known as manual visual inspection. However, using human inspectors is very time consuming, very expensive and poses a risk to human safety. Another negative side is the fact that the task generally requires road to be closed. Hence, automatic prevention and reparation of cracks on the asphalt surface pavements is an important task, especially because the advanced stages of road deformation lead to formation of potholes. This has negative impact on the total reparation cost. In this paper, we proposed a new unsupervised method for the detection of cracks with gray color based histogram and Ostu's thresholding method on 2D pavement image. At first, the method divides the input image into a four independent equally sized sub-images. Then, the search for cracks is based on the ratio between Ostu's threshold and the maximum histogram value for every sub-image. Finally, all sub-images are assembled into the resulting image. The method was tested on the dataset which contains different pavement images with very versatile types of cracks. The results showed that the proposed method achieves satisfactory performance, especially in the cases of low signal-to-noise ratio, and is very fast.**

Keywords: Cracks detection, Unsupervised method, Image processing, Image segmentation, Computer Vision

I. Introduction

Image-based pavement health monitoring techniques have a history of more than 30 years [1]. Techniques range from early windshield surveying to manual and/or computer aided analysis of pavement surfaces digital images. Currently, it is common practice to capture and analyze 2D digital images with the high-speed cameras mounted on a specialized or passenger vehicles. The analysis is usually performed off-line on an as-needed basis, or online to obtain current information. Today, many pavement maintenance agencies employ the semi-automated and the fully-automated image-based methods for collection of the pavement state data. For example, the national roads in France are periodically inspected in a three years cycle [2], while in Germany the relevant surface characteristics are inspected in a four year cycle [3].

The analysis of pavement images should reveal various existing distresses on asphalt pavement surfaces. They are usually classified as high- or low-level severity distresses. Former are commonly known as potholes [4]–[6] and cracks, while latter are patches [7], surface deformations and defects. Cracks on asphalt pavement surfaces are the most common distress type. They represent important indication of possible structural damage that may lead to dangerous situations. Many algorithms with different approaches exist in literature [1], [8]–[11], however the advancements in development of accurate, automated, low-cost, effective and reliable image-based pavement cracks detection are still needed.

2D image analysis of any type of distress is a challenging task due to limiting range of information that can be extracted from 2D space. Cracks on images appear as thin, irregular, darker intensity lines, surrounded by strong textured noise. Technologies such as 3D imaging and texture analysis can provide additional information, but they are considered expensive in two ways: use of expensive equipment and very high demand for computational processing. Many supervised algorithms exist in literature [12]–[17], however very few fully unsupervised [18], [19] methods exist.

In this paper, we address the problem of efficient automated pavement cracks detection. We use unsupervised vision-based approach to analyze photometric data from 2D asphalt surface pavements images and extract important information to perform efficient image segmentation. The method consists of two major phases. In the first phase, the original image is sliced into a four sub-images, then arithmetic mean and standard deviation of each sub-image is calculated. In the second phase, we calculate histogram and Otsu's thresholding for each sub-image. Then, we define the smallest ratio between minimal and maximal absolute difference between these two values for all four sub-images. This information is then used to eliminate the background pixels and effectively select pixels that represent cracks. We have performed the comprehensive tests on the real pavement images with cracks at different severity levels. Tests show promising results with very low signal-to-noise ratio and very fast execution time. The method is applied without pre- or post-filtering and without any knowledge about shapes of cracks. The method is suitable for parallel execution since it can take advantage of spatial distribution of crack pixels and it can analyze four sub-images in parallel.

This paper is organized as follows: the related work is briefly reviewed in Section II. In Section III, a new method for detection of high severity distresses on the asphalt pavements has been proposed. The implementation details, data set and experimental results have been presented in Section IV. The paper is concluded with some remarks in Section V.

II. Related Work

There is a substantial number of methods related to cracks detection in literature. In general, they can be classified into four approaches [8]: 1) photometry-based, 2) geometry constraints-based, 3) photometry- and geometry-based, and 4) minimal path-based approaches. We briefly review all of them to provide some background information.

Photometry-based approaches are based on the photometrical information extracted from the 2D color and spatial information. They usually involve determining some threshold value with simple thresholding operation. The threshold value can be determined based on the global [20] or the local image information with adaptive thresholding [21]. Threshold value can be determined based on Otsu's thresholding method, fuzzy logic or genetic algorithms. Majority of photometry-based approaches are unsupervised, however they can contain some supervised learning step, such as is described in [12]–[14], [22], [23].

Geometry constraints-based approaches include topology information at the local scale. There are various methods based on multi-scale analysis for the fine structure extraction. Two examples are based on the watershed method [24] and the wavelet decomposition [15].

Photometry- and geometry-based approaches combine photometric and topology information to represent cracks as contiguous pixels [2], [25]. This approach is considered as computationally intensive, since it relies on the analysis of statistical information present in the image. It also relies on the statistical parameter tuning, which usually requires some supervised knowledge.

Minimal path-based approaches employ existing Dijkstra's and the fast marching algorithm to exploit the high-level geometrical information, while maintaining processing time and memory usage. Even though these approaches are computationally efficient, it is difficult to implement them in an unsupervised manner, because some information (such as location of two endpoints for each path) are required in advance. Nevertheless, several methods [16], [26]–[28] suggest ways to overcome this problem. They all follow the common overall structure: 1) select the darkest pixels belonging to the crack structure, 2) select pairs of the darkest pixels as endpoints and build the minimal path between them. Some methods require manual input, while others are more automatic.

The comprehensive review and analysis of recent crack detection methods is published in [29].

III. Methodology

The overall design of our method is shown in Fig. 1. There are two major phases in the method: a) Image Slicing and b) Cracks Detection. We describe each phase in dedicated subsection.

A. Image Slicing

At first, the original image I is divided into four equal sub-images $S^{(i)}$ as described in equation (1), where $i \in \{1, 2, 3, 4\}$. Four new sub-images are formed assuming conditions in equation (2), where $p(x, y)^{(i)}_{[R,G,B]}$ represents pixel values of (x, y) location for RGB color components of sub-image $S^{(i)}$

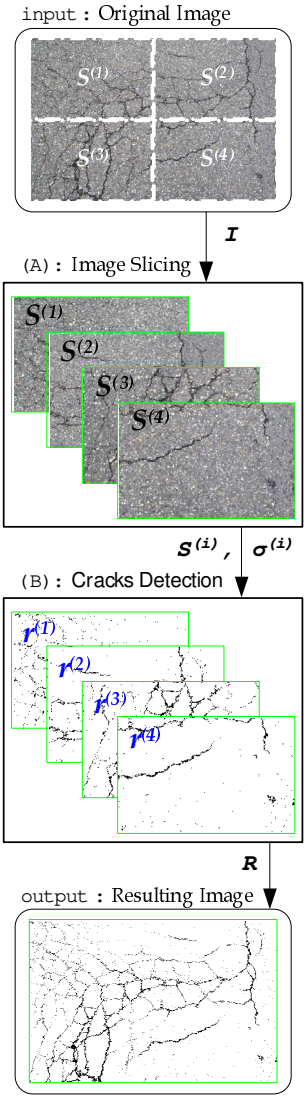

Figure 1: Block diagram of proposed method for cracks detection.

and $P(X, Y)_{[R,G,B]}$ represents pixel values of (X, Y) location for RGB color components of the original image I.

$$S^{(i)} = p(x, y)^{(i)}_{[R,G,B]} \tag{1}$$

$$\begin{gathered} p(x, y)^{(i)}_{[R,G,B]} \subset P(X, Y)_{[R,G,B]} \\ (x, y) \subset (X, Y) \end{gathered} \tag{2}$$

The arithmetic mean μ and the standard deviation σ are calculated by equation 3 and 4, respectively. This information is later used for image segmentation.

$$\mu^{(i)} = \frac{1}{N \times M \times 3} \sum_{x} \sum_{y} \sum_{[R,G,B]} p(x, y)^{(i)}_{[R,G,B]} \tag{3}$$

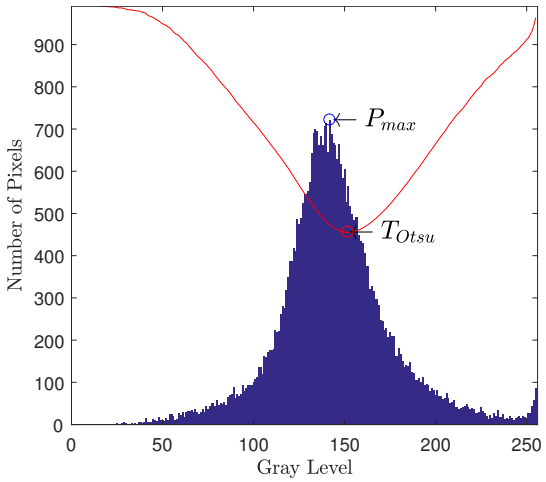

Figure 2: Histogram and Otsu's threshold for the sub-image $I^{(i)}$.

$$\sigma^{(i)} = \sqrt{\frac{1}{3NM-1}\sum_{x}\sum_{y}\sum_{[R,G,B]}[p(x,y)^{(i)}_{[R,G,B]} - \mu^{(i)}]^2} \tag{4}$$

Parameters N, M and $[R,G,B]$ denote height, width and color information of the $S^{(i)}$ sub-image, respectively.

The resulting $S^{(i)}$ and $\sigma^{(i)}$ are passed to the next phase.

B. Cracks Detection

In cracks detection phase, each sub-image $S^{(i)}$ is converted into gray scale image $I^{(i)}$. Then, histogram and Otsu's threshold is calculated for each sub-image $I^{(i)}$, as shown in Fig. 2. The value T_{Otsu} is Otsu's threshold, while P_{max} is the value of the most frequent pixel in the sub-image.

Detection of cracks on an image requires efficient elimination of background pixels. Hence, we define a set of values in equation (5), (6) and (7). Equation (5) describes ratio between minimal and maximal absolute difference between T_{Otsu} and P_{max} of all four sub-images. The values $T^{(i)}_{Otsu}$ and $T^{(j)}_{Otsu}$ are Otsu's thresholds, while $P^{(i)}_{max}$ and $P^{(j)}_{max}$ are gray levels of the most frequent pixels in the sub-images i and j, respectively. The resulting ϵ is the smallest value between the four sub-images.

$$\epsilon = \frac{\min|T^{(i)}_{Otsu} - P^{(i)}_{max}|}{\max|T^{(j)}_{Otsu} - P^{(j)}_{max}|}, \quad \forall i,j = \{1,2,3,4\} \tag{5}$$

Next, we define modified value $\hat{\epsilon}$ to eliminate ϵ values greater than $1/2$ in equation (6). The result is less noise around cracks, since more pixels surrounding cracks are marked as background pixels. Cracks appear thinner and more accurate. This has shown promising results in cases when asphalt pavement is partially covered with water (i.e. after the rainy weather conditions).

$$\hat{\epsilon} = \begin{cases} 1/2, & \epsilon > 1/2 \\ \epsilon, & otherwise \end{cases} \tag{6}$$

In equation (7), we define new constant value δ for image segmentation. The equation was defined based on our test dataset (Section IV.B), however it showed promising results when applied to similar images.

$$\delta = \hat{\epsilon} + \begin{cases} 1.20, & |T^{(i)}_{Otsu} - P^{(i)}_{max}| > 30 \\ 1.17, & 30 \geq |T^{(i)}_{Otsu} - P^{(i)}_{max}| > 1 \\ 1.15, & otherwise \end{cases} \tag{7}$$

Image segmentation is described for two distinct cases: 1) for $T_{Otsu} > P_{max}$ defined in equations (8) and (9), and 2) for $P_{max} > T_{Otsu}$ defined in equations (10) and (11). Image segmentation is performed by a number of conditions. The majority of conditions require previously described values, such as δ, σ, T_{Otsu} and P_{max}.

The selection of background and cracks pixels is carried out in two passes. In the first pass, the values $g^{(i)}_{(x,y)}$ and $h^{(i)}_{(x,y)}$ describe initial selection of background and cracks pixels. This pass selects majority of pixels. In the second pass, the values $\hat{g}^{(i)}_{(x,y)}$ and $\hat{h}^{(i)}_{(x,y)}$ select remaining pixels for both cases.

$$g^{(i)}_{(x,y)} = \begin{cases} 0, & P^{(i)}_{max} < 10 \wedge I^{(i)}_{(x,y)} < 2 \cdot P^{(i)}_{max} \cdot \delta/\sigma^{(i)} \\ & \cdot(T^{(i)}_{Otsu} - P^{(i)}_{max}) \\ 0, & T^{(i)}_{Otsu} - P^{(i)}_{max} \geq 10 \wedge \\ & I^{(i)}_{(x,y)} < (T^{(i)}_{Otsu} - P^{(i)}_{max}) \cdot \delta \\ 0, & T^{(i)}_{Otsu} - P^{(i)}_{max} < 10 \wedge \\ & \sigma^{(i)}/(T^{(i)}_{Otsu} - P^{(i)}_{max}) > 6 \wedge \\ & \sigma^{(i)} > 30 \wedge I^{(i)}_{(x,y)} < \delta \cdot \sigma^{(i)} \\ 0, & T^{(i)}_{Otsu} - P^{(i)}_{max} < 10 \wedge \\ & I^{(i)}_{(x,y)} < (T^{(i)}_{Otsu} - P^{(i)}_{max}) \cdot \delta \wedge \\ & \left(\sigma^{(i)}/(T^{(i)}_{Otsu} - P^{(i)}_{max}) \leq 6 \vee \sigma^{(i)} \leq 30\right) \\ 0, & I^{(i)}_{(x,y)} \geq (T^{(i)}_{Otsu} - P^{(i)}_{max}) \cdot \delta \wedge \\ & I^{(i)}_{(x,y)} < T^{(i)}_{Otsu}/\delta \end{cases} \tag{8}$$

$$\hat{g}^{(i)}_{(x,y)} = \begin{cases} 1, & I^{(i)}_{(x,y)} > T^{(i)}_{Otsu} \\ g^{(i)}_{(x,y)}, & P^{(i)}_{max} < 128 \\ 0, & I^{(i)}_{(x,y)} < T^{(i)}_{Otsu}/\delta \wedge P^{(i)}_{max} \geq 128 \\ 1, & otherwise \end{cases} \tag{9}$$

$$h^{(i)}_{(x,y)} = \begin{cases} 0, & T^{(i)}_{Otsu} < 10 \wedge \left(I^{(i)}_{(x,y)} < 2 \cdot T^{(i)}_{Otsu} \right. \\ & \cdot\delta \cdot 1/\sigma^{(i)} \cdot |T^{(i)}_{Otsu} - P^{(i)}_{max}| \vee \\ & \left. I^{(i)}_{(x,y)} < (P^{(i)}_{max} - T^{(i)}_{Otsu}) \cdot \delta\right) \\ 0, & P^{(i)}_{max} - T^{(i)}_{Otsu} \geq 10 \wedge \\ & I^{(i)}_{(x,y)} < (P^{(i)}_{max} - T^{(i)}_{Otsu}) \cdot \delta \\ 0, & I^{(i)}_{(x,y)} \geq (P^{(i)}_{max} - T^{(i)}_{Otsu}) \cdot \delta \wedge \\ & I^{(i)}_{(x,y)} < P^{(i)}_{max}/\delta \end{cases} \tag{10}$$

$$\hat{h}^{(i)}_{(x,y)} = \begin{cases} 1, & I^{(i)}_{(x,y)} > P^{(i)}_{max} \\ h^{(i)}_{(x,y)}, & T^{(i)}_{Otsu} < 128 \\ 0, & I^{(i)}_{(x,y)} < T^{(i)}_{Otsu}/\delta \wedge P^{(i)}_{max} \geq 128 \\ 1, & otherwise \end{cases} \tag{11}$$

The pseudocode of our algorithm is described in Algorithm 1. The resulting image $r^{(i)}_{(x,y)}$ (lines 14 and 16) depends on the values T_{Otsu} and P_{max}. For the case when $T_{Otsu} > P_{max}$, the resulting image is $\hat{g}^{(i)}_{(x,y)}$, and for the case when $T_{Otsu} < P_{max}$, the resulting image is $\hat{h}^{(i)}_{(x,y)}$.

In the final step, four resulting sub-images $r^{(i)}$ are assembled into one resulting image R.

Algorithm 1 Cracks detection

Require: I - input RGB image
1: **for** $i \leq 4; i \leftarrow i+1$ **do**
2: $S^{(i)} \leftarrow$ Equation (1) ▷ Sub-image $S^{(i)}$
3: $\sigma^{(i)} \leftarrow$ std($S^{(i)}$) ▷ Standard deviation of the RGB sub-image $S^{(i)}$ defined by equation (4).
4: $I^{(i)} \leftarrow$ rgb2gray($S^{(i)}$) ▷ Conversion from RGB to grayscale.
5: $[cntOfPix, p] \leftarrow histogram(I^{(i)})$
6: $P^{(i)}_{max} \leftarrow \arg\max_{p}(cntOfPix)$ ▷ Parameter $cntOfPix$ is number of pixels per gray level p of sub-image $I^{(i)}$.
7: $T^{(i)}_{Otsu} \leftarrow Otsu(I^{(i)})$ ▷ Otsu threshold for the sub-image $I^{(i)}$.
8: **end for**
9:
10: $\delta \leftarrow$ Eq. 7 ▷ Calculation of δ using equation (7).
11:
12: **for** $i \leq 4; i \leftarrow i+1$ **do** ▷ i denotes current sub-image $I^{(i)}$.
13: **if** $T^{(i)}_{Otsu} > P^{(i)}_{max}$ **then**
14: $r^{(i)}_{(x,y)} \leftarrow \hat{g}^{(i)}_{(x,y)}$ ▷ The case when $T^{(i)}_{Otsu} > P^{(i)}_{max}$ defined in equation (8) and (9).
15: **else**
16: $r^{(i)}_{(x,y)} \leftarrow \hat{h}^{(i)}_{(x,y)}$ ▷ The case when $T^{(i)}_{Otsu} \leq P^{(i)}_{max}$ defined in equation (10) and (11).
17: **end if**
18: **if** $I^{(i)}_{(x,y)} > 0$ **then**
19: $r^{(i)}_{(x,y)} \leftarrow 1$ ▷ For every pixels $p(x,y) > 0$ of the sub-image $r^{(i)}$ set value 1 where $I^{(i)}_{(x,y)} > 0$.
20: **end if**
21: **end for**
22: **return** $R = \begin{bmatrix} r^{(1)} & r^{(2)} \\ r^{(3)} & r^{(4)} \end{bmatrix}$ ▷ Returns detected objects (assembled image R).

IV. Implementation and Results

A. Implementation

The method has been implemented in MATLAB version 9.1 (R2016b) with Image Processing Toolbox. The image processing was performed on Intel Core2 2.80 GHz CPU with 8GB of RAM.

B. Dataset

The effectiveness of our method was verified on a new image dataset[1] with 50 selected images from Google search engine (keyword "pavement cracks"). From the review of current literature, there is a lack of publicly available dataset with RGB images that enables standardized way of results verification, as well as comparison of different methods. Hence, we've selected characteristic images ranging from simple uniform cracks to more complex networks of cracks, under the influence of different illumination conditions and different weather conditions (i.e. after rain).

The selected images are collected with different types of cameras from various angles. Currently, it is common practice to analyze data captured with fixed position camera (front or back camera mounted on a specialized or passenger vehicle). This practice enables extraction of common features that can be used for segmentation. However, our method does not depend on extraction of these features, hence it can be used to analyze images from a variety of angles. We believe that this unstructured dataset can be used to examine the true potential of a method.

C. Results

The method was tested on 50 different images from our dataset. We selected images with different conditions, such as presence of lanes, vertical and horizontal cracks, pavement with water remains (i.e. rain), pavement with different shades of color (ranging from dark to light color), recessed asphalt pavement and concrete pavement. The results from selected images are shown in Fig. 3.

The method successfully detects and removes any presence of lanes in an image, even in difficult situations when lane is less visible (Fig. 3. image 1.1) or when it appears very thin due to camera angle (image 1.3b). This is enabled by application of conditions described in equation 9. The results are very promising when there are water remains on the asphalt surface. In this case, the surrounding asphalt pixels appear darker than the non-cracks pixels, hence it is very challenging to detect cracks pixels accurately. Our method detects this conditions and successfully selects only cracks pixels (image 1.1, 2.3, 3.3, 4.1, 5.3). This is enabled by applying conditions described in the equations (5) and (6). One drawback after applying these conditions is unwanted noise in the resulting images for some cases. The noise can be removed by applying simple noise-removal filter in the additional post-processing step.

Different color of the asphalt surface does not affect detection capabilities. For example, images 1.3a and 4.3 show comparable result to any other lighter color asphalt conditions. Color disbalance (image 4.1) and shadows (image 7.3) also do not have any significant impact on the resulting image. In the image 3.1 with concrete pavement, cracks have been detected with the same effectiveness as the images with asphalt pavement. In the remaining images, we showed that the method can achieve promising results whether the image has one continuous crack, a couple of interconnected horizontal and vertical cracks, or a network of many cracks.

The average execution time on the given dataset for average image size (580×800) was 338.97 ms. The method has low computational cost when compared to supervised methods and it is fast.

In Table I, we provide quantitative results for our method. The method's accuracy has been evaluated based on Precision, Sensitivity and F-Score. We compare our results to pixel-based results. Our method shows significant improvements when compared to all unsupervised methods in [17], especially for cases when there are water remains present in asphalt surface pavements (shown as bold in Table I).

[1]The dataset is available at http://people.etf.unsa.ba/~aakagic/cracks_detection/

TABLE I: Quantitative analysis of results.

	Water Remains	Dry Condition	Average
Sensitivity (Recall)	**77.82**%	77.73%	77.77%
Specificity	98.62%	98.97%	98.79%
Precision	**77.72**%	76.83%	77.27%
Accuracy	97.51%	96.75%	97.13%
F-Score	**77.70**%	74.49%	76.09%

V. Conclusion

In the recent years, computer vision has accelerated innovation process across multiple industries, from self-driving cars, advanced robotics, surveillance to facial recognition software. Development of new methods for various scientific fields is needed to achieve automatic visual understanding of useful information from a single image or a sequence of images. For public infrastructures visual inspection, it is common practice to collect data automatically with specialized vehicles, and to evaluate asphalt surface characteristics and conditions manually. Hence, time span between acquisition of data and extraction of useful information from this data can be up to several months. This is very undesirable.

In this paper, we proposed new unsupervised vision-based method for automated pavement cracks detection based on analysis of photometric information from 2D images. The method was tested on 50 images with different selection criteria. The results indicate that the method can be used for rough estimation of cracks on asphalt surface pavement. It is unsupervised method, hence it does not require existence of great amount of data needed for training. The method is simple and efficient. Its execution time is very fast. Satisfactory performance is achieved, especially in the case of low signal-to-noise ratio images.

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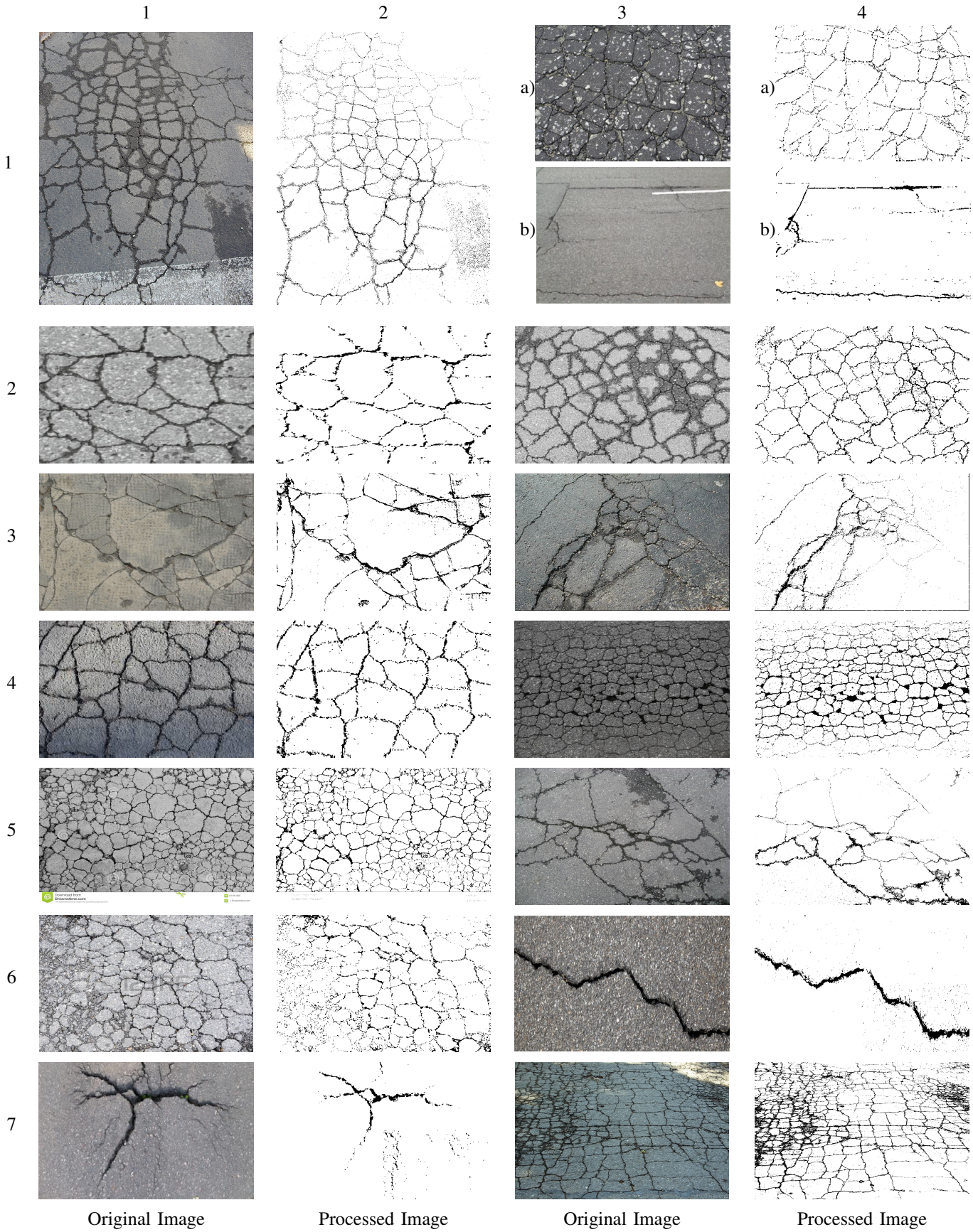

Figure 3: Cracks detection capabilities of our method showing *Original* and *Processed* images - detected cracks.

An Overview of Thermal Face Recognition Methods

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***Abstract* – The popularity of surveillance systems grows as well as a need for better security systems particularly in a bad lighting conditions or at night. The aim of a security system is to collect as many details as possible to enable a better recognition of persons. In this paper, a comparison of representative thermal face recognition methods will be given, emphasizing their strengths and weaknesses. Then, trends in the development of surveillance and security systems will be outlined such as fusion of visible and thermal images and use of convolutional neural networks. Also, existing challenges of thermal facial recognition and its applications in a real world will be pointed out.**

Keywords: thermal facial biometrics, thermal imaging, face recognition, surveillance, access control

I. INTRODUCTION

Video surveillance systems are placed everywhere, and a need for a better security system is growing. Today, cameras monitor banks, airports, schools, important or popular places where people gather or hang out, border crossings and all protected areas and infrastructure objects.

The video surveillance industry is not new but has significantly changed in last 20 years when high-quality digital cameras and network-based video surveillance systems were used [1]. Earlier video surveillance systems were very dependent on human operator who had to monitor the video footages of protected areas and detect a presence of persons in the monitored area. Also, the operator should recognize each authorized person and accordingly approve or reject access. Later on, surveillance systems are associated with biometric systems that took the role of recognizing authorized/ unauthorized persons and of access permission [2].

Most biometric systems use standard video cameras that capture face or palm images in the visual part of the spectrum [3]. However, because of an increasing demand for a better security systems and for a better surveillance in night-time and poorly illuminated areas, the thermal cameras are nowadays included into the system, Fig.1.

Fig. 1 Application of thermal cameras in real-world applications [4]

The thermal infrared (IR) camera captures the heat emitted by the subject of the surveillance and forms an image using IR radiation, so-called thermogram. In surveillance systems these images are used for object detection (e.g. ability to distinguish an object from the background), recognition (e.g. ability to classify an object in one of the classes like human, animal, vehicle) and ability to describe monitored object in details (like a man with a coat, a woman with a hat, a bear, …). It is a non-intrusive way of identifying a person since the camera can capture face from certain distances away. The identification or verification of people based only on their thermal information is not an easy task to accomplish, but thermal face biometrics can contribute to that task.

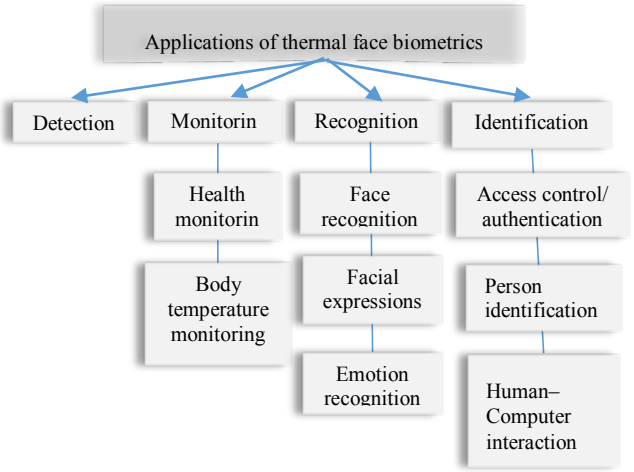

Fig. 2 Thermal biometrics applications

Application areas of thermal face biometrics are broad including identification and access control to secure computer networks and facilities such as government buildings, authentication for secure banking and financial transactions, automatic screening at airports for known terrorists, and video surveillance usage, recognition of face expression for high-end security applications, monitoring body temperature for medical diagnostics, etc., Fig. 2. Due to the omnipresence of surveillance cameras, there is a concern about privacy protection, so de-identification methods are developed in parallel [6].

In this paper, an overview of thermal facial features and methods that have proven to be successful in detection and person recognition and verification will be given. In Section II characteristic of infrared images are highlighted. Kinds of features commonly extracted from facial thermal images and comparison of thermal recognition methods are given in Section III. In Section

IV. commonly used datasets in terms of IR band usage and application purposes are listed. Research trends such as use of CNN, and fusion of visible and thermal images as well as remaining challenges in facial thermal biometrics and its applications in real-world applications are pointed out in Discussion and Conclusion.

II. INFRARED THERMAL IMAGING BASICS

Infrared (IR) thermal sensors have the capability of imaging scenes and objects based upon either the IR light reflectance or upon the IR radiation emittance. The IR radiation is an electromagnetic radiation emitted in proportion to the heat generated/ reflected by an object and, therefore IR imaging is referred to as thermal imaging. The wavelengths of IR are longer than those of visible light, so IR is invisible to humans [6].

The IR spectrum can be divided given the wavelength (Fig. 3) in the following bands according to [7]:

- Near-Infrared - NIR, ranges from 0,7 to 1 μm;
- Short-Wave infrared - SWIR, ranges from 1 to 3 μm;
- Mid-Wave infrared - MWIR, ranges of 3 to 5 μm;
- Long-Wave infrared - LWIR, ranges from 8 to 14 μm;
- Very Long-Wave infrared - VLWIR, in a range greater than 14 μm.

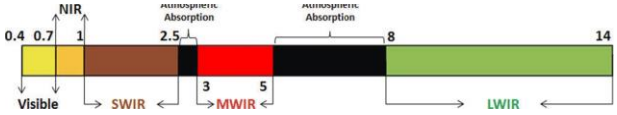

Fig. 3 Electromagnetic spectrum with illustrated IR segments wavelengths in μm [7]

The NIR and SWIR bands are sometimes referred to as "the reflected infrared radiation" and MWIR and LWIR bands as "thermal infrared radiation". The latter does not require an additional source of light or heat since the thermal radiation sensors can form an image of the environment or object solely by reading the emission of thermal energy of observed objects in the scene, Fig. 4. Since IR sensors depend on the amount of emission of the thermal energy of a recorded object, they are, unlike the visible light cameras, invariant to illuminating conditions, robust to a wide range of light variations [4, 8] and weather conditions, and so can operate in a total darkness.

Fig. 4 Thermal vs. visual image (www.multicopterwarehouse.com)

On the other hand, IR cameras are very sensitive to the variations of surrounding's temperature and provide fewer details than visible light cameras since color captured in visible spectrum provides much more information and is easier to interpret.

Thermal face images can be captured under SWIR, MWIR and LWIR bands. Differences between the face image in the visual and IR bands are presented in Fig. 5. Lighter areas are with higher temperature (eyes, lips) and it is obvious that level of detail on face image decreases with the wavelength increase, that is, the most details are in the image captured with the visual camera, and the least with the LWIR cameras. To achieve full invariance to lighting conditions, the LWIR band is mostly used [4, 8].

Fig. 5 A face simultaneously imaged in the (a) visible spectrum, 0.4 - 0.7 μm; (b) short-wave infrared, 1,0 – 3,0 μm; (c) mid-wave infrared, 3,0 – 5,0 μm; (d) long-wave infrared, 8,0-14,0 μm [8].

Furthermore, when IR images are captured in high resolution, the anatomical information, such as the structure of the blood vessels and the tissue on the face can be extracted from IR imaging (Fig. 6).

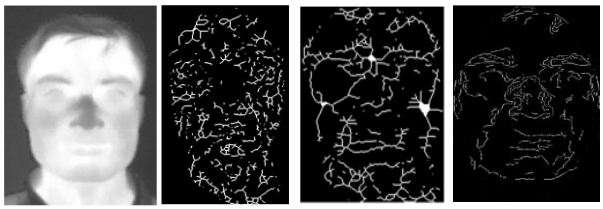

Fig. 6 Face grayscale thermal image (a), blood perfusion obtained transforming a medial axis on bit-plane (b); morphological gray level erosion and medical axis transform (c); result of Sobel operator (d) [9]

Due to the difference between visual and thermal images, the features and traditional methods for face recognition had to be tailored to properties of thermal images in order to achieve better recognition performance.

III. THERMAL FACE RECOGNITION METHODS

The human face is a biometric feature that can be used in security systems for person identification or authentication. The main challenge of the face recognition methods is to accurately match the input face with the face image of the same person already stored in the system database. In case of thermal face recognition, methods deal with facial thermograms. A related task and a prerequisite for face recognition is the detection of a face in the image. For the purposes of thermal face recognition, a thermal face image should be represented with biometrics features that highlight thermal face characteristic and are compact and easy to use for classification. Since thermal face images provide different details than images in visible spectrum it was necessary to define features that can be used in thermal biometrics.

Recently, a comprehensive survey on thermal face recognition methods has been published [10]. The authors analyze the influence of local and global descriptors on recognition performance. Some of the used descriptors were Local Binary Pattern (LBP) [11], the WLD (Weber

Linear Descriptor) [12], the GJD (Gabor Jet Descriptor) [13], SIFT (Scale-Invariant Feature Transform) [14] and SURF (Speeded Up Robust Features) [15] and the best results were reported with SIFT descriptor. In [16] a wide range of methods for facial recognition on the thermal images are presented and grouped as: Appearance-Based Methods, Feature-Based Methods, Multi-Spectral and Hyper-Spectral Methods, Multimodal Methods and other Approaches based on geometric invariant moments [17], elastic graph matching [18], isotherms [19], and other methods [20-22]. In [23] the authors give an overview of different approaches for the face recognition using fusion of thermal and visible images, heterogeneous face recognition using concatenated features, as well as application of deep neural networks for the thermal face recognition.

Here, general approaches to thermal face recognition are pointed out, with their strengths and weaknesses. Representative recognition methods are compared and difference highlighted in terms of IR band, environment conditions, features, datasets, application of recognition methods and performance.

Problems of intra-spectral and cross-spectral face recognition in different environments are presented in [7, 23]. The authors have tested the performance of face recognition in different IR bands vs. visible face images as well as between different IR bands when conditions of environment and distance change. The authors have demonstrated the feasibility of intra-spectral and cross-spectral matching, e.g. a 100% accuracy was achieved with visible vs. SWIR band under controlled conditions at a distance of 30 m. They also showed that with increasing recording distance, the recognition rate decreases regardless of IR band used, especially when the distance is greater than 90 m.

In [24], experiments were conducted on the multispectral images from the Equinox multimodal facial image dataset (Visible, SWIR, MWIR, LWIR) [25] and Laval University Multispectral Database (Visible, NIR, MWIR, LWIR), developed by the authors. The face images contain variations like facial expressions, pose, eyeglasses, beard, etc. To reduce sensitivity to noise, illumination conditions and facial expressions, texture features are extracted from thermal images. Face regions are represented by local binary descriptors (LBP) and local ternary descriptors (LTP), and simple differential LTP (DLTP).

Authors have reported the best accuracy (96%) on SWIR images from Equinox dataset when a combination of LBP descriptors and LLE methods for dimensionality reduction is used. The Laval University Multispectral Database better shows real conditions, so the best result (86%) are achieved with LBP in MWIR band. Reported results have shown that texture descriptors are a good solution for multispectral face recognition system, particularly in case of illumination changes and facial expression variations.

The effectiveness of LBP descriptors for face recognition purpose on LWIR images from Equinox dataset was presented in [26]. LWIR images are insensitive to the illumination conditions but are sensitive to the noise. Several scenarios were tested in experiment e.g. the presence of glasses, different facial expressions, etc. A satisfactory recognition rate of 97,3% was reported even with a presence of glasses, and without image pre-processing. A Bayesian probabilistic framework and SVM are used for the thermal face detection and identification in [27]. The experiment was conducted on images from Equinox and Laval University multispectral face databases. The best-reported result was 95% obtained with LDA method in LWIR band.

In [28] images were collected recording 24 persons with two facial expressions (normal, smile) at a distance of approx. 2m and from three viewpoints (frontal, 45°, profile), giving a total of 288 images. Experiments were conducted applying Eigenfaces and have reported 96% of identification accuracy for frontal face and 100% for profile images.

Approach for human face recognition that uses veins structure in thermal face image is proposed [29]. The topology of the vascular network depends on the genetic and physical characteristics of each person (e.g. face skin, fat deposits). To be used as a biometric feature, a facial vascular network should be segmented first using common segmentation methods such as region growing or directional anisotropic diffusion (DAD). In [29] authors stated that facial veins structure provides a unique thermal face signature similar to a fingerprint. For classification, a five-layer feed-forward back propagation neural network has been used, and the highest recognition accuracy of 95,24% was achieved when bit-plane slicing and medial axis transform were used for extraction of vein structure. The main advantage of this approach is a simple implementation, independent of face geometry. The disadvantage is that the face should be taken at short distances and with a uniform background.

Regions of the thermal image with heat imbalance present a physiological information. A heat imbalance arises as a result of the convection heat effect of blood flow in the main face surface vessels. The human face temperature is uniform and ranges from 35.5°C to 37.5°C in healthy people, providing a consistent thermal signature unique for each person. A thermal face pattern can be obtained with segmentation and morphological operations (e.g. dilatation, erosion, reconstruct, …).

In [29] a body heat transfers and Penn's equation [30] were proposed to improve the performance of IR face recognition. Application of Penn's equation converts the thermal information into blood perfusion rate, which is a discriminative facial biological feature of the face image. Similarly, in [31] a face recognition system RIFARS was proposed. Reported recognition accuracy was up to 98% and one of the key reason for high performance was the robustness to variable ambient temperatures.

The authors in [32] stated that face recognition on thermal images should focus on changes in temperature on facial blood veins. Furthermore, they pointed out that these temperature changes can be observed as texture features and have proposed Haar wavelet transform for extracting the low-frequency regions. Experiments were conducted on Terravic database [33], and the best-reported recognition accuracy was 95%.

A significant problem in face thermal biometrics is the high impact of emotional and health status of a person on body temperature and thus thermogram. The solution for this disadvantage is proposed in [34] where infrared thermal imaging was combined with an optical recording. Similarly, in [35], a comparative analysis of the thermal and optical images was conducted but authors have used one sensor capable to simultaneously record optical and thermal images (CCD and LWIR microbolometer), unlike the previous methods where images were taken by two separate sensors. Authors have shown that eigenfaces, and ARENA [36], perform differently when brightness on visual images was changed while on the thermogram there was no impact.

A whole series of weaknesses regarding the use of thermograms for face recognition is given in [37]. Some of the mentioned shortcomings are the high cost of the thermal imaging system, low-resolution of thermal sensors, high noise in the images and high sensitivity on the glass, as the glass is an obstacle to recording thermograms due it's reflectivity. In [38] authors deal with the problem of thermal face recognition with existing glasses. Glasses hide some parts of the face and negatively influence recognition accuracy. Proposed system besides common fazes as preprocessing, face alignment (eyes and lips), detection and extraction of facial features detects glasses. Because of the symmetry of the face, only requires detection of the left part of the face (with and without glasses in thermal images). Reported results of the 1 to N comparison are best when the fusion of visual and thermal images is performed with the low-pass filter. With thermal images reported result is 82% while in case of fusion achieved recognition rate is 90% without glasses and 97% with glasses.

The traditional methods for thermal face recognition mainly concentrate on the hand-crafted features that require significant efforts for selection and extraction of features and usually has relatively lower recognition rate. In [39] a convolutional neural network (CNN) architecture for thermal face recognition is proposed. Similar architectures for thermal face recognition based on CNN followed [40].

Experiment results on RGB-D-T face database [41] show that proposed CNN architecture achieves higher recognition rate compared with the traditional features such as LBP and HOG. In [42] the authors presented a NIRFaceNet, Fig. 7, that is modified from GoogLeNet, but has a more compact structure (only 8 layers and without fully connected layers) and achieves identification rate of 98,48%.

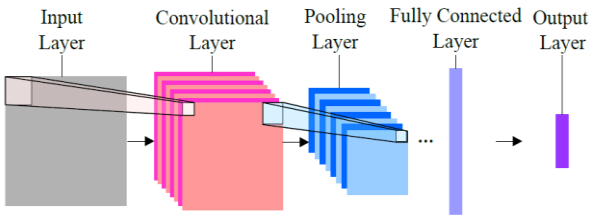

Fig. 7 Structure of a convolutional neural network (CNN) [42]

The use of CNN and Fast Wavelet Transform (FWT) is presented in [43]. An ensemble of classifiers and feature extractors is explored in [43], to reduce errors in face recognition from poor lighting and spoofing. They used CNN tools from, Rasmus Berg Palm's, deep learning tool box [44] and formed a deep neural network of 6 layers; an input layer, 2 convolution layers, with 2 subsampling layers and an output layer. Achieved results showed a mean percentage classification error of 0.84%, on Terravic Facial Infrared Database [45]. When the images where pre-processed with PCA, LDA and KNN, a mean percentage classification error of 0.68% was achieved.

In [46] deep neural network Inception v3 [47] was used for face detection and tracking of elderly people and patients from low resolution thermal images acquired with a portable camera (Lepton thermal camera). For the training 11714 thermal face images recorded with Lepton thermal camera and 73905 other thermal images were used. The best reported result of true positive are 89.2%.

To increase reliability of biometrics systems, research trends are fusion of visible and thermal images, cross-spectral, multi-modal and heterogeneous systems [48]. In [49] a Tensorflow framework for the face recognition called TV-GAN (Thermal-to-Visible Generative Adversarial Network) is presented that is able to transform thermal face images into their corresponding VLD (Visible Light Domain) images in order to maintain an identity information sufficient enough for VLD face recognition models.

In [50] authors have explored if features from a CNN pre-trained on visible spectrum face images can be used to perform heterogeneous face recognition. They explored different metric learning strategies to reduce the discrepancies between the different modalities. Experimental results showed that CNNs trained on visible spectrum images can be used for heterogeneous recognition with near-infrared images and sketches and reported results that are state-of-the-art.

IV. THERMAL FACE IMAGE DATASETS

In the evaluation of recognition methods, significant role plays datasets that are used for training and testing of the model. Datasets differ according to IR band, quality of thermal cameras, recording distances, number of recorded subjects, setup of recording environment, illumination variation, pose changes, facial expressions, glasses, etc. Some authors have created their own datasets. For example, in [7] a dataset is created for each IR band and for visual images with different recording setup and different time period. SWIR images are recorded in controlled and semi-controlled indoor and uncontrolled outdoor environment with distances from 60 to 400 m. MWIR images were created indoor using FLIR camera at a distance of approx. 1,95 m during 20 days. The same distance of 1,95 m but from three viewpoints (frontal, 45° and profile) was used in [10] for SWIR data set. Even smaller recording distance of 0.62 m was used in [9] for the recording of 17 persons sitting on the chair.

IRIS Thermal/Visible Face Database [37], Equinox [25] and Laval University dataset [24] become benchmark facial image datasets (Visible, SWIR, MWIR, LWIR) with images recorded under several scenarios - with the presence of glasses, different facial expressions, etc. A concise representation of representative thermal face datasets with respect of IR band coverage are given in Table 1. In Table 2. datasets for thermal face expression task are listed.

Table 1. Thermal face biometrics datasets with respect of IR band coverage

NIR	SWIR	MWIR	LWIR
	Laval University multispectral face database [24]		
West Virginia University dataset: [7] (NIR: 30- 120 m distance, outdoors, at night time, time period of 20 days; SWIR: controlled and semi-controlled environment, 50 subjects, over two sessions; distances of 50 m and 106 m; uncontrolled outdoor environment, day and night, 16 uncooperative subjects, multiple sessions, distances from 60 to 400 meters; MWIR: live face capture configuration, distance 2 m, indoors, 50 subjects, 15 full frontal face)			[31] 20 persons, indoor/outdoor; face variations: front, left, right; glasses, hat
CASIA database: [51] 197 persons, 3940 pictures, different head poses, glasses, different expressions.	**Cincinnati Electronics** [27] distance: 1,95 m; head poses; 288 images	**IRIS dataset**: [37] 30 subjects, 4228 pairs of thermal/visible images, 11 roughly matching poses; illumination variations	

Table 2. Thermal face expression datasets

Dataset	IR band	Description
Equinox database [24, 26]	SWIR-LWIR	controlled conditions, illumination changes, facial images with and without eyeglasses, 91 subjects 4-second (40 frames) video sequence, subjects pronounced the vowels; facial expressions: smile, frown, surprise; 3 positions: frontal, left lateral, right lateral.
RGB-D-T face dataset [41]		51 persons, 900 images/subject, total 45900 images, controlled, varying rotation, illumination and facial expression
NIST database [34]	Visible and LWIR	image pairs; total: 25.000 frames from 91 subjects; face expressions: pronounced the vowels, smile, frown, surprise, with and without glasses
University of Notre Dame: [44]	LWIR	82 subjects, 2,293 images; face expression: neutral, smiling, laughing; lighting change; time-lapse
[31]	LWIR	76 individuals; different pose and facial expression: happy, surprise, fear, etc.
[9]	LWIR	Distance 0,62 m; 17 persons, emotion type without changing head orientation, different views

Discussion

In reviewed methods authors have experimented with all IR bands. Presented results show that recognition rate depends on various parameters (facial features, classification algorithms, dimensionality reduction methods, etc.). The highest recognition accuracy was achieved in SWIR band (100% for frontal face image) in controlled indoor conditions and with fully cooperative persons. Most methods use LWIR band since energy emitted by the human body is highest in that band and reported accuracy rate comes up to 95 %, even with pose change and different illuminate conditions.

The main advantage of thermal face biometrics and thermal images is invariance to illumination, as they can be recorded in dark and under reduced visibility conditions. But, the limitation is small recording distance since accuracy rate decreases with the increase of distance. Other drawbacks are glass sensitivity and impact of health and emotional state on the thermal images. A proposed solution to overcome these problems in facial thermal biometric is a fusion of visible and IR images and use of CNNs.

V. CONCLUSION

The use of IR thermal imaging for thermal facial biometrics has attracted recent research and commercial attention as an alternative to visual spectrum based security systems. Unlike the visible light cameras, IR thermal sensors could facilitate greater robustness to illumination changes and can operate in dark environments. Also, IR images can capture new anatomical and physiological face information, such as a structure of the blood vessels and facial vascular network and thermal face signature, that can be used as a unique biometric feature for each person.

Due to the special features of the IR image, two research directions of developing facial recognition methods can be determined. The first relates to the use of physiological features (e.g. vascular networks), and the other to use of multi-modal fusion of complementary data types (e.g. visible and IR). Both research directions are still in their early stages, but the use of CNN and deep learning will further contribute to improving the results.

Achieved an accuracy of thermal face recognition methods are rather high but the need for increased accuracy still exists since in security systems high accuracy is essential because even the smallest error can impact on national security, access control, and similar threats.

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Application of firefly and bat algorithms to multilevel thresholding of x-ray images

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Abstract - Multilevel image thresholding is a challenging digital image processing problem with numerous applications, including image segmentation, image analysis and higher level image processing. Although, threshold estimation based on exhaustive search is a relatively straight forward task, it can be computationally very expensive to evaluate optimal thresholds when the number of threshold levels is large. In this paper, a metaheuristic approach to multilevel thresholding of x-ray images has been examined. Specifically, firefly and bat algorithms are used in the conjunction with Kapur's entropy, Tsallis entropy and Otsu's between-class variance criterion to estimate optimal threshold values. The performance of various image segmentation strategies have been evaluated on a dataset of x-ray images. The simulation results show that the bat algorithm in conjunction with Otsu's objective function offers the best X-ray image segmentation strategy. Out of all considered strategies, this multilevel thresholding approach to image segmentation produces the highest PSNR and SSIM values as well as fast execution times.

Keywords— image segmentation, multilevel thresholding, bat algorithm, firefly algorithm, Kapur's entropy, Otsu's between-class variance, Tsallis entropy.

I. INTRODUCTION

Image segmentation is defined as the partitioning of an image into non-overlapping, constituent regions having some similar features and properties. The principal objective here is to enable simplification in image representation and facilitate understanding and further analysis of an image. Image segmentation has numerous applications, including medical imaging analysis and medical diagnosis [1, 2], object detection [3], and various recognition tasks such as optical character recognition [4] and fingerprint recognition [5]. Traditionally, image segmentation is a very challenging field of digital image processing. Thus, over the years various approaches to image segmentation have been developed, such as threshold based segmentation, edge based segmentation and region based segmentation.

Edge-based methods rely on the presence of discontinuities between distinct image regions [6]. Firstly, these methods detect image edges and subsequently these edges are connected together to form boundaries in-between different image segments. Pixels that are not separated by an edge are deemed to belong to the same class of pixels. Sobel, Canny and Robert's operators are commonly employed to detect image edges.

The region based segmentation methods partition image into areas on the basis of some image property [7]. Segmentation process ensures that the pixels within one image region share some image property. These image properties can include intensity values from original images, texture, spectral profiles, etc.

Threshold based segmentation includes two specific problems, bi-level thresholding and multilevel thresholding. Here, the term bi-level thresholding refers to the process of segmenting an image into two classes (e.g. separate the object of interest from background), and multilevel thresholding, where an image is segmented into more than two classes. A specific class defines a range of pixel intensity values in-between two adjacent threshold values.

In general, there are two approaches to thresholding, local thresholding and global thresholding. In local thresholding, specific threshold values are assigned to each pixel on the basis of information contained in a local neighborhood of that pixel. In contrast, global thresholding assigns a fixed set of threshold values that are applied to the entire image.

Furthermore, thresholding methods can be categorized as either parametric or nonparametric. The parametric approach entails estimation of statistical parameters to describe the distribution of each class. On the other hand, the nonparametric approach abandons the idea of modeling class distributions, but instead uses some objective function to ascertain threshold values. Examples of commonly used objective functions include Otsu's between-class variance function [8], Kapur's entropy [9] and Tsallis Entropy [10]. In practice, the nonparametric methods tend to be more robust and computationally less expensive than the parametric methods.

The complexity of exhaustive search in the context of multilevel threshold estimation problem increases exponentially with the number of thresholds. In order to overcome this problem, metaheuristic algorithms can be applied to enable faster threshold estimation. Some prominent examples of metaheuristic algorithms include particle swarm optimization [11], cuckoo search [12], artificial bee colony inspired algorithms [13, 14], bat algorithm [15], firefly algorithm [16], etc.

In this paper, the problem of multilevel image thresholding of x-ray images based on two prominent metaheuristic algorithms, bat algorithm and firefly algorithms is examined. The study is based on three different objective functions, namely Otsu's between-class variance function [8], Kapur's entropy [9] and Tsallis

Entropy [10]. The quality of image segmentation is evaluated based on attained fitness function values, execution time, peak signal-to-noise ratio (PSNR) and the structural similarity index (SSIM).

The paper is organized as follows. Section II examines three different objective functions, specifically Kapur's entropy, Tsallis entropy and Otsu's between-class. Bat and firefly algorithms are presented in Section III. Section IV presents and discusses simulation results. Finally, Section V concludes the paper.

II. Objective Functions

A. Kapur's entropy

The Kapur's entropy for an image I with intensity levels {0, 1,…, L-1}, and k thresholds, specifying k+1 image classes, is defined as

$$f(t_0, t_1, \dots, t_k) = \sum_{j=0}^{k} H_j \tag{1}$$

$$H_0 = -\sum_{i=0}^{t_0-1} \frac{p_i}{\omega_0} ln \frac{p_i}{\omega_0}, \quad \omega_0 = \sum_{i=0}^{t_0-1} p_i$$

$$H_1 = -\sum_{i=t_0}^{t_1-1} \frac{p_i}{\omega_1} ln \frac{p_i}{\omega_1}, \quad \omega_1 = \sum_{i=t_0}^{t_1-1} p_i \tag{2}$$

$$H_k = -\sum_{i=t_{k-1}}^{L-1} \frac{p_i}{\omega_k} ln \frac{p_i}{\omega_k}, \quad \omega_k = \sum_{i=t_{k-1}}^{L-1} p_i$$

Here, p_i denotes the probability of intensity level i. The set of optimal thresholds $\{t_0, t_1, \dots, t_k\}$ maximize the Kapur's entropy.

B. Otsu's between-class variance

Otsu's approach selects the set of optimal threshold values that minimizes the weighted sum of within-class variances. Consequently, this threshold set minimizes the between-class variance. The Otsu's objective function f_O, is defined as

$$f_O(t_0, t_1, \dots, t_k) = \sum_{j=0}^{k} \sigma_k \tag{3}$$

$$\sigma_0 = \omega_0 \left(\sum_{i=0}^{t_0-1} \frac{ip_i}{\omega_0} - \sum_{i=0}^{L-1} ip_i\right)^2, \omega_0 = \sum_{i=0}^{t_0-1} p_i$$

$$\sigma_1 = \omega_1 \left(\sum_{i=t_0}^{t_1-1} \frac{ip_i}{\omega_1} - \sum_{i=0}^{L-1} ip_i\right)^2, \omega_1 = \sum_{i=t_0}^{t_1-1} p_i \tag{4}$$

$$\sigma_k = \omega_k \left(\sum_{i=t_{k-1}}^{L-1} \frac{ip_i}{\omega_k} - \sum_{i=0}^{L-1} ip_i\right)^2, \omega_k = \sum_{i=t_{k-1}}^{L-1} p_i$$

C. Tsallis Entropy

Non-extensive entropy concept of Tsallis, f_T is defined as:

$$f_T(t_0, t_1, \dots, t_k) = \sum_{j=0}^{k} S_j + (1-q) \prod_{j=0}^{k} S_j \tag{5}$$

$$S_0 = \frac{1-\sum_{i=0}^{t_0-1} \left(\frac{p_i}{\omega_0}\right)^q}{q-1}, \quad \omega_0 = \sum_{i=0}^{t_0-1} p_i$$

$$S_1 = \frac{1-\sum_{i=t_0}^{t_1-1} \left(\frac{p_i}{\omega_1}\right)^q}{q-1}, \quad \omega_1 = \sum_{i=t_0}^{t_1-1} p_i \tag{6}$$

$$S_k = \frac{1-\sum_{i=t_{k-1}}^{L-1} \left(\frac{p_i}{\omega_k}\right)^q}{q-1}, \quad \omega_k = \sum_{i=t_{k-1}}^{L-1} p_i$$

The optimal thresholds maximize Tsallis entropy. Here, q represents the measure of degree of nonextensivity of the system known as Tsallis parameter or entropic index.

```
Objective function f(x),  x = (x_1, x_1, ..., x_D)
Initialize a population x_i and v_i (i = 1,2, ..., N)
Initialize pulse rates r_i and the loudness A_i
Find the best solution x*
while (t < MaxGeneration)
   bat movement by adjusting frequency/velocities/ location
   if (rand>r_i)
      Select a solution among the best solutions
      Generate a local solution around the selected best
   Endif {local search}
   Evaluate the new solution
   if (rand < A_i and f(x_i) < f(x*))
      Accept the new solution
      Increase r_i and reduce A_i
   endif {replacement}
   Rank the bats and find the best solution x*
end while
```

Figure 1. Pseudocode of bat algorithm

III. Metaheuristic algorithms

A. Bat algorithm

Bat algorithm is inspired by the behavior of microbeats and their ability to use echolocation to detect pray and avoid obstacles [15]. All bets use echolocation and know their surroundings. Bets automatically adjust wavelength of the pulses, as well as the pulse rate and loudness. The pseudo code of the bat algorithm is given in Fig. 1. The initial population of bats and their corresponding velocities are generated randomly. The dimensionality of some i^{th} candidate $\mathbf{x}_i$ and the size of bat populations are denoted as D, and N, respectively. After all candidates are evaluated, the best solution is determined, x*. The movement of bats is associated with physical rules of echolocation and is described as:

$$f_i = f_{min} + (f_{max} - f_{min})\beta$$
$$\mathbf{v}_i^{t+1} = \mathbf{v}_i^t + (\mathbf{x}_i^t - \mathbf{x}^*) f_i \tag{7}$$
$$\mathbf{x}_i^{t+1} = \mathbf{x}_i^t + \mathbf{v}_i^{t+1}$$

The frequency factor, f_i, controls the step size of the bat movement. Recommended frequency bounds are $f_{min} = 0$ and $f_{max} = 2$. The term β is a random value drawn from a uniform distribution over the closed interval [0, 1]. The local search corresponding to exploitation phase is defined as

$$\mathbf{x}_{new} = \mathbf{x}_{old} + \epsilon A^t \tag{8}$$

Here, $\epsilon \in [-1, 1]$ is a random number drawn from a uniform distribution and A^t denotes the average loudness across candidates at the current computational step. Increase in pulse rate and decrease in pulse loudness are defined as

$$A_i^{t+1} = \alpha A_i^t, \; r_i^{t+1} = r_i^0 [1 - e^{-\gamma t}] \tag{9}$$

Her, α and γ are constants. The former constant controls the convergence rate in a similar manner as the cooling factor does in simulated annealing. Subsequently the beat solution is memorized and the procedure is iteratively repeated until a termination criteria is reached.

Objective function $f(x)$, $\mathbf{x} = (x_1, x_1, \ldots, x_D)$
Initialize a population of fireflies $\mathbf{x}_i$ $(i = 1,2, \ldots, N)$
Define light absorption coefficient γ
while (t < MaxGeneration)
  for i = 1 : N all N fireflies
    for j = 1 : N all N fireflies
      if $(I_j > I_i)$
        Move firefly $\mathbf{x}_i$ towards firefly $\mathbf{x}_j$
      endif
      Evaluate new solution and update light intensity
    endfor j
  endfor i
  Rank the fireflies and find the best solution x*
end while

Figure 2. Pseudocode of firefly algorithm

B. *Firefly algorithm*

Firefly algorithm is inspired by the behavior of tropical fireflies [16]. The ability to generate flashing light through the process of bioluminence is the most distinguishing characteristic of fireflies. The flashing light is used as a primary courtship signal to attract mates. Also, the attraction between the tropical fireflies is related to the intensity of light $I(r)$, which in turn is inversely proportional to the square of the distance r. Furthermore, the air absorption makes the light weaker with increasing distance. The overall behavior of fireflies is too complex to be faithfully represented by some global optimum search algorithm. Thus, some simplifications are put forward for the benefit of algorithm efficiency. All fireflies are unisex and their attraction is proportional to their brightness. The brightness of a firefly is described by some objective function. The pseudo code of the firefly algorithm is given in Fig. 2. Here, D and N denote the dimensionality of solution candidates and the population size respectively. The attractiveness of a firefly, β, is a monotonically decreasing function with respect to distance, r:

$$\beta(r) = \beta_0 e^{-\gamma r^2} \tag{10}$$

The distance between two fireflies r corresponds to their Euclidian distance. The terms β_0 and γ denote the attractiveness at r = 0 and light absorption coefficient respectively. The movement of a firefly $\mathbf{x}_i$ due to attraction to firefly $\mathbf{x}_j$ is modeled as follows:

$$\mathbf{x}_i = \mathbf{x}_i + \beta_0 e^{-\gamma r^2}\left(\mathbf{x}_j - \mathbf{x}_i\right) + \alpha\epsilon_i \tag{11}$$

Here, α denotes the randomization parameter, while the term ϵ_i is a vector of random numbers drawn from uniform distribution U(-0.5,0.5).

IV. Experiments and Discussion

All the experiments and simulations are conducted on a PC with Intel Core i7 4510U @2 GHz, Dual-Core with 8GB RAM on Windows 10 operating system in MATLAB. The experimental results are obtained on the Indiana University Chest X-ray Collection that includes 75 X-ray images [17]. All images are converted to gray scale with 256 levels. Four test images, along with their corresponding histograms are presented in Fig. 3-6. The test images names are: CXR1000_IM-0003-3001, CXR1002_IM-0004-1001, CXR1005_IM-0006-1001, CXR1008_IM-0009-2001. The images are of following sizes: 624x512, 420x512, 420x512, and 512x512, respectively. From now on, these four images will referred to as image A, image B, image C and image D, respectively. In each case, the quality of image segmentation is evaluated based on attained fitness function values, execution time, peak signal-to-noise ratio (PSNR) and the structural similarity index (SSIM). PSNR and SSIM for original image I and segmented image $\hat{I}$ and are defined as:

$$PSNR(I,\hat{I}) = 20log_{10}\left(\frac{255}{RMSE}\right), \tag{12}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\sum_{j=1}^{M}(I(i,j)-\hat{I}(i,j))^2}{N\cdot M}}$$

$$SSIM(I,\hat{I}) = \frac{(2\mu_I\mu_{\hat{I}}+c_1)(2\sigma_{I,\hat{I}}+c_2))}{\left(\mu_I^2+\mu_{\hat{I}}^2+c_1\right)\left(\sigma_I^2+\sigma_{\hat{I}}^2+c_2\right)} \tag{13}$$

Here, the terms μ and σ denote mean and standard deviation values, respectively. The term $\sigma_{I,\hat{I}}$represents the correlation between two images. The remaining constants are defined as c_1=6.5025 and c_2=58.52252. In the first experiment, the image segmentation is evaluated using firefly and bat algorithm to obtain the optimal thresholds for each of the four test images. The following threshold levels are considered. 2, 3, 4, and 5. Two metaheuristic algorithms are applied to estimate optimal thresholds on the basis of three different objective functions, namely, Otsu's between-class variance, Kapur's entropy and Tsallis entropy. In the experiments that follow, Tsallis entropy is evaluated for the measure of nonextensivity of the system set to q=4, as recommended by [18].

The image segmentation performance results are reported in Table I. These results correspond to the average PSNR and SSIM values obtained over thirty independent trials. In order to facilitate adequate comparison between the algorithms, in each case the population size is kept constant, N=30, and the estimation process is constrained to a maximum of 40 iterations.

The bat algorithm parameters are defined as follows. Minimum and maximum frequency bounds are set to values $f_{\min}$=0 and $f_{\max}$ =1. The loudness and impulse rate are initialized to A=0.99, and r=0.5, respectively. Both constants α and γ are set to 0.9.

On the other hand, the firefly algorithm is defined as follows. The light absorption coefficient and the attractiveness at zero distance are initialized to γ =1 and β_0=0.2, respectively. The randomization parameter is set to 2.5.

In consideration of results presented in Table I, it is very clear that both algorithms perform better when Otsu's between-class variance is used as an objective function rather than the Kapur's or Tsallis entropy. Otsu's function clearly offers better image segmentation performance in terms of attained PSNR and SSIM levels. This is true for both the bat and firefly algorithm. Furthermore, this objective function offers consistently better performance across the considered threshold levels and across the dataset of test images. The segmentation performance based on Otsu's objective function is illustrated in Fig 3-6.

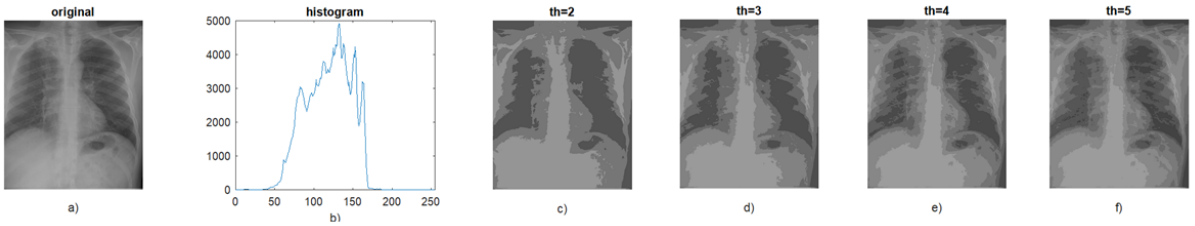

Figure 3. Image A: a) original; b) histogram; Segmented image for c) 2-thresholds d) 3-thresholds e) 4-thresholds f) 4-thresholds

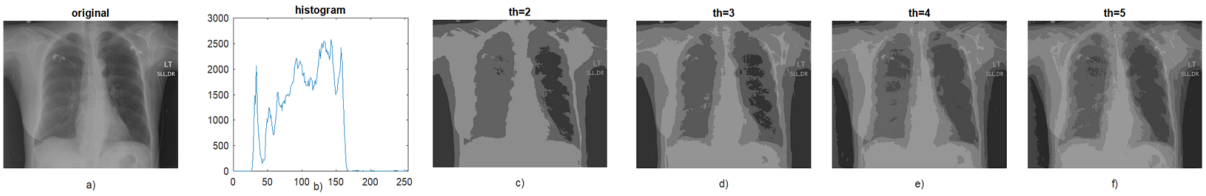

Figure 4. Image A: a) original; b) histogram; Segmented image for c) 2-thresholds d) 3-thresholds e) 4-thresholds f) 4-thresholds

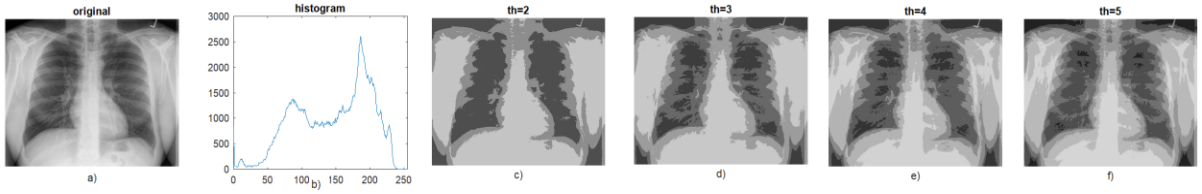

Figure 5. Image A: a) original; b) histogram; Segmented image for c) 2-thresholds d) 3-thresholds e) 4-thresholds f) 4-thresholds

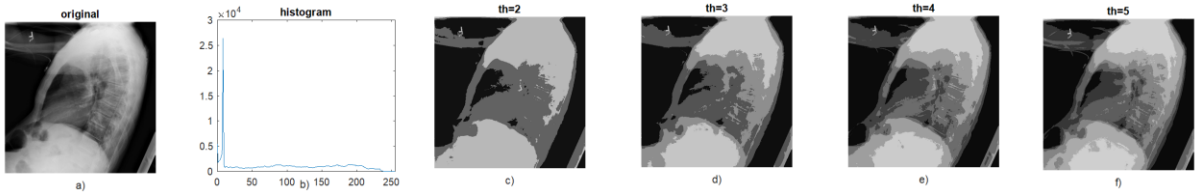

Figure 6. Image A: a) original; b) histogram; Segmented image for c) 2-thresholds d) 3-thresholds e) 4-thresholds f) 4-thresholds

Here, the image segmentation results are shown for each of the considered number of threshold levels and for each test image. These results correspond to the optimal threshold values obtained through the exhaustive search. The subjective quality evaluation of the presented image segmentation results are in accordance with the results presented in Table I.

Since it has been shown that Otsu's objective function offers better X-ray image segmentation performance than the other considered alternatives, the performance of the bat and firefly algorithm based on Otsu's objective function will be considered in more detail.

In the experiment that followed, the threshold estimation performance of the two metaheuristic algorithms is evaluated in terms of the mean and standard deviation values that describe the distribution of Otsu's objective function values over thirty independent runs. As before, the performance is evaluated on four test images and the results are reported in Table II. In addition, the table also shows the optimal threshold levels for each test image and the average execution time for each algorithm.

The average objective function values associated with the bat algorithm and firefly algorithms obtained over all threshold levels and all test images results are 2.3744 and 2.3747, respectively. The two algorithms are also compared in terms of image segmentation performance. The average PSNR results attained over all threshold levels and all test images are as follows. The bat algorithm attains PSNR=27.1982, while the firefly algorithm attains PSNR=27.1567. Similar results are attained using the SSIM measure as well. Clearly, in terms the quality image segmentation, it is hard to differentiate between the algorithms. However, the firefly algorithm offers a slightly more robust performance compared to the bat algorithm. This is evident by the somewhat smaller standard deviation values attained over the considered test images and threshold levels. However, when CPU times are compared, the bat algorithm significantly outperforms the firefly algorithm.

Thus, having considered four different X-ray test images with significantly different histograms, various threshold levels and three different objective functions, Kapur's entropy, Otsu's between-class variance, Tsallis entropy, we can conclude that the best image segmentation and image thresholding performances are obtained using Otsu's between-class variance objective function and the bat algorithm. The application of bat algorithm using Otsu's between-class variance objective function offers a fast thresholding performance and high quality image segmentation performance as indicated by the objective image quality measures, namely PSNR and SSIM values.

TABLE I. IMAGE SEGMENTATION PERFORMANCE FOR THREE DIFFERENT OBJECTIVE FUNCTIONS.

Image	Thr	Kapur				Otsu				Tsallis			
		PSNR		SSIM		PSNR		SSIM		PSNR		SSIM	
		Bat	FF	Bat	FF	Bat	FF	Bat	FF	Bat	FF	Bat	FF
A	2	24.5986	24.5986	0.8512	0.8512	27.3103	27.8403	0.8437	0.8422	25.7521	27.4873	0.8473	0.8437
	3	26.5944	25.6244	0.8435	0.8491	29.7705	29.9821	0.8535	0.8535	27.3370	27.9568	0.8466	0.8461
	4	27.4051	27.0612	0.8442	0.8441	31.2378	30.8881	0.8602	0.8588	26.3655	29.1319	0.8526	0.8505
	5	28.0507	29.0753	0.8455	0.8440	32.5455	32.0687	0.8701	0.8657	26.7299	29.8324	0.8606	0.8538
B	2	22.5237	22.4087	0.8005	0.8000	25.8982	25.8982	0.8157	0.8157	22.5729	22.6155	0.8066	0.8075
	3	25.9454	26.0715	0.8157	0.8162	27.9505	27.8247	0.8161	0.8162	25.2185	25.7245	0.8132	0.8128
	4	26.8307	26.3724	0.8156	0.8158	29.4805	29.2421	0.8315	0.8302	26.7281	27.6502	0.8168	0.8154
	5	28.1793	28.1854	0.8162	0.8113	30.7076	30.4423	0.8415	0.8395	28.5883	28.9983	0.8255	0.8229
C	2	21.0601	21.0634	0.6895	0.6894	22.6105	22.6105	0.7024	0.7024	21.2368	22.4916	0.6992	0.7019
	3	23.9286	23.9286	0.7052	0.7052	24.4223	24.4223	0.7076	0.7077	22.5928	24.2616	0.7054	0.7145
	4	25.7936	25.8282	0.7155	0.7105	26.2011	26.2063	0.7189	0.7199	24.2521	25.8182	0.7159	0.7265
	5	27.5030	27.5959	0.7354	0.7341	27.7188	27.7540	0.7411	0.7405	25.8921	27.6122	0.7328	0.7469
D	2	19.7397	19.7397	0.5977	0.5977	21.5358	21.5358	0.6824	0.6824	12.5769	13.6392	0.5134	0.5197
	3	23.0314	23.0314	0.6548	0.6548	24.0947	24.0947	0.7036	0.7036	14.3282	15.3918	0.5251	0.5355
	4	25.0298	24.9045	0.6821	0.6794	26.0758	26.0752	0.7353	0.7354	16.0328	16.9647	0.5453	0.5586
	5	27.4733	27.4372	0.7444	0.7429	27.6113	27.6218	0.7539	0.7523	17.5930	18.6967	0.5721	0.5905

TABLE II. TABLE II THRESHOLD ESTIMATION PERFORMANCE USING OTSU'S OBJECTIVE FUNCTION

Image	Optimal		Objective function value				Mean CPU	
	Thr.	Threshold vales	Bat		Firefly		Bat	FF
	No		mean	std	mean	std		
A	2	101, 134	646.5237	43.7621	665.7657	1.1563e-13	0.0383	0.2044
	3	92, 118, 142	702.2643	18.5612	706.6132	12.0829	0.0447	0.4523
	4	85, 106, 126, 146	722.9950	9.2291	718.9574	8.9367	0.0484	0.6219
	5	77, 96, 114, 130, 147	735.7279	8.3552	731.7252	7.0217	0.0537	0.8681
B	2	77, 120	1093.1	4.6252e-13	1093.1	0	0.0382	0.1947
	3	70, 105, 135	1155.7	11.8114	1152.0	17.4878	0.0438	0.4497
	4	59, 87, 114, 139	1185.8	14.9857	1181.5	15.3202	0.0499	0.6119
	5	55, 80, 102, 123, 143	1204.3	10.5093	1201.1	8.3063	0.0537	0.7961
C	2	110, 169	2502.3	0	2502.3	0	0.0383	0.1822
	3	83, 130, 178	2623.9	0.0137	2623.9	4.6252e-13	0.0435	0.4002
	4	73,116, 159, 195	2702.8	0.4547	2703.0	0	0.0496	0.5879
	5	56, 96, 132, 168, 199	2748.8	1.2938	2749.8	1.3876e-12	0.0544	0.7581
D	2	58, 141	4780.6	0	4780.6	0	0.0383	0.1735
	3	49, 113, 170	4983.8	0	4983.8	0	0.0432	0.3592
	4	38, 87, 134, 181	5076.6	0.0241	5076.6	0	0.0486	0.5453
	5	33, 74, 113, 152, 189	5124.4	0.4222	5124.7	2.7751e-12	0.0536	0.7454

V. CONLUSION

In this paper, the problem of x-ray image segmentation based on the multi-level thresholding is considered. Specifically the application of three different objective functions, Otsu's between-class variance function, Kapur's entropy and Tsallis Entropy and two different metaheuristic algorithms, bat and firefly algorithm for image segmentation is studied. The image segmentation performance is evaluate for a range of threshold levels and a set of four test images and the results are reported in terms of signal-to-noise ratio (PSNR) and the structural similarity index (SSIM). The experimental results have shown that the best multilevel thresholding performance is attained when the bat algorithm is used in conjunction with Otsu's objective function. The results show that Otsu's between-class variance function offers better image segmentation performance consistently across test images and threshold levels. When two metaheuristic algorithms are compared, the attained PSNR and SSIM values are image segmentation performance are very similar. However, the bat algorithm offers significantly faster performance over the firefly algorithm.

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Prediction of HSV color model parameter values of cloud movement picture based on artificial neural networks

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Abstract – In order to predict the exact moment of Sun shading by clouds and Sun cover duration to optimize the energy flow in the microgrid with solar photo electric system, it is essential to transform cloud images from RGB color model into HSV color model to be able to precisely detect cloud edges and determine the position of centroids for prediction of cloud movements. Parameters that define the quality of the image depend on the range of values for Hue, Saturation and Value (HSV) components. The dynamics of clouds and changing their shapes, sizes and colors require constant adjustments of those parameters by a human to get the best results. This paper deals with prediction and automatic setting of the HSV parameters by using artificial neural network and supervised learning. The image processing and parameters prediction was performed by an application developed in Java programming language based on JavaCV library and Encog framework for implementation of the artificial neural network.

Keywords – prediction of image parameters, HSV color model, neural networks, Java, Encog

I. INTRODUCTION

In order to track clouds on the sky and detect the moment of Sun shading by clouds, specific image transformations should be performed. These transformations include conversion from RGB to HSV color model for edge detection and performing the morphological operations erosion and dilatation [1]. For every of H, S and V components the minimum and maximum values should be determined to form a "filter" for image parameters in order to determine optimal cloud shape to get the most precise measurements. For the purposes of this paper a Java application that uses JavaCV [2] library has been developed. The Java application is used to perform described image transformations and to display the transformed image which consist of detected edges of the clouds in black, approximation of the shapes of the clouds with rectangle shape (in white) and ellipsis shape (in green), as shown on Figure 1. Also, the Java application draws the presumed location of the Sun (in yellow), detects the nearest cloud to the Sun (the rectangle and ellipsis of the nearest cloud are in red color), determines covered surface of the Sun (in black) and shows the current movement direction of the clouds based on detected centroid point and the location change of this point within 12 seconds (line in red that points from the centroid point to the image border). The clouds with the area smaller than 1000 pixels are ignored because they do not affect the Sun coverage. Similarly, in cases of merging several smaller clouds to one larger cloud, or disintegration of one larger cloud into several smaller clouds, generate a centroid position change that is ignored since it does not represent the movement of the clouds. For example, Figure 1 contains two objects without the red direction line from their centroids because they were forming a bigger cloud 12 seconds ago and this large cloud split into two smaller clouds. All other clouds contain this line because 12 seconds ago they got the similar shape.

The determination of centroid position is calculated every 12 seconds and the red direction line connects the last two calculated centroids, starting from next-to-last to the last, all through to the border of the image.

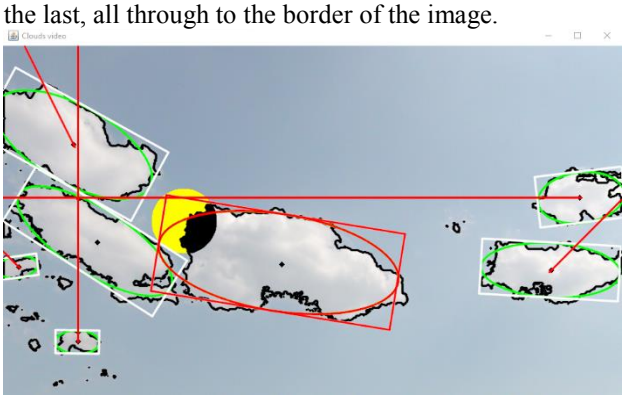

Figure 1. Java application screen with transformed image of the clouds

In addition to the Java application screen that shows the transformed image of the clouds, within Java application two additional screens are implemented: one with the histogram of the image (Figure 2) and one with slider components for fine tuning of H, S and V parameters of the image (minimum and maximum values) and the size of the structure element for erosion and dilatation operation purposes (Figure 3). Parameters show on those two figures were used as input or output data of the artificial neural network. For the generation of the histogram JFreeChart library [3] is used. R, G and B values from the histogram will be used as one the inputs for the artificial neural network used for automatically adjust the H, S and V

parameters to get the best results of cloud edges detection. The artificial neural network automatically adjusts the parameters shown on the Figure 3 to keep the quality of the edge detection high and, at the same time, to maintain the precision of determining the position of the centroid based on closed curves.

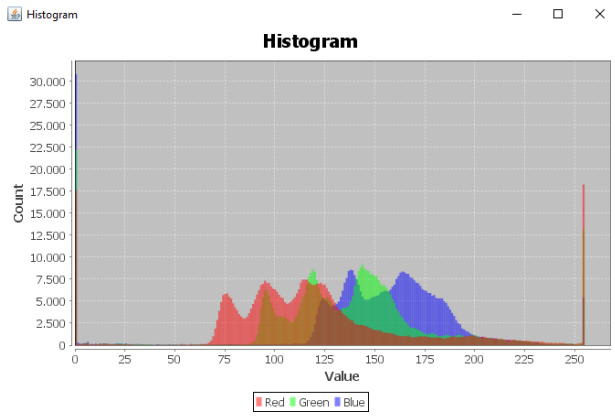

Figure 2. Histogram screen

Every of H, S and V components has the minimum and maximum value (for example, "HUE MIN" and "HUE MAX", as shown on the Figure 3). The size of the structural element defines a number of pixels used to precisely define the cloud edges using morphological operations erosion and dilatation. [1][4] The size of the structural element defines a precision of the cloud edge detection: the lower the size, the black line follows the shape of the cloud more precisely. If the structural element is too big, the precision of the cloud edge detection is not on the satisfactory level.

Figure 1 shows the case in which H, S and V parameters are optimally set, but if the values are not properly fine-tuned, the edges of the clouds could not be precisely defined. Figure 4 shows the case in which the S parameter is too high and Figure 5 show the case in which the S element is too low.

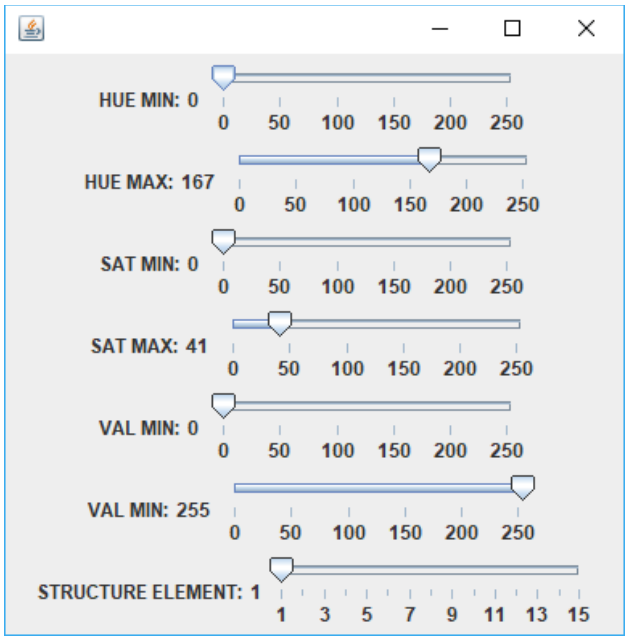

Figure 3. Screen for H, S and V and structure element size fine-tuning

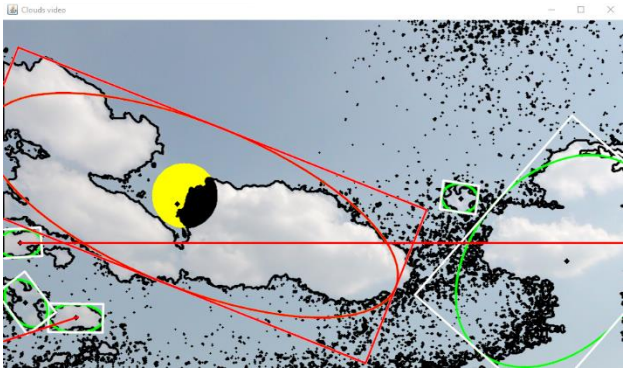

Figure 4. Image with too high value for the S parameter

Figure 5. Image with too low value for the S parameter

II. AUTOMATIC DETERMINATION OF H, S AND V PARAMETER VALUES BY USING ARTIFICIAL NEURAL NETWORK

For the purpose of automatically determining the optimal values for the H, S and V components, the neural network and the Encog framework implemented in Java programming language were used.

The neural network has 5 layers of neurons, input layer, three hidden layers and one output layer as shown on Figure 6. The first input layer has 6 neurons and every neuron is used for one of the following parameters used in learning phase: the average R value from the histogram (Figure 2) from the previous image processed 12 seconds ago, the average value of the G component from the histogram from the previous image, the average value of the B component from the histogram from the previous image, the number of very large clouds (with the area greater than 20.000 pixels), the number of clouds with an area greater than zero pixels, but less than 100 pixels, and as the last parameter the number of clouds with the surface equal to zero (this can happen when one of the values that represent H, S and V components, like shown on Figure 4 and 5, has a value that was not optimized for cloud edges detection). All those values are based on the previous image and affects the parameters on the next image. Structure element size wasn't taken into calculations since the best result were generated with the value of 1.

Output layer has six neurons each of which is assigned one of the following normalized values for the following parameters: "HUE MIN", "HUE MAX", "SAT MIN", "SAT MAX", "VAL MIN" and "VAL MAX". All these parameters match the values used on image configuration

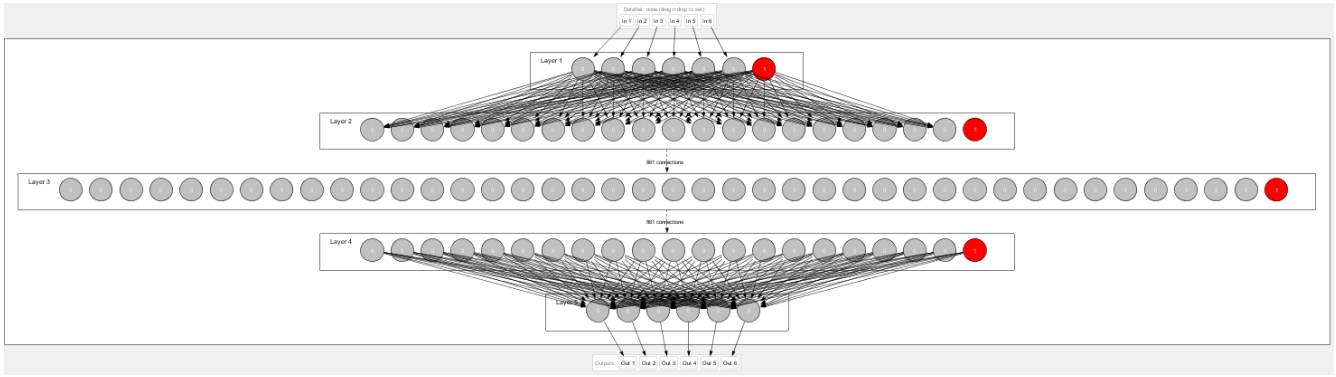

Figure 6. Neural network structure

screen shown on Figure 3 and define the boundary values for "filtering" the set of H, S and V values to optimally detect the cloud shapes on the image.

Three hidden layers between the input and the output of the neural network had the following number of neurons: 20 neurons in second layer, 40 neurons in third layer and 20 neurons in the fourth layer. All hidden layers and input used sigmoid activation function and bias neurons. Only the output layer didn't use a bias neuron. The neural network structure is shown on the Figure 6 that was generated using the Neuroph, Java neural network framework. [5] Bias neurons are marked in red, while other neurons are in gray.

During the learning phase, input values were normalized so that the values were divided by the number of 256 in order to convert their values to the range between 0 and 1. These values were set as input values for the first three neurons of the input layer of the neural network. Depending on the number of clouds and elements in the image, if the number of elements with the area equal to 0 (represented by the small black points in Figures 4 and 5) was more than 200, then the input value for the fourth neuron was 1, and otherwise it was 0. If the number of clouds with the area greater than 0 but less than 100 was above 50, the value given to the fifth neuron was 1, otherwise it was 0. The last neuron was set to 1 when there was at least one a large cloud of 20,000, and if there were not so large clouds in the picture, then the sixth neuron set the value 0. These values are defined by the experts and are based on experience.

Supervised learning was performed by setting the image parameters (every 300th image that was processed, sampled every 12 seconds from the video) as input values for the neural network, where the application user, as the expert for setting the image parameters, could adjust the optimal parameters for the H, S and V components values through the whole video duration. After a certain number of processed images, the input and output data were submitted for learning as long as the error did not fall below the threshold of 0.15%. Collected neural network knowledge is stored to the external file and is loaded after every restart of the application during the autonomous application phase. [6]

III. EXPERIMENTAL RESULTS

Using the prepared neural networks to determine the optimal H, S and V parameter values on images other than those used in supervised learning phase gave the results shown in the next tables.

Firstly, the neural network was taught on 100 images of clouds and was used to automatically process 471 images for which the optimal parameters were defined by the image processing expert. After that, the amount of images for learning increased to 200, 300 and at the end of 400 images.

For supervised learning on 100 images to minimize errors below 0.15%, 701 learning iteration were needed. In the case of learning on 200 images, only 30 learning iterations were needed to minimize the error below 0,15%. For learning on the sample of 300 images, only 14 learning iterations were required, and on a sample of 400 images the network error fell below 0.15%, after only 6 learning iterations. In Table 1 the relative errors in prediction of all six output values in comparison to the image processing expert for different learning periods were shown. Since the changes within a time frame of 12 seconds were not significant, the relative errors were also small.

Table 1. Relative error values of predicted values for H, S and V image components

Learning period (number of images)	H MIN	H MAX	S MIN	S MAX	V MIN	V MAX
100	0%	0,0043%	0%	0,0017%	0%	0,0001%
200	0%	0,00225%	0%	0,0004%	0%	0,0001%
300	0%	0,00173%	0%	0,00056%	0%	0,00013%
400	0%	0,001525%	0%	0,0002%	0%	0,00005%

Given that the minimum values of H, S and V components during the entire supervised learning phase were set to 0, the neural network outputs were also identical to that value. Increasing the number of patterns (images) for learning, the error was getting smaller and it was possible to reduce acceptable the error level before using the neural network in the autonomous mode. For example, taking the maximum number of 10,000 iterations into consideration that were allowed to process before the learning process is interrupted, a lower maximum error rate for larger learning patterns was achieved, up to 0.007% for 400 learning patterns (in comparison to 0,15% in the case of lower number of processed iterations), as shown in Table 2.

Table 2. Minimum error rates that were achieved by using up to 10.000 learning iterations

Learning period (number of images)	Number of iterations	Minimum error rate
100	2693	0,14%
200	338	0,08%
300	769	0,08%
400	127	0,07%

The highest error rates that occurred when using a neural network for a particular H, S or V parameter are shown in Table 3. The highest error rates are related to the H and S parameters which were most often changed during the whole cloud tracking time.

Table 3. Maximum error rates of predicted values for H, S and V image components

Learning period (number of images)	H MIN	H MAX	S MIN	S MAX	V MIN	V MAX
100	0%	26,34%	0%	29,27%	0%	1,96%
200	0%	22,16%	0%	17,07%	0%	0,78%
300	0%	14,37%	0%	31,71%	0%	1,18%
400	0%	25,75%	0%	21,95%	0%	2,35%

Table 1 shows the relative error rates of the neural network when predicting the H, S, and V parameters of the image including the recognition of the same input parameters patterns used by the neural network at learning. If these values are excluded and the network is only used on those input values that were not used to learn, the average and maximum error values are shown in Tables 4 and 5.

Table 4. Relative error values of predicted values for H, S and V image components without using the learning patterns

Learning period (number of images)	H MIN	H MAX	S MIN	S MAX	V MIN	V MAX
100	0%	0,0002%	0%	0,0003%	0%	0,0003%
200	0%	0,00005%	0%	0,00005%	0%	0,00005%
300	0%	0,000033%	0%	0,000166%	0%	0,000033%
400	0%	0,00%	0%	0,000075%	0%	0,000025%

Table 5. Maximum error values of predicted values for H, S and V image components without using the learning patterns

Learning period (number of images)	H MIN	H MAX	S MIN	S MAX	V MIN	V MAX
100	0%	0,85%	0%	27,27%	0%	1,26%
200	0%	0,39%	0%	2,17%	0%	0,39%
300	0%	0,39%	0%	35,71%	0%	0,39%
400	0%	0,00%	0%	17,65%	0%	0,39%

IV. CONCLUSION

This paper presents one of the ways in which automated determination of optimal values of H, S and V components can be automated in order to adequately detect the edges of the clouds and to track their movement. Because of the unpredictable nature of clouds, it was not possible to precisely determine an algorithm to predict the H, S and V values, the artificial neural network was implemented using Java programming language and the Encog framework. Experimental results have shown that the error rates are smaller if the neural network had learned on a large number of images. Although it cannot be determined how exactly the neural network because of its "black box nature", and other disadvantages like greater computational burden, proneness to overfitting and the empirical nature of model development [7], the advantages like requiring less format statistical training, ability to implicitly detect complex nonlinear relationships between dependent and independent variables, ability to detect all possible interactions between predictor variables and the availability of multiple training algorithm can be very effectively used, like in this case.

The motivation for this work resulted of the need for constant presence of an expert who would need to adjust the H, S and V parameters for good image processing results. Instead, an artificial neural network can make a good substitute for that and is able to be further developed, on the basis of an expert system where one can intervene if necessary and correct the output results of the neural network if necessary and to create the new learning patterns. Additional new samples collected after the initial learning period of the neural network can be used to further improve accuracy of the future predictions, should be used in combination with the samples that were used before in order to maintain the present knowledge and enrich it with newer elements.

Other methods for solar radiation prediction can be based on geographical and meteorological data as inputs for the artificial neural network [8], but use different input parameters also show that by using the soft computing methods the prediction results can be used creating an autonomous photovoltaic system.

V. FUTURE WORK

The result in this paper will be used to further develop and automate the algorithm for predicting the clouds movement and calculate the exact moment and duration of the shadow over the Sun. These information can be directly used to predict the amount of direct solar irradiance and the amount of generated energy within the short period of times.

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A review of soft biometrics for IoT

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***Abstract*— The Internet of Things (IoT) can be defined as everyday physical objects being connected to the internet and being able to identify themselves to other devices. In recent years the Internet of Things (IoT) was identified as one of the emerging technologies. Research in this area has increased considerably and future research will have to include other technologies such as biometrics to complement the development of IoT devices. The idea of this paper is to give an overview of biometric characteristics applicable to IoT with emphasis on soft biometric characteristics and possible application ideas in IoT.**

Keywords*— *biometrics, internet of things, soft biometric characteristics

I. Introduction

In recent years, the Internet of Things (IoT) has become one of the most researched and discussed topics in technology. With its wide application area it gained recognition across different fields. Researchers estimate that the IoT will consist of almost 50 billion objects by 2020 [1]. Gaikwad [1] states that "The major objectives for IoT are the creation of smart environments/spaces and self-aware things (for example: smart transport, products, cities, buildings, rural areas, energy, health, living, etc.) for climate, food, energy, mobility, digital society and health applications ".

In most of the IoT application areas, some form of person identification or classification is necessary. Henniger et al. [2] recognise two main approaches for user identification: (1) by a specific token and (2) using biometric characteristics. The main advantage of biometric characteristics is that they are bound to a person and cannot be forgotten, stolen or lost unlike passwords or tokens. Most common biometric characteristics used for person identification are hard biometric characteristics such as fingerprint, face or iris. The problems that are most frequently mentioned with usage of hard biometrics are the computational complexity and privacy. In order to circumvent those issues, soft biometrics can be used.

This paper gives an overview of soft biometric characteristics with emphasis on the characteristics which can be acquired at a distance. Advantages of using soft biometric characteristics in IoT will be described and their possible applications in IoT systems will be shown.

II. Biometrics

Biometrics can be defined as the science of recognising individuals based on their physical, behavioural, and physiological attributes such as fingerprint, face, iris, gait and voice [3]. These attributes are also known as biometric characteristics or traits. There are different ways in which these characteristics can be categorised. One such categorisation distinguishes between hard, or traditional, biometric characteristics and soft biometric characteristics. Hard biometric characteristics are those traditionally used for person identification based on their physical or behavioural features [4]. These characteristics can be divided into physical characteristics (DNA, ear, iris, retina, face, fingerprint, palm, veins, smell and body) and behavioral characteristics (gait, signature, keystroke dynamics, mouse move dynamics, voice, brain wave structure).

Soft biometric characteristics have been defined in many different ways. One of the first definitions of soft biometric was by Jain et al. [5] who defined soft biometrics as "the set of characteristics that provide some information for recognising individuals, but that are not capable of distinguishing between individuals, mainly due to their lack of distinctiveness and permanence." The most up to date and comprehensive definition of soft biometrics is by Dantcheva et al. [6]: "Soft biometric traits are physical, behavioural, or material accessories, which are associated with an individual, and which can be useful for recognising an individual. These attributes are typically gleaned from primary biometric data, are classifiable in pre-defined human understandable categories, and can be extracted in an automated manner. " Soft biometric traits can be classified in different groups. Dantcheva et al. [6] define four groups in which soft biometric traits are classified: (1) demographic, (2) anthropometric and geometric attributes, (3) medical attributes and (4) material and behavioral attributes. Demographic attributes include age, gender, ethnicity, eye color, hair color and skin color. Anthropometric and geometric attributes include body geometry and face geometry. Medical attributes are health condition, BMI, body weight and wrinkles. Material and behavioural attributes are hats, scarfs, bags, clothes, lenses, and glasses.

Application of soft biometrics has many advantages in comparison to hard biometric traits. Hard biometric traits can rarely be described using labels understood by people which only allows identification of users whose biometric signature

has been recorded previously. Soft biometric characteristics are often used by humans to describe others and therefore bridge the gap between biometric measurements and human descriptions [4]. Second great advantage of soft biometrics is non-invasiveness. Soft biometric characteristics can easily be collected at a distance [4] [7] [6] with no additional action from the subjects or their cooperation or consent. Another advantage is lower computational complexity of soft biometric characteristics. One important issue with hard biometric traits is the lack of privacy. The idea of soft biometrics most often is not to identify a person, but to identify a group a person belongs to, which means that soft biometric traits are not distinctive [6]. These advantages are the main reason why the field of soft biometrics is becoming more popular in recent years, especially for usage in smart environments.

III. The Internet of Things (IoT)

The Internet of Thing (IoT) is a heterogeneous field defined as “a variety of things or objects (...) which, through unique addressing schemes, are able to interact with each other and cooperate with their neighbours to reach common goals” [8]. The devices referred to as "things" may include for example various kinds of sensors and actuators, mobile devices, car/vehicle computers, TV sets; but also non-ICT appliances like light bulbs, speakers, dishwashers, microwave ovens, refrigerators, electrical energy sources and building components [9], equipped with computing, communication and sensing capabilities. The ubiquitous nature of current IoT technologies can be observed through its numerous application areas, which include, but are not limited to: smart cities [10], smart power grids [11], smart health [12], smart transport [13], smart buildings [14], smart living solutions [15], smart human settlements [16], [17], [18], and other.

Within a smart living environment, there are several common application and services contexts that could utilise the identification possibilities based on soft biometrics [19]: targeted and personalised information, communication, energy management, health and care services, surveillance. Since those services may exist in a multi-user environments, security, privacy and personalization are all important factors that need to be considered. A more detailed "perspective on the background and current status of security, privacy and trust in smart environments" is overview in [20], arguing that there are many areas still not covered, such as access control, identity management, legal and socio-technical issues, and biometric aspects.

The use of biometrics within the ambient intelligence and IoT domains can be useful not only in understanding human behaviour, but also to identify the person, or class of persons with similar characteristics, so the service system could decide on their needs and desires through soft-biometric traits (height, weight, emotions, gestures, gait) [21].

The scope of the IEEE 2413 project falls within the standardisation of an Architectural Framework for the Internet of Things, encompassing for example descriptions of various IoT domains[1], depicted in Figure 1 [22].

In [23], possible IoT application domains are listed a follows: Aerospace and aviation (systems status monitoring, green operations); Automotive (systems status monitoring, V2V and V2I communication); Telecommunications; Intelligent Buildings (automatic energy metering/ home automation/ wireless monitoring); Medical Technology, Healthcare, (personal area networks, monitoring of parameters, positioning, real time location systems); Independent Living (wellness, mobility, monitoring of an aging population); Pharmaceutical; Retail, Logistics, Supply Chain Management; Manufacturing, Product Lifecycle Management (from cradle to grave); Processing industries - Oil and Gas; Safety, Security and Privacy; Environment Monitoring; People and Goods Transportation; Food traceability; Agriculture and Breeding; Media, entertainment and Ticketing; Insurance; Recycling.

IV. Literature Overview

In [19], authors illustrate problems regarding unauthorised access to data created within the smart environments, such as behavioural and heath-related information, with examples like speech-recognition, gaining insight into the residents' whereabouts and break-in possibilities, gaining insights into another person's medical records, etc. Considering the trade-off between biometric accuracy and usability, authors suggest the use of a number of biometric information sources (multi-biometrics) [24], where each biometrics source may be less accurate and more robust, but by fusing these different sources, the higher overall accuracy may be achieved.

Indoor localisation and fall detection are subjects of integrated ambient assisted living (AAL) solutions, where authors [25] present CapFloor, a "Flexible Capacitive Indoor Localization System". Arguing that existing solutions based on capacitive sensing systems have high installation requirements and high integration price, they propose a flexible, integrated solution based on open source hardware that consists of sensing mats capable of wirelessly transmitting data to a central platform with localization and fall detection services.

Authors in [26] propose the Internet of Biometric Things (IoBT) concept as a "cloud-centric biometric identification architecture consisting of connected devices that require biometric authentication." The proposed system couples biometric and context-aware authentication techniques in order to protect mobile applications from unauthorized access. As authors argue, biometric authentication has not been considered for IoT applications for two main reasons; 1) IoT architectures aim at automatization with no human interventions [27], 2) A number of IoT devices have limited computing capabilities, whereas hard and soft biometric identification methods include more complex calculations (decision making, identity prediction clasifiers, meta-biometric prediction classifiers [28]).

Abate et al. [29] propose Multiagent Biometrics for Ambient Intelligence (MUBAI) architecture, "which specifies the

[1]Information about IEEE 2413 project is available at: http://standards.ieee.org/develop/project/2413.html

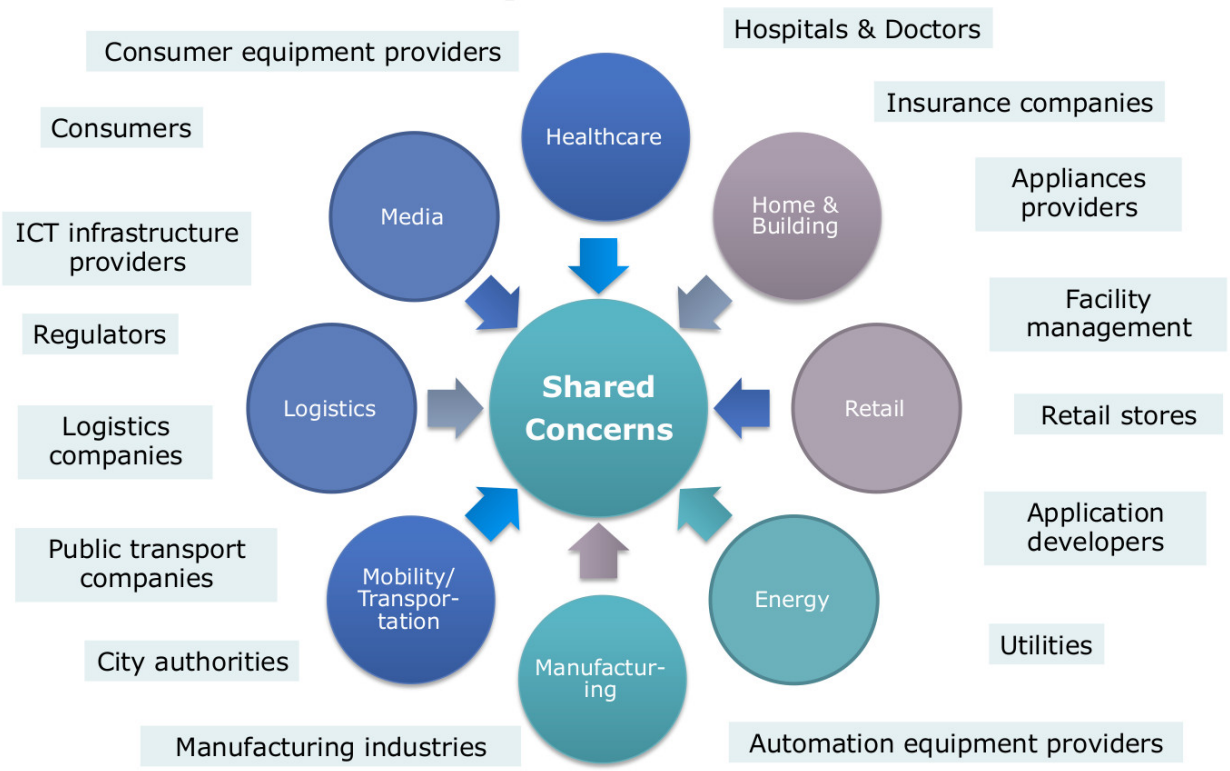

Fig. 1: Selected domains and staheholders in IoT [22]

composition of more biometric modules in a multiagent recognition system.", arguing that MUBAI architecture allows to achieve better results in comparison to single classifiers.

The biometric technology is also used in IoT context in [30], where authors propose an IoT based biometrics architecture that can be used for security and access control mechanisms and claim that the "system can be applied at all places where authentication is required". The biometric system involved is a multimodal one, with face and fingerprint traits under consideration.

The potential of biometric technologies within the general domain of ambient intelligence is analysed in [31], along with the effort to identify "some key technological issues which may respond to privacy concerns". Moreover, the authors tackle the usefulness of soft biometrics where, for example, facial expressions can be used to better relate the user with the surrounding environment, providing the input for the system enabling services, but with the clear advantage of not compromising user's privacy.

Using biometric data as a source for randomness is discussed in [32]. Authors assess the feasibility of using IoT devices to gather biometric data on human behaviour by using several smartphone sensors: magnetometer, gyroscope, rotation, accelerometer, gravity, linear acceleration and sound. The results showed that using one single sensor source is not adequate for creating randomness used in cryptographic applications, nor is the subject's gait, which would be better utilized in identifying the person.

Shahim et al. [33] propose a system that would use Raspberry Pi as an IoT device together with the leap motion controller in an attempt to authenticate system users through hand geometry and a series of gestures. User classification would be achieved through the machine learning classification techniques. Authors also suggest an application scenario, where medical surgeons would gain "access to an operating theatre once they have disinfected their hands and would not like to touch any surfaces before entering." Surgeons would thereby gesture towards the authentication system, which would grant or deny the access accordingly.

An intelligent add-on for the smart devices, which would enable continuous verification of users in a Social Internet of Things, is proposed in [34]. Authors have collected online behaviometrics of mobile users by extracting features from smartphone sensors and users' social network interactions. The results showed that "genuine users can be verified without any disruption 97% of the time whereas the users can keep using the devices 90% of the time without any disruption".

V. Soft biometric characteristics applicable to IoT domain

If we put biometric characteristics in the context of IoT application areas, biometric sensors and their distance from users play an important role. Tistarelli and Schouten [35] recognise that there are three categories of biometric sensing modalities: (1) contact, (2) contact-less and (3) at a distance. In using contact biometric devices users are required to touch the

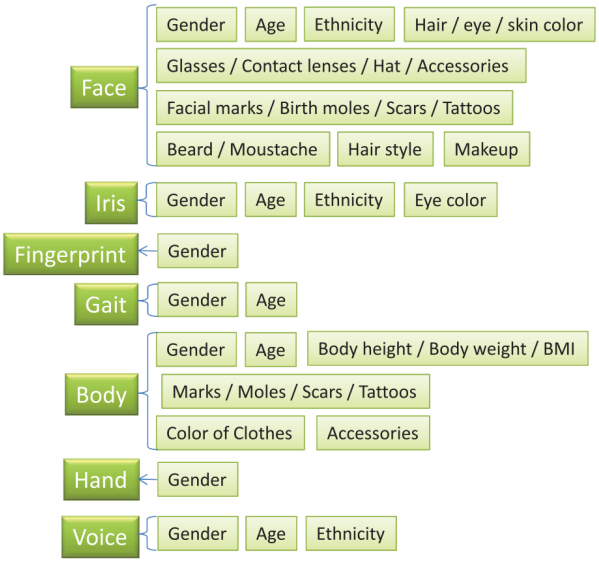

Fig. 2: Soft biometric information and biometric characteristics from which they can be acquired [6]

sensor, which is not the case in contact-less and at a distance biometric acquisition. The difference between contact-less and at a distance sensors is that in the former the distance between the user and the sensor is short. Sensors capable of biometric data acquisition at a distance do not require special actions from users. Biometric characteristics able to be acquired from at a distance sensors are particularly interesting in smart environment scenarios [35].

Dantcheva et al. [6] give a list of the soft biometric information which can be acquired from different biometric modalities (Figure 2). If only biometric modalities which can be acquired from at a distance sensors are taken into consideration, some of the modalities can be eliminated. Modalities appropriate for usage with at a distance sensors most commonly used in IoT are face, gait and body. As soft biometric information can be acquired from different biometric modalities, this elimination does not reduce the soft biometric information acquired (for example, gender information can be acquired from all of the previously mentioned biometric modalities).

As summarised within Table I, soft biometrics could be applied within several IoT domains. A smart home system can track resident's movements in order to conserve energy within rooms that are not currently occupied (switching off the lights, appliances, reducing ambient temperatures, etc.); if detecting that the resident is sleeping, it could lower the ambient temperature by a few degrees. The system could observe resident's body and face for signs of health-related symptoms and states, alerting the resident and/or health workers if deemed necessary. It could track resident's weight and BMI on daily basis, and offer diet and/or recreation activity advice accordingly. The system might detect home intruders by detecting unusual biometric traits, and alert authorities. It could also detect children and not allow them to open doors.

Within the Media domain, age, gender, ethnicity could present relevant factors in tailoring the customized channels, articles, news feeds, etc. Health related issues and emergencies could be discovered or anticipated based on person's age, gender, skin color or heartbeat, preventing possibly undesirable outcomes. Wearable devices, cameras, or other connected IoT devices equipped with appropriate sensors, could generate sufficient input for biometric systems.

Driving restrictions could be initiated on the basis of detected alcohol intoxication and/or insufficient age of the driver. The IoT system within the vehicle could respond to driver's voice commands, but also analyse the voice in order to detect possible risk situations (tiredness, intoxication, etc.).

Threat assessment could be performed by numerous IoT devices on airports, based on soft-biometric traits. Retail industry could offer customised shopping experiences and tailored product suggestions, but also perform long-term analysis of customer demographics and in-store behaviours. Soft biometrics' approach could also help in identifying potential shoplifters.

VI. Conclusion & Future Work

Although the currently available body of research shows a certain amount of work dealing with biometrics applications within the Internet of Things context, presented in Section IV, there are only a number of references for using soft biometrics within the IoT context.

In this paper, we summarized the state of the art in research concerning the application of biometrics within the relevant Internet of Things domains, focusing on soft biometric traits and their possible application scenarios. We have purposefully discarded some of the IoT domains that we've found to be unfeasible for soft-biometrics approaches, for example, domains which are not user-centric, or where there are no relevant human-computer interactions.

Our future work will progress on the non-intrusive soft-biometrics approach within the Internet of Things context, with special focus on the model development and specific technologies required to implement scenarios (included, but not limited to) discussed within this paper.

After the introductory section I we have introduced the biometrics concept in section II, with special focus on soft biometric characteristics, associated traits and its advantages in comparison to hard biometric approaches. Internet of Things concept was discussed in section III, where possible application domains for the use of soft biometrics were derived from related work. Section IV presented the state of the art research concerning the usage of biometrics in the Internet of Things application domains.

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IoT AD	Soft biometric information	Usage scenario
Home and Building	emotions	ambiental adjustments
	glasses, contact lenses, age, presence	localization; energy conservation; ambiental adjustments
	weight, height, BMI	diet recommendations
	age, gender	intruder detection; physical access control
Media	age, gender, ethnicity	customized media delivery
	age, gender, ethnicity	thematic group recommendations
Energy	glasses, contact lenses, age, scars	energy usage optimisation; demand side management ambient temperature adjustments
Healthcare	age, gender, skin color, heartbeat	medical emergency detection; body statistics; health recommendation systems
Mobility transportation	substance abuse, emotions, age	driving restrictions
	accessories, ethnicity, emotions	threat assessment
	substance abuse, emotions	vehicle voice commands
Retail	height, weight, gender, age, clothes, accessories	customised shopping experience, tailored product suggestions, customer demographics, in-store behaviours, potential perpetrator detection

TABLE I: Proposed soft biometrics within relevant IoT domains

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Benefits of Utilisation of GPS Error Mitigation Models for Intelligent Transport Systems

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***Abstract* - This manuscript outlines the research results of potential pitfalls in utilisation due to inadequate or inappropriate usage of the GPS satellite navigation system for Intelligent Transport Systems. The impact of the error correction models and techniques on the GPS positioning performance is addressed through analysis of three use-case studies conducted on a GPS software-defined radio fed with experimetally collected GPS pseudoranges. Recommendations are proposed in regard to utilisation of the standard error mitigation procedures for Intelligent Transport Systems.**

***Keywords* - SATELLITE NAVIGATION, GPS correction models, INTELLIGENT TRANSPORT SYSTEMS (ITS), autonomous vehicles.**

I. INTRODUCTION

SATELLITE navigation systems (Global Navigation Satellite System – GNSS, or its sub-sets: the US GPS, Russian Glonass, the EU's Galileo, and Chinese Beidou) are imbedded component of increasing number of technology and socio-economic systems, driving developments and improvements on various scales of daily life and economy. Susceptible to various sources of vulnerabilities, satellite navigation systems may enhance, as well as bring down, the systems relying on them. Thus, the understanding of the GNSS resilience techniques and methods becomes the common practice for every developer and researcher who attempts to benefit from satellite navigation utilisation. Here we address the problem of the GPS utilisation for Intelligent Transport Systems, as a case study for the GNSS resilience development in this particularly important transport domain.

II. PROBLEM DESCRIPTION AND PREVIOUS RESEARCH

The positioning performance of satellite navigation systems depends not only on system performance, but on the means the user equipment is utilised in parent systems. Satellite navigation is increasingly an embedded technology that allows for development and operation of larger systems, such as Intelligent Transport Systems. In due course, the performance of satellite navigation systems influences significantly the quality of parent system's services [1] .

Various processes may cause the GNSS/GPS positioning performance disruptions and degradations, that grade from minor to significant. From the perspective of Intelligent Transport Systems, the ionospheric and multi-path effects emerge as the major causes of GNSS-related disruptions and degradations.

While GNSS and its sub-systems offer error mitigation procedures in constant operation, usually in a form of correction models, it has become important to understand when and why such procedures should (or should not) be applied in particular GNSS/GPS applications [2].

III. CROSS-VALIDATION OF DIFFERENT GPS-BASED POSITIONING SCENARIOS

The utilisation of satellite navigation systems for ITS faces important challenges. Here we assess the GPS positioning performance as encountered by a commercial single-frequency GPS receiver, a sort of equipment that dominates todays satellite navigation market.

A. Methodology

The research presented in this manuscript was based on simulation conducted using RTKLIB, an open-source software-defined GNSS radio, fed with the real 24-hours GPS pseudoranges collected at the International GNSS Service's reference station in Padua, Italy on the day 142 (21st May) in 2016. The choice of the day was governed by the lack of significant space weather disturbances, thus allowing for commensurate effects of all the other variables influencing the GPS positioning performance [3].

Three use-case scenarios was envisaged, that reflects the most frequent means of the GPS utilisation for ITS, as follows.

The first of them assumes utilisation of all GPS error correction models supported by GPS service: ionospheric correction model (according to Klobuchar), tropospheric correction model (according to Saastamoinen), and satellite ephemeris and clock correction model. Such a case is a common for commercial-grade GPS receivers when end-users simply accept the correction scheme provided by the GPS system operator.

The second use case assumes utilisation of the satellite ephemeris and clock correction model only. Such an essential use-case with the most of modelling capacity stripped off reflects the advanced utilisation in periods of significant space weather disturbances, when Klobuchar model may introduce unwanted error due to the nature of its operation, rather than to correct the existing one.

Finally, the third use-case reflects a situation common in urban areas, where a GPS engineer may attempt to mitigate the effects of multi-path error by increasing the GPS mask

angle, say, from 10° to 25°.

B. RTKLIB software-defined radio as a research tool

The open-source software-defined GNSS receiver RTKLIB provides all the feature of an GNSS software-defined radio [4]. Modular composition of its software allows for separate utilisation of various functionalities, among the post-processing of GNSS/GPS pseudoranges using observation and navigation RINEX data files [5].

An RTKLIB user has a formidable liberty in setting the receiver to different use-case scenarios, [6] as depicted in Fig. 1.

The optional settings were used for creation of the three use-case scenarios described in Section 3.1.

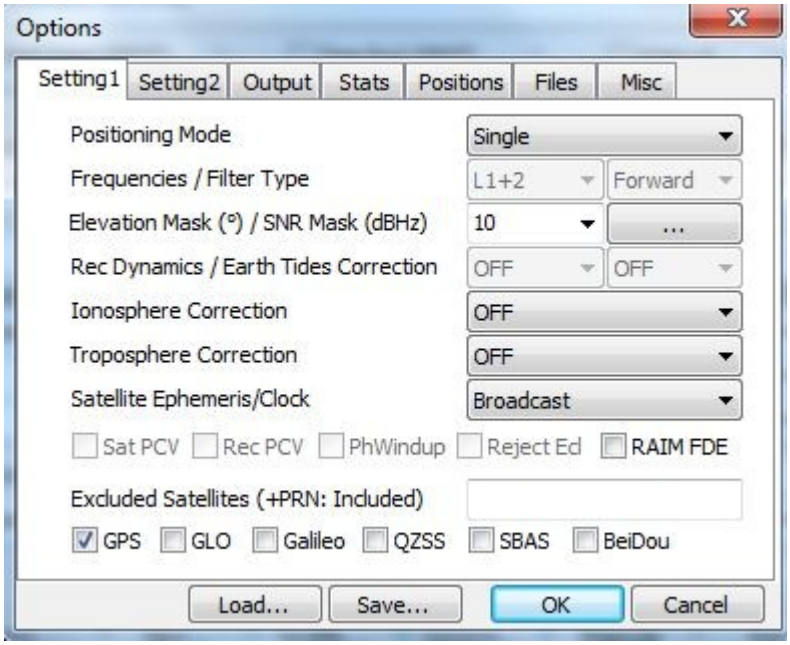

Fig. 1. Optional RTKLIB/RTKPOS settings that allows for definition of various use-case scenarios

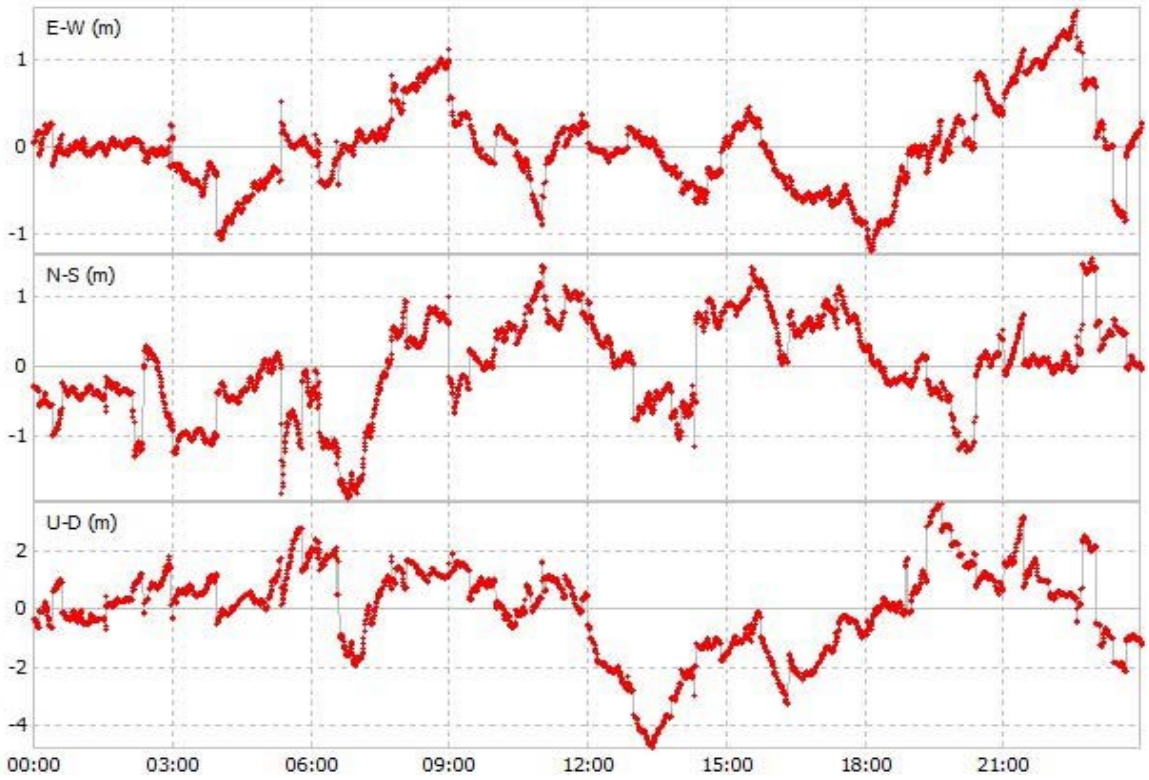

Fig. 2. Time series of easting (upper), northing (middle) and height (lower) positioning errors, respectively, with standard correction models applied

IV. RESEARCH RESULTS

The research outcome related to three use-case scenarios is presented in this Section, comprising, respectively, time series of positioning errors in easting, northing and height directions (Figs 2-4), as well as the GPS positioning error statistics (Tables 1 and 2).

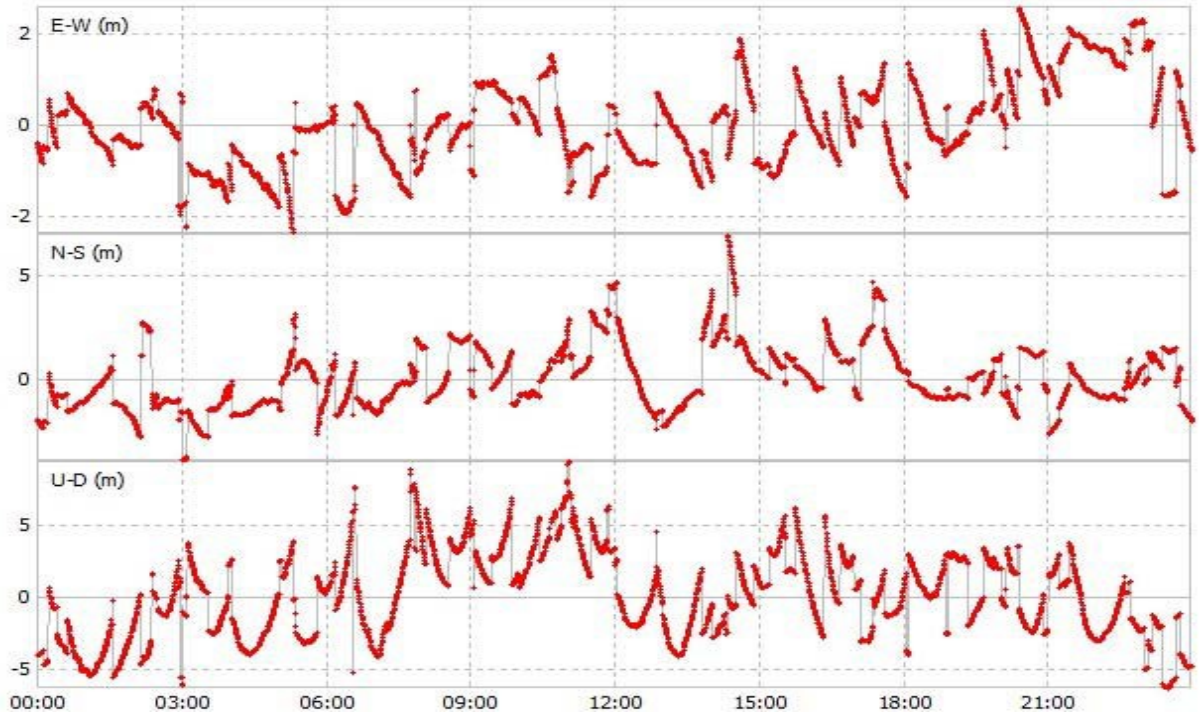

Fig. 3. Time series of easting (upper), northing (middle) and height (lower) positoning errors, respectively, with satellite ephemeris/clock corrections applied only

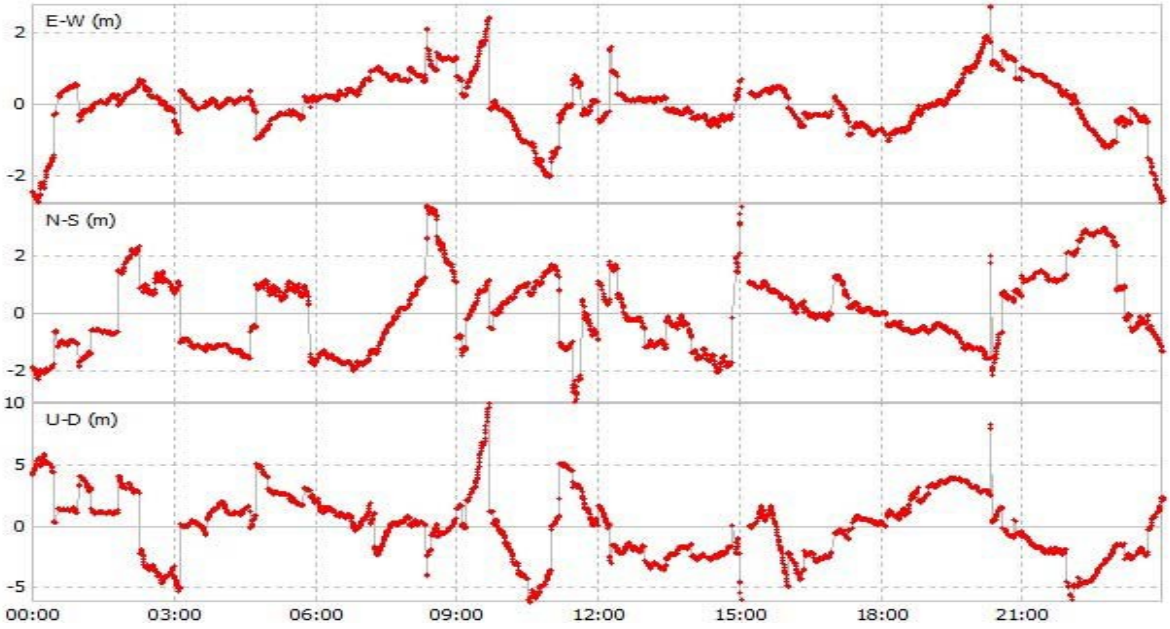

Fig. 4. Time series of easting (upper), northing (middle) and height (lower) positoning errors, respectively, with standard correction models applied and the mask angle set at 25°

TABLE 1 MEAN POSITIONING ERRORS IN RELATION TO APPLIED GPS CORRECTION MODELS

Errors in [m]	**Standard corrections apply**	**Satellite ephemeris/clock corrections only**	**Standard corrections apply, with elevation mask at 25°**
Easting error	2.189	3.868	3.274
Northing error	3.004	5.265	5.117
Height error	5.500	10.110	10.720

TABLE 2 MAXIMUM POSITIONING ERRORS IN RELATION TO APPLIED GPS CORRECTION MODELS

Errors in [m]	Standard corrections apply	Satellite ephemeris/clock corrections only	Standard corrections apply, with elevation mask at 25°
Easting error	3.116	5.755	8.928
Northing error	6.724	9.999	32.370
Height error	9.302	18.220	71.780

V. DISCUSSION

Three characteristic use-case scenarios of the GPS utilisation for Intelligent Transport Systems reveal an interesting insight into effects of the utilisation of GPS error correction models.

The first use-case scenario shows the success of the positioning error mitigation methods (models) and techniques in the relatively mild space weather conditions, as prevailed on 21 May, 2016. The positioning errors in all the reference directions remained at impecable levels, complying with the requested performance for non-crtical ITS applications, such as: road information system, and motorway and congestion charging (the critical ones have the necessary augmentations and fortification already in operation). However, a significant local ionospheric disturbance (not encompassed by global Klobuchar ionospheric correction model), or an unfrendly local positioning environment with a plentyful of multipath, may cause significant degradation of GPS positioning performance for ITS.

The second use-case shows the impact of an attempt to mitigate unresponsiveness of Klobuchar model to a local ionospheric event through avoidance of the model. The positioning performance was generally worse than with the case of all the standard correction models applied. It is the subject of further research to assess the comparison between the two in case of a severe ionopheric storm [8].

The third use-case reveals a significant degradation of positioning performance if the mask angle increase is attempted as the multi-path mitigation method. Again, the future field tests will reveal the level of degradation achieved by the effects of the very multipath.

An ITS developer has a number of GNSS resilience development, and error mitigation and correction methods and techniques. However, a skilled deplyoment of all of them is an essential pre-requisite for the successful utilisation of satellite navigation in ITS.

Here we propose the following recommendation, emerging from discussion of our research, as follows.

First, the error mitigation methods and techniques render satellite navigation positioning performance more robust, and less vulnerable to various error sources.

Then, the utilisation of particular error mitigation methods and techniques requires knowledge and skills, thus requiring continuous education of ITS developers willing to benefit from GNSS utilisation.

Finally, a proper reporting of cases of GNSS positioning performance disruptions and degradations enhances the pool of knowledge, and should be encourage among the professionals.

VI. A LOOK INTO THE FUTURE AND APPLICATION

The development and use of autonomous vehicles began with their utilisation for military purposes. Today, automotive vehicles are used as working machines, for eg. in mining. However, we will wait for some time for their application in urban traffic. The reason is legislation, but also the outdated infrastructure that does not support autonomous vehicles.

Automobile traffic nowadays has the highest percentage of deaths among all types of traffic. Using autonomous vehicles that would drive people from "door-to-door" would reduce the number of fatalities caused by drunk driving or fatigue and exhaustion. But there is a question of who would take responsibility for any accidents caused by a systematic error. If we take into consideration the information from the automotive industry about frequent calls to car services due to factory faults, the question that arises is about the amount of acceptable risk in traffic [7].

Most experts envision management of autonomous vehicles through user interfaces for humans, as well as via M2M real-time communication with the environment. People would make a decision about a route based on personal needs and traffic data visible on the GPS map, while driving would be performed by the car itself. In order to successfully achieve the evolutionary shift from classic steering to autonomous support in vehicle movement, it is considered that a period of 10 years will be needed.

An interesting example of a test autonomous vehicle is Volkswagen Touareg Stanley, which was jointly developed by Stanford University and the Volkswagen Electronics Research Laboratory. A group of sensors allows the Stanley vehicle to recognize the way to be passed (Fig.5).

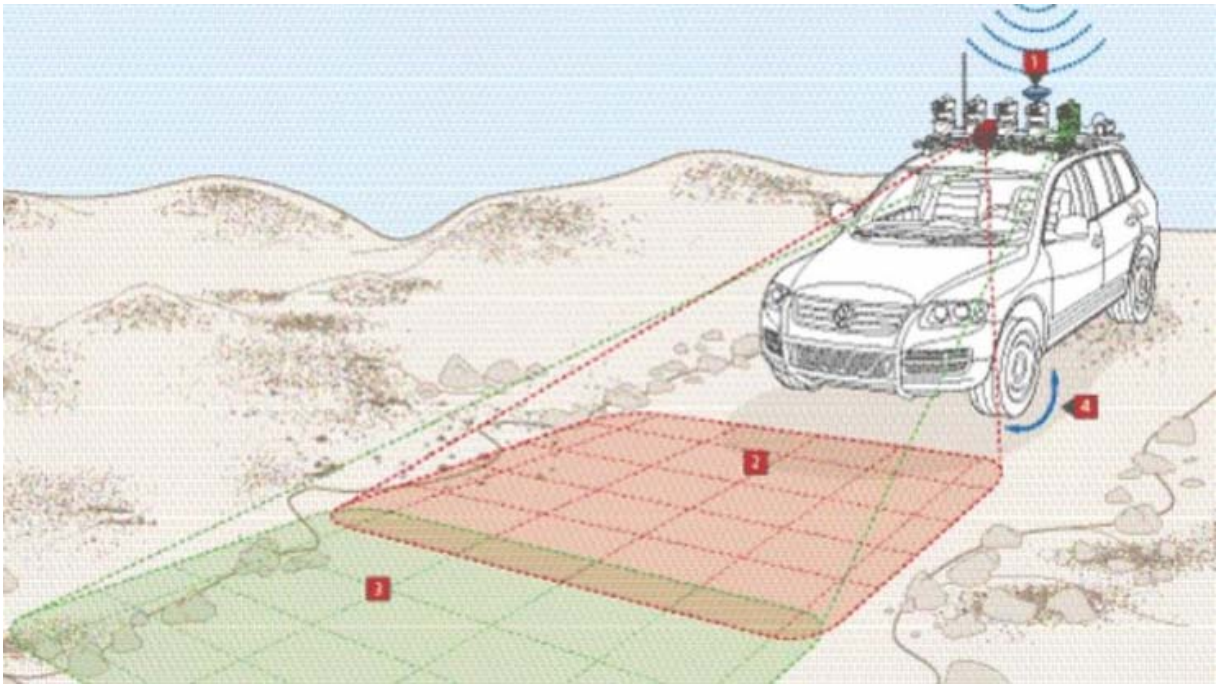

Fig.5. Sensors in an autonomous vehicle: 1. GPS antenna, 2. laser scanner, 3. video camera, 4. odometer, [7]

The group consists of five laser distance meters scanning the ground 25 meters in front of the vehicle, a video camera scanning the way off the reach of those lasers and two radar sensors covering the front space up to 200 meters away. This system works so that the laser identifies the driving area, and the software searches the same characteristics in the video camera data and radar data and thus allows for a secure acceleration. On the roof of the vehicle behind these sensors, there are antennas of the positioning sensors - three GPS antennas of the vehicle positioning system. This positioning system is supplemented with an inertial measuring unit located in the trunk and with an odometer, which allow to determine the position and speed when no GPS is available. The E-Stop system is also located on the roof, made up of a radio antenna and three GPS antennas. It is a wireless system to safely stop the vehicle in case of extreme emergency. The computer system is located in the trunk, and consists of six computers with installed Linux operating systems, three of which run the driving software, one stores data, and two are idle in redundancy mode.

Further development of automotive robotics is based on increasing computer speeds and wider use of GPS.

VII. CONCLUSION

Satellite navigation is a driving technology in Intelligent Transport System development. Vulnerable to a number of error causes, it may affect the operation and quality of ITS as well. Satellite navigation systems provide already support for a number of the error mitigation methods and techniques. We presented the research results of three use-case studies of the error mitigation techniques and methods deployment, and propose the recommendation for its utilisation.

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Real Time Human Activity Recognition on Smartphones using LSTM Networks

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***Abstract*— Activity detection is becoming an integral part of many mobile applications. Therefore, the algorithms for this purpose should be lightweight to operate on mobile or other wearable device, but accurate at the same time. In this paper, we develop a new lightweight algorithm for activity detection based on Long Short Term Memory networks, which is able to learn features from raw accelerometer data, completely bypassing the process of generating hand-crafted features. We evaluate our algorithm on data collected in controlled setting, as well as on data collected under field conditions, and we show that our algorithm is robust and performs almost equally good for both scenarios, while outperforming other approaches from the literature.**

Keywords— activity recognition; LSTM, smartphone; wearable

I. INTRODUCTION

Physical activity duration, intensity and frequency are major lifestyle factors associated with beneficial health effects across the life span [1]. Therefore, activity detection is becoming the most important part of many healthcare applications, ranging from epidemiological and clinical studies to smartphone based "stay-fit" and "weight loss" applications.

Traditional way to measure activity is by attaching special hardware devices on predefined location, like hip and ankle. Sensor measurements from those devices are recorded on internal memory, to be later analyzed for different purposes [2]. Many of the epidemiological and clinical studies still use this method in their research [1]. With the technology improvement, body sensor networks allow more advanced approach, where sensor measurements can be sent directly to the users' smartphone to be analyzed on the fly [3]. In the last few years, modern smartphones are equipped with dozens of different sensors, therefore, smartphone measurements can be used for the process of activity detection, bypassing the need for extra hardware devices [4].

There are many research in the literature that intend to perform activity detection and recognition from smartphone data [5]-[8]. In [5], different classification methods are applied (Multilayer Perceptron, Random Forest, etc.), achieving an overall accuracy rate of 91.15%. In [6], autoregressive coefficients, signal magnitude area and Kernel Discriminant Analysis are used to extract the features, while artificial neural nets are used for classification, achieving average accuracy of about 96%. Hardware-friendly approach in [7] adapts the standard Support Vector Machine (SVM) to reduce computational cost while maintaining accuracy comparable to other traditional SVM based classification methods. More recent approaches are focused on features extraction from the raw acceleration data. In [8], an unsupervised classification method is used for activity recognition.

The challenge in designing such algorithm is not only the accuracy of the algorithm, but also its computation cost, since it should operate on smartphone in real time [9]. Although modern smartphones have performances comparable with those of the computers, the power remains a challenging problem, since battery technology has not kept pace with information and communication technologies. Other issues regarding energy consumption is sampling frequency, as it is an important parameter for the accuracy of the algorithm.

The man goal of this paper was to develop a new lightweight algorithm for activity recognition, with the following characteristics: *(i)* to be easily implementable on mobile applications; *(ii)* to outperform other approaches from the literature by means of accuracy; and *(iii)* to be robust enough to perform almost equally good on data collected under field conditions as on data collected in a controlled environment. Our algorithm is based on neural network, i.e. Long Short Term Memory networks, which is able to learn features from raw accelerometer data, completely bypassing the process of generating hand-crafted features. Although this algorithm has been previously used for activity recognition [10], to the best of our knowledge, this is the first research that evaluates the algorithm on data collected from smartphone sensors.

The rest of this paper is organized as follows. In the next section, we explain the algorithm used for activity recognition, as well as tools used for its implementation as part of a mobile application. In the third section, we elaborate the data used for evaluation of our algorithm. Section four discusses the results. This paper is concluded in section five.

II. SYSTEM IMPLEMENTATION

Although there are many techniques in the literature for activity recognition, in this paper we investigated a neural network approach based on Long Short Term Memory (LSTM) networks.

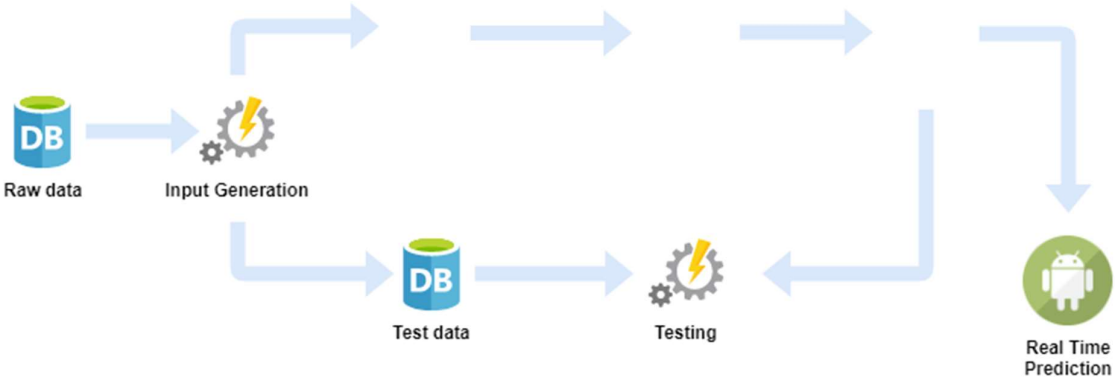

Fig. 1 Computation pipeline

LSTM network as a deep learning system is appropriate for temporal modeling and has shown improvements over Deep Neural Networks for speech recognition problem [11]. It was initially proposed by Hochreiter [12] and later improved in 2000 by Gers [13]. Since 2016, LSTM became integral part of many applications and services delivered by Google, Microsoft and Apple, including personalized speech recognition on smartphones [14] and gesture typing decoding [15]. In [10], LSTM is used for offline activity recognition, using different sensors from wearables. The authors identify that LSTM is suitable for multimodal wearables and does not require expert knowledge in designing features. Still, they do not implement LSTM on wearable devices.

In this section, a brief mathematical introduction of LSTM is given, followed by the computational procedure and software tools used for its implementation. Additionally, an Android mobile application was developed, explained in the last subsection.

A. Mathematical background

Long Short Term Memory (LSTM) networks are a special type of neural networks that remember information from further back in the past. Given a sequence of inputs $X = \{x_1, x_2, ..., x_n\}$, LSTM associates each time step with an input gate, memory gate and output gate, denoted respectively as i_t, f_t and o_t. The information from the past is remembered using the state vector c_{t-1}. The forget gate decides how much of the previous information is going to be forgotten. The input gate decides how to update the state vector using the information from the current input. The l_t vector consists of the information from the current input added to the state. Finally, the output gate decides what information to output at the current time step. This process is formalized as in (1),

$$\begin{aligned} i_t &= \sigma(W_i \cdot [h_{t-1}, x_t]) \\ f_t &= \sigma(W_f \cdot [h_{t-1}, x_t]) \\ o_t &= \sigma(W_o \cdot [h_{t-1}, x_t]) \\ l_t &= \tanh(W_l \cdot [h_{t-1}, x_t]) \\ c_t &= f_t \cdot c_{t-1} + i_t \cdot l_t \\ h_t &= o_t \cdot \tanh(c_t) \end{aligned} \quad (1)$$

where W_i, W_f, W_o and W_l have dimensions $D \times 2N$, D is the number of memory cells and N is the dimension of the input vector. These matrices represent the parameters of the network. LSTM is local in space and time since its computational complexity per time step and weight is $O(1)$ [12].

B. Computational procedure

The computation pipeline used in this study follows standard procedure. A schematic flowchart in Fig. 1 shows an outline of this process. It begins with raw data, collected in controlled laboratory setting, which is processed into sequences of length 200. Afterwards, the generated inputs are divided into a training (80%) and testing (20%) datasets. The training set is used to train the LSTM network and to generate the model. The model alongside the testing set is used to calculate the accuracy of the algorithm. Additionally, the model is transferred to an Android device as part of a mobile application which performs accelerometer measurements, real time prediction and calculation of the LSTM accuracy.

C. Implementation tools

For the implementation of the LSTM network, the Python library TensorFlow was used [16]. The data was divided into 10-second segments (sequences of 200 samples) and each segment was used as an input in the network. We use three LSTM layers with 64 neurons each. Additionally, we use a L2 regularization with loss of 0.0015. Recently, the Adam Optimizer has gained a lot of popularity, so we decided to use this optimizer with a learning rate of 0.0025. The neural network was trained for 100 epochs, as we observed that longer training than 100 epochs doesn't improve the performance.

D. Real time Android application

In order to test the real-time performance of our model, we developed an Android application. The application collects measurement from the device's accelerometer every 50ms and outputs the probability of each of the six activities occurring during the previous 10-second window. For the implementation of this application we exported our TensorFlow model and imported it in Android using TensorFlowInferenceInterface. Additionally, we use the text-to-speech Android API which tells the user the predicted activity during the previous 10-second window. A view of this application is given in Fig. 2.

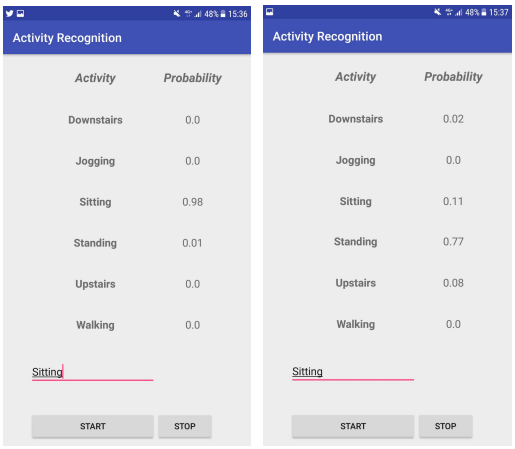

Fig.2 Interface of the Android mobile application

When algorithms are needed to be tested under field conditions, the standard procedure is by using diary, where users record their activities. This is labor-intensive task prone to errors. Therefore, our mobile application can operate in a testing mode for users that want to participate in the process of accuracy identification. As can be seen in Fig. 2, in this mode, the user can manually enter the perfromed activity, so the application is able to calculate the accuracy for each user separately.

III. DATA COLLECTION AND COMPUTATION

In this section, the datasets used in our research are explained in detail.

A. Lab Data

Our LSTM based algorithm was trained and evaluated on data collected in controlled laboratory setting as described in [17]. Hereafter, we refer to this data as *"Lab Data"*. The data was collected from 29 volunteers carrying a smartphone in their front leg pocket. The subjects were asked to do six specific activities: sitting, standing, walking, jogging, ascend stairs and descend stairs. The accelerometer data was collected using an Android application. A sample was collected every 50ms. Every sample contains a timestamp, user ID, as well as the x, y and z accelerometer values.

B. Field data

To test the generalization power of our algorithm, we collected our own dataset under field conditions, doing the same six activities outdoors in a less controlled environment. Hereafter, we refer to this data as *"Field Data"*. The accelerometer data was collected from two subjects, one male and one female, carrying a smartphone in front leg pocket. Our Android application contains the same fields and records the data with the same frequency as in [17]. We plot 10-second windows of the accelerometer data for all activities in Figures 3-8. We observe that "Sitting" and "Standing" do not have periodic behavior but can be distinguished based on the relative magnitudes of the x, y and z values. For all other activities we observe periodic behavior. As expected, the "Jogging" activity shows greatest acceleration, followed by "Walking", while "Upstairs" and "Downstairs" having smaller acceleration.

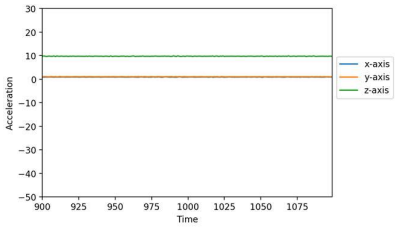

Fig. 3 Time series for activity "Sitting"

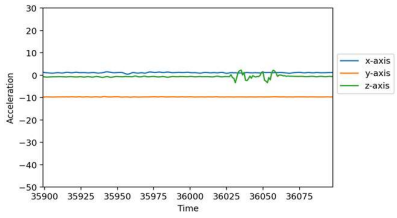

Fig. 4 Time series for activity "Standing"

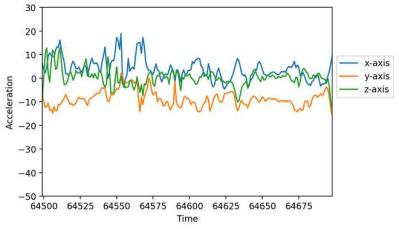

Fig. 5 Time series for activity "Walking"

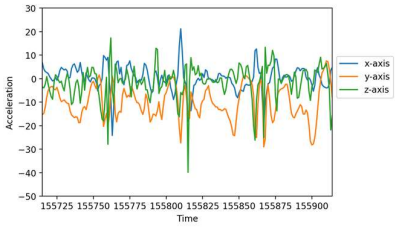

Fig 6. Time series for activity "Jogging"

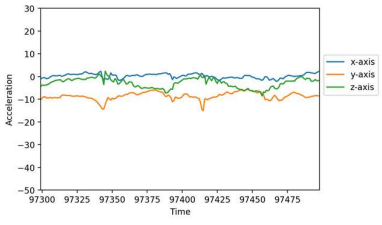

Fig 7. Time series for activity "Upstairs"

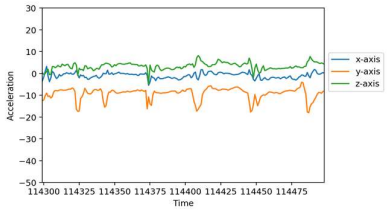

Fig 8. Time series for activity "Downstairs"

IV. RESULTS AND DISCUSSION

The results of our LSTM based algorithm were compared with the results from other methods reported in [17], as given in Table I. From the results, we can conclude that LSTM gives almost as good overall performance as the best method used in [17]. The advantage of LSTM is that it works directly with the raw accelerometer data, and completely bypasses the process of generating hand-crafted features. This allows the network to better learn the underlying data distribution. Furthermore, for the "Walking", "Upstairs", "Sitting" and "Standing" classes, LSTM gives better performance than other methods investigated in [17], i.e. decision trees J48, logistic regression, multilayer perceptron and straw man. The straw man strategy in [17] always predicts the most frequently occurring activity. LSTM achieves perfect performance on the "Standing" class. Additionally, for the classes of "Jogging" and "Downstairs", the LSTM approach is only slightly worse than the best achieved performance in [17]. Therefore, LSTM works almost as good or better than the approaches that use hand-crafted features which means that we can confidently skip the process of features selection and work directly with the raw accelerometer data.

TABLE I. % OF CORRECTLY PREDICTED ACTIVITIES

	J48	LOGISTIC REGRESSION	MULTILAYER PERCEPTRON	STRAW MAN	LSTM
WALKING	89.90	93.60	91.70	37.20	**95.30**
JOGGING	96.50	98.00	**98.30**	29.20	96.50
UPSTAIRS	59.30	27.50	61.50	12.20	**67.00**
DOWNSTAIRS	**55.50**	12.30	44.30	10.00	50.30
SITTING	95.70	92.20	95.00	6.40	**96.90**
STANDING	93.30	87.00	91.90	5.00	**100.00**
OVERALL	85.10	78.10	**91.70**	37.20	88.60

In Table II we present the confusion matrix for the LSTM model. The most important activities to analyze are the "Upstairs" and "Downstairs" activities which are most difficult to recognize. From the confusion matrix we can see that these two activities are mostly confused with each other, and less commonly with the "Jogging" activity. Looking at Fig. 7 and Fig. 8, it can be seen that these two activities are very similar and thus all the algorithms are facing difficulties to distinguish them.

The comparison between the performance on the *"Lab Data"* [17] and the *"Field Data"* is presented in Table III. From the results it can be seen that LSTM algorithm performs few percentage points worse on the *"Field Data"* for the classes of "Walking", "Jogging" and "Standing". We manage to achieve slightly better performance for the classes of "Upstairs" and "Sitting". On the other hand, we observe much worse performance for the "Downstairs" activity. We can conclude that the "Downstairs" activity is much harder to be predicted compared to other activities. This conclusion is further supported by the fact that even on the *"Lab Data"* no algorithm can achieve accuracy greater than 55% for the "Downstairs" activity. Finally, we can conclude that our algorithm is able to generalize well on data from different subjects and sources and still achieve comparable performance.

TABLE II. CONFUSION MATRIX FOR LSTM

Predicted / Actual	Downstairs	Jogging	Sitting	Standing	Upstairs	Walking
Downstairs	75	9	0	0	55	10
Jogging	8	498	0	0	5	5
Sitting	0	0	95	2	1	0
Standing	0	0	0	70	0	0
Upstairs	33	18	1	0	128	11
Walking	8	7	2	0	12	595

TABLE III. COMPARISON OF CORRECTLY PREDICTED ACTIVITIES FOR LAB DATA AND FIELD DATA (IN %)

	LAB DATA	FIELD DATA
WALKING	**95.30**	90.49
JOGGING	**96.50**	96.11
UPSTAIRS	67.00	**75.69**
DOWNSTAIRS	**50.30**	21.02
SITTING	96.90	**97.84**
STANDING	**100.00**	97.20
OVERALL	**88.60**	82.20

Each of the Figures 9-14 correspond to one activity. Each plot shows the predicted activity from *"Field Data"*. From the results, we can conclude that "Sitting" and "Standing" (Fig. 9 and Fig. 10) are correctly predicted except for several samples which can be considered as random noise. "Walking" is mainly confused with "Jogging" (Fig. 11). During our testing we observed that faster walking is generally classified as "Walking", which is probably caused by the collection strategy of the original dataset (*"Lab Data"*) on which our algorithm is trained. The "Jogging" is much less frequently confused with "Walking" which can be explained with a user slowing down to rest during the testing stage (Fig. 12). The "Upstairs" activity is mostly confused with "Walking", which might be caused by the difference in the type of stairs or the speed of climbing between the *"Lab Data"* and *"Field Data"* datasets (Fig. 13). "Downstairs" is most often confused with "Upstairs", a trend that is observed even in the original *"Lab Data"* dataset (Fig. 14).

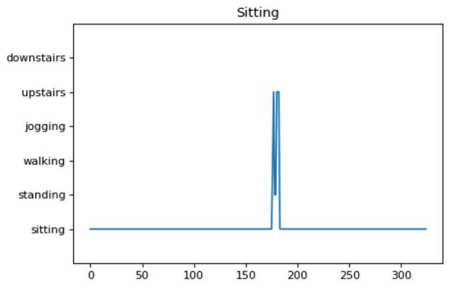

Fig. 9 Activity prediction for "Sitting" activity

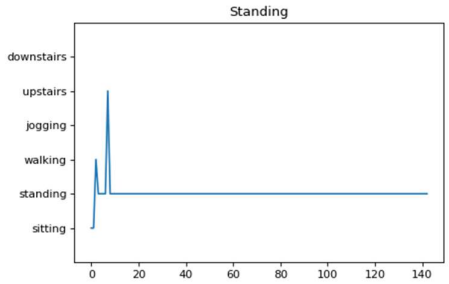

Fig. 10 Activity prediction for "Standing" activity

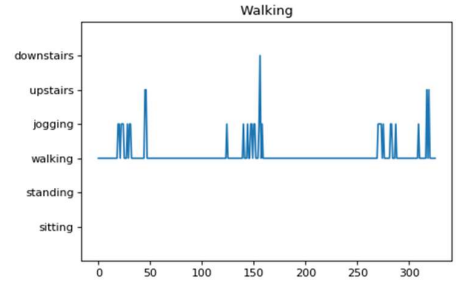

Fig. 11 Activity prediction for "Walking" activity

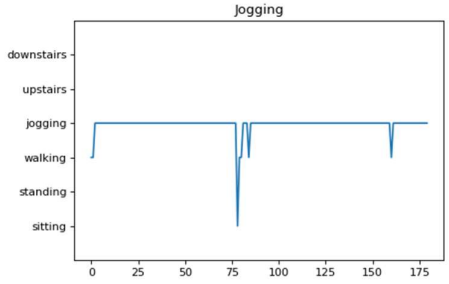

Fig. 12 Activity prediction for "Jogging" activity

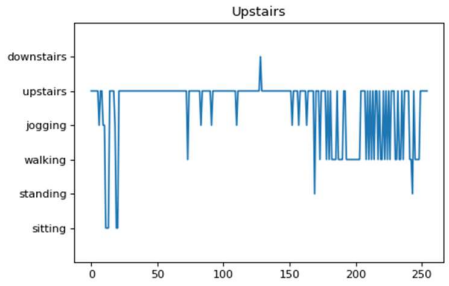

Fig. 13 Activity prediction for "Upstairs" activity

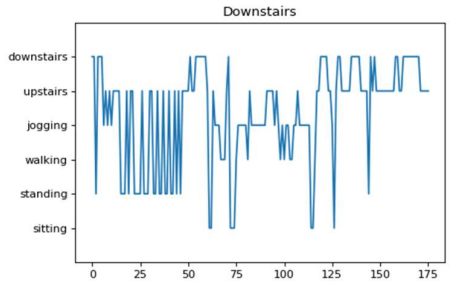

Fig. 14 Activity prediction for "Downstairs" activity

V. CONCLUSION

In this paper we developed and implemented a lightweight algorithm for human activity recognition from smartphone accelerometer data. It is based on long short term memory (LSTM) network, a relatively new approach suitable for multimodal wearables. LSTM does not require expert knowledge in designing features and learns features from raw accelerometer data, completely bypassing the process of generating hand-crafted features. Therefore, LSTM is lightweight with computational complexity of $O(1)$, appropriate to operate in real-time on wearables and smartphones.

LSTM was compared with other approaches from the literature [17], i.e. decision trees J48, logistic regression and multilayer perceptron, and it was shown that LSTM works almost as good or better than the approaches that use hand-crafted features.

To evaluate the usability of LSTM for real smartphone applications, we trained and tested our algorithm on data collected in controlled setting, but we also tested on data collected under field conditions. Our initial results show that LSTM algorithm performs almost equally good on smartphone data collected under field conditions, which makes it (and its future improvements) suitable candidate to be improved and implemented for commercial mobile applications.

ACKNOWLEDGMENT

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Upravljanje znanjem i baze znanja u kontakt centrima

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***Sažetak* - Upravljanje znanjem koje je danas potpomognuto modernom tehnologijom važan je čimbenik uspješnosti poslovnih sustava, pa tako i kontakt centara. Poseban izazov u izgradnji baze znanja kontakt centra predstavlja organiziranje i strukturiranje podataka i znanja prikupljenog kroz različite kanale, a potrebno ga je sistematizirati, strukturirati i pohraniti te potom ponovno učiniti dostupnim zaposlenicima (agentima) i korisnicima kontakt centara (također kroz različite kanale). Baza znanja kontakt centra koja uključuje različite tipove podataka, pa i multimedijske podatke, te njezino otvaranje korisnicima ima ulogu osigurati što jednostavniji pristup znanju, informacijama i podacima, i omogućiti korisniku samostalno rješenje problema prije samog poziva agentu kontakt centra. Rad istražuje moguće pristupe upravljanju znanjem u kontakt centrima kroz izgradnju baza i grafova znanja. Analiza postojećih istraživanja o korištenju koncepata upravljanja znanjem u kontakt centrima i sustavima za upravljanje odnosima s klijentima (CRM) pokazala je da u postupku integracije ova dva pristupa postoji znatan prostor za napredak, te su navedeni mogući smjerovi razvoja.**

Ključne riječi - upravljanje znanjem; baze znanja; graf znanja; kontakt centar; CRM

I. UVOD

Kontakt centri (eng. *contact centre*) koji pružaju neprestanu podršku svojim korisnicima kontinuirano se razvijaju u skladu s razvojem tehnologija i usluga, kako bi ta podrška uvijek bila što kvalitetnija. Praćenje tehnološkog razvoja omogućava sve jednostavnije, brže i praktičnije dopiranje do krajnjih korisnika, a time i učinkovitiju podršku u smislu otklanjanja problema, diseminacije informacija i marketinških ponuda.

Postojećih rješenja za kontakt centre ima mnogo, a zasnovana su na raznim dostupnim tehnologijama, platformama i sustavima. Iako postojeća rješenja pokušavaju objediniti što više mogućnosti, brzi tehnološki razvoj i potrebe korisnika potiču još veću integraciju. Pri tome je potreban visoki stupanj inovativnosti i prilagodljivosti za razvoj i plasiranje proizvoda koji objedinjuje sve pozitivne strane drugih rješenja te ujedno uvodi nove funkcionalnosti u skladu sa rastućim zahtjevima.

Kako bi se razvilo takvo integrirano rješenje za kontakt centar, potrebno je analizirati funkcionalnosti dostupnih kontakt centara s fokusom na elemente koji predstavljaju važne čimbenike uspješnosti kontakt centra: ljudske resurse i njihovu administraciju, komunikacijske kanale, mogućnosti izvještavanja, kao i mogućnosti praćenja ključnih informacija za pravilno upravljanje agentima (zaposlenicima koji odgovaraju na upite krajnjih korisnika) i prilagodbu krajnjim korisnicima, te novitetima i rastućim trendovima u području razvoja kontakt centara.

Poseban izazov pri razvoju novog integriranog rješenja predstavlja organiziranje i strukturiranje podataka i znanja koje se prikuplja kroz različite kanale, a potrebno ga je sistematizirati, strukturirati i pohraniti te potom ponovno učiniti dostupnim agentima i korisnicima kontakt centara također kroz različite kanale. Baza znanja kontakt centra i njezino otvaranje korisnicima trebali bi imati ulogu osigurati što jednostavniji pristup znanju, informacijama i podacima te omogućiti korisniku samostalno rješenje problema prije samog poziva agentu kontakt centra.

U nastavku ovog rada bit će opisan rezultat analize literature i postojećih istraživanja o stanju i važnosti upravljanja znanjem u svrhu transformacije i povećanja efikasnosti kontakt centara (drugo poglavlje) i sustava za upravljanje odnosa s klijentima (treće poglavlje). Potom se u radu analiziraju još dva važna aspekta upravljanja znanjem koja se odnose na način opisa, pohrane i dohvata multimedijskih podataka (četvrto poglavlje), te reprezentacije znanja pomoću grafa znanja (peto poglavlje). U posljednjem poglavlju su sistematizirani najvažniji zaključci analize literature i postojećih istraživanja prezentiranih u ovome radu.

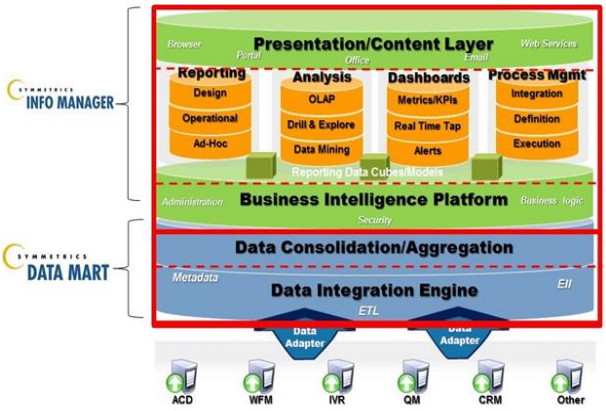
II. UPRAVLJANJE ZNANJEM I KONTAKT CENTRI

Upravljanje znanjem važno je za uspješnost poslovanja svih organizacija. Fluss [1] nabraja osam tehnologija koje su važne za transformaciju kontakt centara, a jedna od njih je upravo upravljanje znanjem, gdje bi nove informacijske tehnologije mogle odigrati ulogu u stvaranju novih rješenja, kao i u razvoju kulture upravljanja znanjem općenito. Nove informacijske tehnologije mogu pomoći u procesima stjecanja, korištenja, prilagodbe, diseminacije i generiranja znanja, pri čemu je potrebno svo eksplicitno, implicitno i kulturološko znanje koje se u raznim oblicima nalazi u kontakt centrima zapisati i oblikovati u novo znanje za kasnije korištenje [2]. Važnost spremanja znanja naglašavaju i rezultati istraživanja koje su proveli Johantab i Garcia-Perez [3] (u transportnom sektoru), pri čemu je ustanovljeno da od 9000 analiziranih slučajeva gotovo 45% korisnika nije zadovoljno uslugom, pri čemu četvrtina kao razlog navodi nedostatak ažurnih

informacija i znanja u pozivnom centru, uključujući neidentificiranje problema, nerazumljivost danih informacija te njihovu netočnost i kontradiktornost.

Heyman [4] naglašava da u kontakt centrima „*strukturirano znanje… može dosljedno osigurati efikasni pristup do točnih odgovora, na temelju korištenja i iskustva svih korisnika*“ te da također može „*omogućiti efikasnost preko višestrukih kanala komunikacije*“ (str. 410). U istraživanju koje je provedeno 2017. godine [5] pregledan je veliki broj znanstvene literature (90 radova) koja se bavi kontakt centrima, uz podjelu na analitički i menadžerski aspekt, s ciljem utvrđivanja važnih izazovnih područja koja su izostavljena iz istraživanja. Tijekom te analize Saberi, Hussain i Chang su ustanovili da se literatura s analitičkog aspekta često bavi rudarenjem podataka, rudarenjem teksta i analizom poziva, a s menadžerskog aspekta učinkom kontakt centara, kvalitetom agenata i unajmljivanjem usluge (eng. *outsourcing*) kontakt centara, te da su dva važna područja izostavljena: nedovoljna interakcija u kontakt centrima i loše upravljanje nestrukturiranim podacima. Navodeći da je 80% podataka u kontakt centrima nestrukturirano ili polustrukturirano, spomenuti autori identificiraju dva problema koja to uzrokuje: poteškoće u objedinjavanju podataka te previše složene strukturalne veze zbog heterogenosti podataka; rješenje bi mogle dati nove tehnike za povezivanje podataka, gdje se autori pozivaju na analitiku velikih podataka, ali ne i na poboljšavanje same strukture baze znanja. U prilog tome govori i činjenica da je na prezentaciji dva rješenja za kontakt centre koja razvijaju i/ili administriraju hrvatske tvrtke, a kojima su autori prisustvovali, uočeno da u bazi znanja ima vrlo malo podataka te da se upisani podaci nalaze u nestrukturiranom tekstualnom obliku.

Od potencijalnih rješenja koja se razmatraju, Adelakun [6] na temelju intervjua u kontakt centru gradske uprave i SWOT analize provedene na literaturi predlaže poslovnu inteligenciju kao opće rješenje te kao primjer navodi arhitekturu rješenja tvrtke Symmetrics (koju je nedavno preuzela tvrtka Calabrio) napravljenog za izvješćivanje i analitiku rada kontakt centara (vidi Sliku 1).



Slika 1. Arhitektura rješenja tvrtke Symmetrics, preuzeto sa https://coceco.wordpress.com/2015/02/20/symmetrics-reporting-analysis-and-bi-for-contact-centers/

Arhitektura rješenja sastoji se od četiri sloja:

- operacijski sloj – sadrži transakcijske baze podataka raznih informacijskih sustava kao što su WFM (eng. *Workforce Management* – upravljanje radnom snagom) ili CRM (eng. *Customer Relationship Management* – sustav za upravljanje odnosima s klijentima);
- sloj pristupa i postavljanja – uključuje ekstrahiranje, konsolidaciju, integraciju i agregaciju podataka iz informacijskih sustava i njihovu pripremu za spremanje pomoću ETL procesa (eng. *Extract–Transform–Load* – dohvati-preoblikuj-učitaj);
- skladište podataka / Data Mart – centralni repozitorij koji sadrži podatke i informacije iz različitih informacijskih sustava;
- prezentacijski i upravljački sloj – sloj za interakciju i razmjenu informacija.

Zastarjela i/ili neintegrirana tehnologija koja onemogućava pristup potrebnim informacijama onda kada su potrebne predstavlja najveći izazov koji identificira čak 44% ispitanih organizacija i njihovih odjela za odnose s klijentima u istraživanju koje je 2016. godine napravio CCIQ, te će stoga najveći broj organizacija, njih čak 55,3% povećati ulaganja upravo u tehnologiju [7]. Kako ističe tvrtka Calabrio [8], takva situacija stvara silose, nepovezane informacije i znanje, koji su prepreka protoku podataka, te tvrdi da polovina kontakt centara prelazi u oblak, čime se može riješiti navedeni problem.

Iako se upravljanje znanjem uz korištenje moderne tehnologije smatra važnim elementom razvoja kontakt centara, dosadašnja istraživanja vezana uz kontakt centre uglavnom nisu bila usmjerena na oblikovanje strukture baze znanja koja bi poboljšala pristup do ažurnih i točnih informacija u različitim oblicima, već više na analitiku raznih heterogenih i nestrukturiranih informacija. Stoga je provedena analiza vezana uz važne elemente kontakt centara, a to su odnosi s klijentima i, vezano uz njih, zahtjevi za različitim kanalima komunikacije za prijenos različitih formata zapisa informacija koje je pak potrebno spremiti u bazu znanja.

III. SUSTAVI ZA UPRAVLJANJE ODNOSIMA S KLIJENTIMA (CRM)

U radu kontakt centara često se koriste i sustavi za upravljanje odnosima s klijentima (CRM) ili njihove izvedenice. Stoga, cilj ovoga poglavlja je prikazati rezultate analize literature i postojećih istraživanja na temu upravljanja znanjem u CRM sustavima.

Lin, Su i Chien [9] su prezentirali model upravljanja odnosima s klijentima baziran na znanju (eng. *knowledge-enabled customer relationship management*). Smatraju da i CRM i pristup upravljanja znanjem može imati pozitivan utjecaj na smanjenje troškova i povećanje dobiti. Poboljšanje odnosa s klijentima korištenjem upravljanja znanjem može generirati velike poslovne mogućnosti. Dostupnost velike količine podataka o klijentima u modernim informacijskim sustavima kreirala je mogućnosti, ali i izazove za poslovne organizacije da se ti podaci iskoriste za stjecanje prednosti pred konkurencijom [9]. Provedene su i tri studije slučajeva [10] na tvrtkama Union Investment, Siemens i Credit Suisse s ciljem otkrivanja najboljih praksi koje primjenjuju znanje za, od i

o klijentima u svrhu nadogradnje CRM sustava. Istraživanje je pokazalo da svi smatraju da je domena upravljanja znanjem bitna u CRM sustavima, ali da se zasad slabo implementira u praksi [10]. Podržavanje CRM procesa sa efikasnom primjenom znanja o korisnicima vodi do značajnih poboljšanja performansi, bilo poboljšanjem kvalitete, smanjenjem potrebnog vremena rada ili čak smanjenjem troškova.

Povezanost između upravljanja znanjem i uspješnosti CRM-a korištenjem SEM metode na 153 španjolska hotela istražili su Garrido-Moreno i Padilla-Melendez [11]. Zaključak empirijskog testiranja njihovog modela potvrdio je da je uloga organizacijskih faktora (liderstvo top menadžmenta, upravljanje ljudskim resursima, funkcijska integracija i organizacijska struktura) u implementaciji CRM sustava neizostavna. Iako se u literaturi često naglašavala uloga upravljanja znanjem kod uspješnosti CRM sustava, njihovo je istraživanje [11] pokazalo da su stvarni preduvjeti za to vezani uz organizacijske varijable. Kako bi inicijative uvođenja upravljanja znanjem u CRM sustave bile uspješne, prvo treba napraviti promjene na organizacijskoj razini.

Četverogodišnje istraživanje u Velikoj Britaniji [12] otkrilo je da su CRM sustavi implementirani od strane mnogih organizacija, ali još uvijek dominira operacionalna primjena poput kontakt centara, te rješenja za prodaju i marketing s ograničenim znanjem o korisnicima dobivenih od samog CRM sustava. Analitička sposobnost CRM sustava još nije do kraja prepoznata u organizacijama. Autori [12] predlažu da se CRM sustavi trebaju nadograditi mogućnostima sustava za upravljanje znanjem kako bi se razvila sposobnost rada sa znanjem o korisnicima. Također, Gebert, Geib, Kolbe i Brenner [13] tvrde da se prednosti korištenja CRM i sustava za upravljanje znanjem mogu proširiti, a istovremeno i smanjiti rizik od neuspješne primjene ovih tehnologija, ako se zajedno integriraju oba pristupa. Upravljanje znanjem pritom preuzima ulogu pružanja usluge CRM sustavu tako da upravlja s četiri glavna aspekta znanja: sadržajem, kompetencijama, kolaboracijom i kompozicijom kako bi se zadovoljili zahtjevi klijenata unutar predviđenih ograničenja budžeta. Stoga, korištenje upravljanja znanjem u CRM-ovima je još u inicijalnoj fazi, pa ima dosta prostora za unapređenje u znanstvenom i stručnom pogledu.

IV. MULTIMEDIJSKI PODACI U KONTAKT CENTRIMA

Kontakt centri generiraju veliku količinu podataka koji nisu isključivo tekstualne prirode. U tipičnom pozivnom centru, razgovor korisnika i agenta se uobičajeno snima te pohranjuje u digitalnom audio formatu. U modernom kontakt centru zahtjev korisnika može biti zaprimljen u tekstualnom obliku, npr. putem web sučelja pričaonice (npr. *chata*), ili u obliku statičnih/dinamičnih slika, npr. fotografije ili videa koji su poslani putem e-pošte.

Osim multimedijskih podataka koji se generiraju tijekom rješavanja korisničkog problema, postoji potreba i za multimedijskim podacima u bazi znanja, kako bi agent ili krajnji korisnik iz baze znanja mogao dobiti upute za potencijalna rješenja korisničkog problema, i to ne samo u tekstualnom obliku, već i u obliku slike ili npr. videa kojim se pojašnjava procedura otklanjanja problema. U tom kontekstu, primjena multimedijske baze znanje uvelike bi olakšala i ubrzala proces rješavanja korisničkih upita. Međutim, upravljanje podacima u multimedijskim bazama podataka, a naročito u multimedijskim bazama znanja predstavlja značajne izazove opisane u nastavku.

Stanje u području multimedijskih baza podataka (eng. *Multimedia Database*, MMDB) sažeto je predstavljeno u članku Chena iz 2012. godine nazvanom *Multimedia Databases and Data Management: A Survey* [14]. Autor navodi da je jaz između karakteristika različitih tipova multimedijskih podataka (teksta, slike, zvuka, videa, animacije) i zahtjeva aplikacija (stolnih, web, mobilnih) doveo do potrebe razvoja naprednijih tehnika upravljanja multimedijskim podacima i ekstrakcije relevantnih informacija iz multimedijskih baza. Iako se konceptualno čini da se upravljanje multimedijskim podacima može ostvariti na isti način kao upravljanje ostalim tipovima podataka u relacijskim bazama podataka; prostorne, temporalne i prostorno-temporalne karakteristike multimedijskih podataka postavljaju veliki izazov za njihovo upravljanje. Sukladno [14], tradicionalni sustavi baza podataka ne mogu pružiti adekvatnu podršku upravljanju, pregledavanju i pretraživanju multimedijskih podataka zbog sljedećih ograničenja: a) nedostaje im sposobnost upravljanja kompozicijom i sinkronicitetom među multimedijskim objektima, b) nedostaje im funkcionalnosti za upravljanje prostorno-temporalnim odnosima između multimedijskih objekata, c) limitirane su u pogledu semantičkog modeliranja vremenski ovisnih multimedijskih podataka poput zvuka i videa, te d) ne obuhvaćaju sve karakteristike za pronalaženje multimedijskih podataka.

Prema Chenu [14] izazovi i otvorena pitanja koji još nisu optimizirani u postojećim rješenjima su veličina multimedijskih podataka (naročito veličina video datoteka, koja ovisi o formatu pohrane i primijenjenom algoritmu za sažimanje podataka), sinkronizacija multimedijskih podataka (npr. video zapis osobe koja nešto pojašnjava treba biti sinkroniziran s govorom) te pretraživanje i pronalazak relevantnih multimedijskih podataka koje se temelji na sadržaju (tzv. semantičko pretraživanje). Dodatno, različiti tipovi multimedijskih podataka u MMDB zahtijevaju naprednije automatske analitičke tehnike koje bi generirale opise visoke razine i zahtijevaju označavanje tih podataka za jednostavnije pronalaženje.

Prema Subrahmanianu (citirano u [14]) zajedničke karakteristike medija uključuju: a) tip medija, npr. slika, video zapis i sl.; b) skup objekata koji se pojavljuju u mediju, npr. pas (na slici), gol (u video snimci zabijanja gola u nogometnu mrežu); c) atributi koji opisuju svojstva objekata, a mogu uključivati prikaz odnosa, npr. opis prostora u kojem se nalazi pas na slici, ili navođenje imena igrača i utakmice na kojoj je realiziran gol; d) ostale relacije stanja, svojstva i atributa koji mogu ovisiti ili biti neovisni o objektu medija.

Osim zajedničkih karakteristika medija, važno je i semantičko razumijevanje multimedijskih podataka. Opisi slika i videa ne bi se trebali temeljiti isključivo na opisu strukture podataka (sintakse), nego bi trebali uključivati i značenje podataka (semantiku). Pristupe semantičkoj

analizi video podataka, između ostalih, predstavili su još 2004. godine Fan i suradnici, te 2008. godine Shyu i suradnici [14]. S porastom količine raznih multimedijskih skupova slika i video zapisa, Jónsson i suradnici [15] navode potrebu za integracijom nekoliko područja (analitike vizualnih informacija, analize multimedijskih podataka i upravljanje bazom podataka), kako bi se ostvarila tzv. skalabilna multimedijska analitika koja će omogućiti točan uvid u sadržaj multimedijskih podataka. Ekstrakciju važnih podataka iz multimedijskih datoteka danas je moguće postići i novim tehnikama rudarenja multimedijskih podataka, poput primjene tehnika dubinskog učenja u području vizualnog rudarenja podataka, kako bi se omogućilo pretraživanje podataka prema sličnosti, identificirale veze među podacima i u svrhu klasifikacije podataka [16].

Multimedijski podaci u bazama znanja temelje se na semantičkom označavanju multimedijskog sadržaja. Postoje različiti pristupi rješavanja problema razumijevanja multimedijskih podataka. Ivasic-Kos i suradnici [17] predstavili su pristup prepoznavanja objekata na slikama koji se temelji na višerazinskoj klasifikaciji slika uz upotrebu neizrazitih Petrijevih mreža. Ontologije su posljednjih godina popularan način za izoliranje, pronalazak, organiziranje i integriranje informacija prema njihovim osnovnim karakteristikama, tj. semantičkom kontekstu. Multimedijske ontologije omogućuju vizualizaciju sadržaja, dijeljenje znanja i učenje te mogu biti modelirane na način da su usklađene s postojećim standardima za opis multimedijskih podataka [18]. Standard MPEG-7 pruža dobro polazište jer, kreiran sa svrhom da opiše multimedijski sadržaj datoteke, u svojoj strukturi, koja je objašnjena u [19], definira element koji podržava unos semantičkog opisa multimedijskog sadržaja. Primjer kreiranja multimedijskih ontologija temeljenih na MPEG-7 opisuje Rinaldi u članku iz 2017. [20], navodeći kako se ne radi o trivijalnom postupku, a u svojem pristupu koristi semantičke mreže.

Jedan od pristupa izradi multimedijske baze znanja temeljene na standardima dali su Lunesu, Pani i Concas [18] kroz definiranje ontologije koja reprezentira semantiku multimedijskog sadržaja i metapodatke o sadržaju, uz korištenje postojećih standarda za opis podataka: Adobe XMP, DUBLIN CORE, EXIF, IPTC. Spomenuti autori izradili su pomoću alata Protegé ontologiju za semantiku metapodataka iz različitih tipova multimedijskih podataka, koja omogućuje prihvaćanje sadržaja sa društvenih mreža (YouTube, Flickr) ili iz sustava za uređivanje sadržaja (CMS), uz pohranu informacija o geolokaciji. Autori smatraju da je ontologija i njena struktura pogodna za izradu softverske platforme koja bi omogućila prikupljanje i dodavanje sadržaja koji potječu iz različitih izvora (web portala, lokalno pohranjenih datoteka) i koji će se moći ocjenjivati i komentirati [18]. Osnovne klase koje su bile uključene u izgradnju ontologije sastojale su se od sljedećeg: a) multimedijskog sadržaja – klasa koja formalizira poveznicu na pripadni multimedijski format; b) multimedijskog formata – format zapisa na dvije razine: kategorizacija formata zapisa (npr. slika) i format unutar pojedine kategorije (npr. jpeg); c) metapodataka – podklasa koje su reprezenti zapisa metapodataka iz spomenutih standarda (XMP, DC, EXIF, IPTC); i d) XMP tipa – sva svojstva koja su predstavljena u metapodacima imaju svoju poddomenu u obliku XMP klase.

Struktura repozitorija obrazovnih sadržaja također bi se mogla iskoristiti za kreiranje strukture multimedijskih baza znanja za potrebe kontakt centra. Istraživanja strukture obrazovnih repozitorija najviše idu u smjeru pronalaska adekvatnih načina označavanja i pretraživanja video zapisa. Repp i suradnici [22] predlažu algoritam za semantičku anotaciju videa (snimljenih predavanja nastavnika) temeljen na ekstrahiranju metapodataka o videu iz dva izvora: a) sadržaja okvira (eng. *frameova*) u videu i transkribiranju govora pomoću *algoritma* za prepoznavanje govora te b) prirodnog govora mapiranog u koncepte/uloge u ontologijama. Metapodaci su zapisivani u OWL formatu (eng. OWL - *Web Ontology Language*), koji se temelji na formalizmu deskriptivnih logika. Njihovo rješenje nije ograničeno samo na označavanje video lekcija, već se može koristiti za prepoznavanje i označavanje bilo kakvog sadržaja (videa, animacije, zapisa zvuka) koji sadrži govor.

Uz različite pristupe i algoritme koje predlaže znanstvena zajednica, industrija i organizacije za standardizaciju također nude svoja rješenja za semantički opis multimedijskih podataka. Godine 2012. konzorcij W3C je objavio „Ontologiju za medijske izvore“ kao službeni standard [21]. Ontologija definira temeljne metapodatke (svojstva) za medijske resurse te njihovo preslikavanje u elemente drugih standarda i formata vezanih uz multimediju, kao i u elemente multimedijskih spremnika odnosno video formata (npr. MP4, OGG i dr.).

V. REPREZENTACIJA ZNANJA KONTAKT CENTRA

Da bi agenti u kontakt centrima mogli pronaći točne odgovore na pitanja korisnika, važno je da su u mogućnosti razumjeti što se od njih traži, odnosno pitanje ili problem korisnika. Strukturiranje znanja u kontakt centrima omogućuje agentima pregled svih informacija kojima centar raspolaže, pa se od agenata jedino očekuje da prepoznaju o kojem se problemu radi [2]. Nakon što se identificira problem, pretraživanjem baze znanja kontakt centra jednostavno je pronaći rješenje korisnikovog problema, što povećava efikasnost agenata u rješavanju korisničkih zahtjeva.

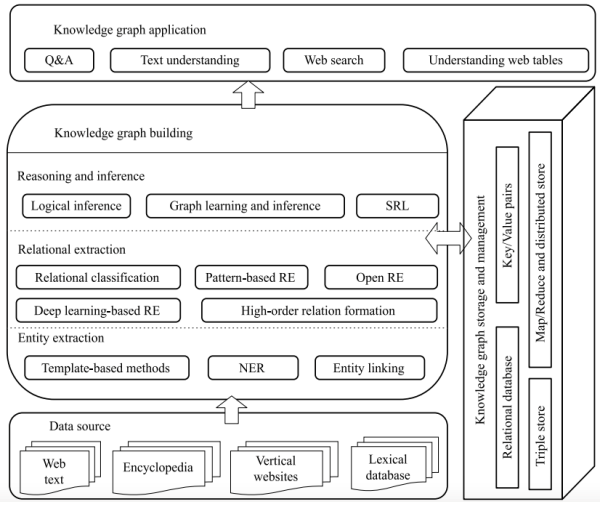
Jedan od načina efikasne reprezentacije znanja je graf znanja (eng. *knowledge graph*) koji se često poistovjećuje s bazom znanja. Graf znanja je semantički graf čiji čvorovi predstavljaju entitete iz stvarnog okruženja, dok veze predstavljaju semantičke veze između tih entiteta [23]. Danas najpoznatiji i najrazvijeniji graf znanja je 2012. godine razvio Google i koristi ga za pružanje što preciznijih i boljih odgovora na upite korisnika u tražilici te povećanje relevantnosti odgovora u rezultatima pretraživanja u što kraćem vremenu [24].

Za pohranu podataka u grafu znanja može se koristiti niz tehnologija iz skupine relacijskih ili (danas sve popularnijih) NoSQL tehnologija. Glavna je prednost NoSQL tehnologija veća fleksibilnost u pohrani podataka i cjelokupna skalabilnost sustava. Koncept NoSQL baza podataka obuhvaća sljedeće pristupe pohrani [25]:

- Ključ-vrijednost baze pohranjuju podatke kao parove ključ-vrijednost (npr. Redis);
- Baze podataka temeljene na dokumentima pohranjuju podatke kao dokumente s atributima u obliku parova ključ-vrijednost (npr. MongoDB);
- Stupčaste baze pohranjuju podatke kao stupce u tablici, gdje svaki novi redak označava atribut i vrijednost atributa (npr. Cassandra);
- Grafovske baze pohranjuju podatke kao čvorove i veze s atributima i oznakama (npr. Neo4j).

U svom su radu, Yan i suradnici [23] predstavili okvir za izgradnju grafa znanja koji je prikazan na slici 2 i koji je orijentiran na pohranu i upravljanje grafom znanja (eng. *knowledge graph storage and management*). Autori su u radu identificirali nekoliko mogućih modela i tehnologija pohrane grafa [23]:

- relacijske baze podataka (G-store u PostgreSQL-u) – danas često korištene, ali nisu primarno namijenjene upravljanju velikim grafovima;
- parovi ključ-vrijednost (VertexDB, CouchDB) – fleksibilnije rješenje koje je moguće skalirati;
- RDF trojke (AllegroGraph, Neo4j, DEX) – "najprirodniji" način pohrane i upravljanja grafom znanja prisutan i u grafovskim bazama;
- Map/Reduce i distribuirana pohrana (Hadoop) – pristup pogodan za efikasno paralelno procesiranje velikog grafa pohranjenog na nekoliko računala.



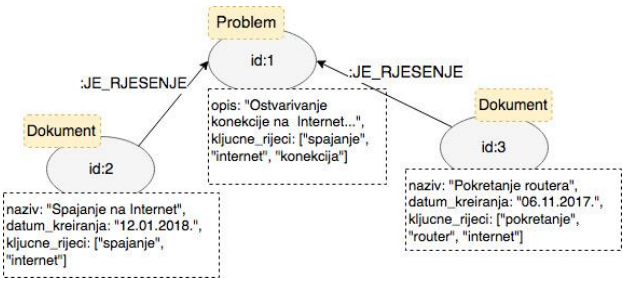
Slika 2. Okvir za izgradnju grafa znanja [21]

Primjerice, ukoliko bi se za generiranje i izgradnju grafa znanja kontakt centra odabrala tehnologija grafovskih baza podataka (npr. Neo4j) i grafovskog modela podataka sa svojstvima u njenoj pozadini, graf znanja kontakt centra mogao bi se prikazati u obliku međusobno povezanih čvorova, kao što je prikazano na slici 3. U prikazanom modelu čvorovi se međusobno razlikuju prema oznaci (Dokument ili Problem) i imaju svoje atribute, a dokumenti koji predstavljaju rješenje određenog problema u modelu podataka prikazani su kao čvorovi s oznakom Dokument koji su povezani vezom tipa :JE_RJESENJE sa čvorom s oznakom Problem. Prilikom izvršavanja korisnikova upita nad grafom znanja kontakt centra, na temelju ključnih riječi iz sadržaja njegova upita moguće je identificirati problem. Za dohvaćanje svih dokumenata koji rješavaju zadani problem iz grafa znanja, sintaksa korisnikova upita bila bi sljedeća (napisano u Cypher upitnom jeziku za Neo4j):

MATCH (d:Dokument)-[:JE_RJESENJE]->(p:Problem)

RETURN d

Izvršavanjem navedenog upita korisniku bi se prikazali svi dokumenti čije ključne riječi odgovaraju ključnim riječima njegova problema.



Slika 3. Primjer modela podataka za graf znanja kontakt centra

Grafovske baze podataka, konkretno Neo4j sustav, koristili su i Caldarola i Rinaldi u svom radu [26] u kojem su pomoću grafovskog modela podataka sa svojstvima i koncepta semantičkih mreža prikazali informacije koje se prikupljaju u online multimedijskim društvenim mrežama (engl. Online Multimedia Social Network). Osim izgradnje grafa znanja, Downing [27] je analizirao upotrebu alata za upravljanje znanjem u pozivnim centrima (eng. *call center*). Iz provedene studije slučaja u pozivnim centrima zaključio je kako je upotreba alata za upravljanje znanjem omogućila rješavanje 80% korisničkih zahtjeva i pitanja, te je, osim povećanja broja uspješno riješenih zahtjeva, rezultirala i većom pouzdanosti i točnosti odgovora na korisničke zahtjeve. Međutim, istraživanje je pokazalo kako korišteni alati za upravljanje znanjem nisu imali značajan utjecaj na vrijeme razgovora agenta s korisnikom, te zbog svoje kompleksnosti zahtijevaju određeno vrijeme prilagodbe agenata. Downing je procijenio kako budućnost upravljanja znanjem u pozivnim i kontakt centrima leži u primjeni protokola za pretraživanje temeljenih na prirodnom jeziku (eng. *natural language search protocol*) i analizi teksta [27].

Prema tome, za pohranu znanja kontakt centra i izgradnju grafa znanja na raspolaganju stoji niz relacijskih i nerelacijskih tehnologija, a odabir tehnologije je uvjetovan okolnostima, karakteristikama te prirodom kontakt centra.

VI. ZAKLJUČAK

Upravljanje znanjem koje je danas potpomognuto modernom tehnologijom važan je čimbenik uspješnosti poslovnih sustava, pa tako i kontakt centara. Međutim, pregled dosadašnjih istraživanja u tom području pokazuje da ona uglavnom nisu bila usmjerena na jedan od važnih elemenata upravljanja znanjem – bazu znanja i njezinu strukturu, odnosno način spremanja podataka i informacija. Većina istraživanja usmjerena je na analitiku

heterogenih i nestrukturiranih informacija, pokušavajući time nadoknaditi nedostatak strukturiranja same baze znanja. S obzirom da oblikovanje strukture baze znanja može poboljšati pristup do ažurnih i točnih informacija u potrebnom obliku, a time poboljšati i uslugu korisnicima kontakt centra, potrebno je također usmjeriti napore i u modeliranje njezine optimalne strukture.

Inicijalno pretraživanje znanstvenih radova o korištenju upravljanja znanjem unutar CRM sustava pokazalo je da ima puno prostora za napredak u sinergiji ova dva pristupa, pošto je većina pokušaja njihove integracije još u početnoj fazi. Uključivanja sustava ili modula za upravljanje znanjem u CRM sustav predstavlja jedan od načina transformacije kontakt centra u efikasne sustave sa zadovoljnim korisnicima.

S porastom količine multimedijskih podataka koji se generiraju na internetu, značaj njihove pohrane te pretraživanja i relevantnog dohvaćanja postaje sve veći. Veliki problem u upravljanju nestrukturiranim ili polustrukturiranim multimedijskim podacima predstavlja njihova veličina, sinkronizacija te pretraživanje i pronalazak relevantnih multimedijskih podataka temeljeno na sadržaju u podacima. Problem se potencijalno može riješiti pomoću multimedijskih baza znanja u kojima se opisi tih podataka ne bi trebali temeljiti isključivo na opisu strukture podataka (sintakse), nego bi trebali uključivati i značenje podataka (semantiku). Primjeri rješenja koji bi bili relevantni za izradu multimedijskih baza znanja u kontakt centrima mogu se pronaći u znanstvenim radovima koji opisuju semantičko označavanje podataka i semantičko pretraživanje.

Poseban problem koji se nameće pri implementaciji baza znanja su načini reprezentacije znanja. Graf znanja jedan je od načina reprezentacije čijim se korištenjem znatno može poboljšati efikasnost i kvaliteta odgovora na upite korisnika. Iako je potrebno prilagodba agenata na takav način reprezentacije znanja, korištenje grafa znanja osim povećanja broja uspješno riješenih zahtjeva, rezultira i većom pouzdanosti i točnosti odgovora na zahtjeve korisnika.

Rezultati analize postojećih istraživanja prikazani u ovom radu nedvojbeno pokazuju da bi poboljšanje strukture baze znanja doprinijelo poboljšanju usluge korisnicima kontakt centara, a postojeća rješenja još uvijek se ne grade na mogućnostima koje pružaju baze znanja. To nam daje za pravo zaključiti da su poželjna i potrebna daljnja istraživanja u svrhu optimizacije korištenja baza znanja u kontakt centrima.

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Inteligentni sustavi budućnosti za aplikativnu tribologiju

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Sažetak - Tribologija kao interdisciplinarna, obuhvaća prvenstveno strojarstvo, metalurgiju, kemiju i fiziku. U današnjem, izotropnom dobu, područje njezine glavne primjene su mehaničke konstrukcije i materijali čije je ponašanje predvidivo. U skoroj budućnosti očekuje se primjena anizotropnih materijala u području tribologije, koji će postati „pametni materijali" koji „surađuju" i pridonose poboljšanju stanja na mjestu gdje su ugrađeni. U radu je prikazano na idejnoj razini buduće rješenje zaštite broda u kojem pametni materijali surađuju i uklanjaju koroziju i druge štetne tvari nataložene na oplatu te time zamjenjuju ljude na održavanju i štede vrijeme i novac. Nanosenzori kao komponente novih mikro–elektro-mehaničkih sustava, (MEMS-a), uz pomoć inteligentnih sustava kognitivne kibernetike, preuzimaju, pohranjuju i prosljeđuju relevantne podatke uz pomoć kojih je moguće trenutno djelovanje, a s obzirom na svojstva anizotropnosti materijala koji se primjenjuju i koncepta „big data" moguće je učenje za budući razvoj.

Ključne riječi - tribologija, katodna, zaštita, pametni materijali, nanosenzori, MEMS

I. UVOD

Spoznaja kako uslijed korozijskih procesa samo u SAD-u na različitim konstrukcijama i objektima kao što su mostovi i brodovi nastaju štete procijenjene na 100 milijardi US $ godišnje bila je izazov da se pristupi istraživanju novih postupaka površinskog čišćenja i antikorozivne zaštite. Odabir sustava zaštite i njezino projektiranje kako je danas uobičajeno, (najčešće katodna zaštita), potrebno je za svaki objekt prilagoditi uvjetima koji vladaju u njegovom neposrednom okolišu, mediju, ali i infrastrukturi. Projektiranje sustava antikorozivne zaštite nije jednostavno i zahtjeva suradnju velikog broja stručnjaka iz različitih prirodnih i tehničkih znanstvenih disciplina i to od početka proizvodnje i zaštite materijala do ugradnje i održavanja u objektu za koji je materijal namijenjen. Nove generacije anizotropnih i pametnih materijala u kombinaciji s novim generacijama nanosenzora a na spoznajama tribologije, u budućnosti mogu pridonijeti racionalizaciji svih troškova antikorozivne zaštite i nekih postupaka održavanja objekata, (npr. brodova), tijekom eksploatacije. Inteligentni sustavi kognitivne kibernetike u mogućnosti su za takve uvjete prikupljati, obrađivati i odašiljati informacije o stanju strukture mjereći omjere ključnih pokazatelja, poput temperature, vlage, prisutnosti različitih elemenata i spojeva poput klora, ugljikovog dioksida, amonijaka, vodikovog peroksida, te različitih plinova. Informacije dobivene ovakvim tehnikama nadzora omogućuju donošenje važnih odluka vezanih uz stanje objekta kojeg nadziru, održavanja, popravake i zamjene. Razvijene su serije više vrsta bežičnih uređaja s nanosenzorima i daljinskim upravljanjem koji se već široko koriste u području transporta, komunikacija, medicine i u vojne svrhe. Istraživanjem je zaključeno da će u budućnosti baš iz razloga ogromnih ušteda i racionalizacije takav razvoj uslijediti i na području antikorozivne zaštite, [1].

A. Tribologija, pametni materijali i nanotehnologije

Tribologija, (grč. *τρίβειν* = trljati), proučava zbivanja na površinama dvaju tijela, (triboelemenata), koji su u dodiru ili relativnom gibanju i međusobno se troše trenjem ali i međusobnim podražajem izazivaju različite efekte, (mehanički, toplinski, biološki, kemijski, biokemijski, optički, magnetski, elektro-osmotski, elektrostatički, piezoelektrični,...). Termin tribologije uveo je Peter Jost još 1966. godine i u samom početku, njena je zadaća bila pronaći odgovarajuće mjere primjenom kojih se sprječava ili smanjuje trenje i trošenje, to jest, postižu se njihove prihvatljive vrijednosti. Danas je područje koje obuhvaća tribologija proširenо i kroz nju se analiziraju ulazni podražaji koji potiču na djelovanje triboelemenata. Nakon primljenog podražaja utvrđuje se odnos među triboelementima odnosno aktivnost ili pasivnost samog materijala te mogućnost promjene unutarnjih svojstava i pretvorbe forme energije primijenjene u ulaznom podražaju. Analizira se i zaključuje na mogućnost kreacije i stvaranja još boljih specifičanih svojstava samog materijala, izbora materijala za zaštitu površina od trošenja, uhodavanja, početnog trošenje kao i tehnoloških obrada. U tom se području zahvaljujući novim saznanjima i novim tehnologijama došlo do "pametnih materijala". U izotropnom stanju materijali se ponašaju predvidivo i kad im se dodijeli određena zadaću, oni je izvršavaju. Ne idu izvan tog konteksta i zapravo su "uniformirani". U anizotropnom stanju koje je podloga za unaprjeđenja svojstava triboelemenata kao pametnih materijala zaključuje se na njihovu suradnju kojom oni sami pridonose poboljšanju stanja čime je započeto novo područje nanotehnologija. U mokrim ili suhim anizotropnim postupcima na materijalima kao što su različiti minerali, metali, polimeri i keramika, pomoću reaktivnih iona, (engl. *Reactive Ion Etching* – RIE), dobivaju se trodimenzionalne, (3D), strukture. [2]. Takve 3D strukture su osnova komponenti kao što su senzori za uređaje mikro-elektro-mehaničkih sustava, (engl. *Micro*

Electro Mechanical Systems - MEMS). Nakon provedenih, opširnih i uspješnih testiranja nanotehnologije čak i u svemirskim uvjetima u ožujku 2006. godine na NASA-inom Nano Chem Sensor Unit-u do danas bežični MEMS uređaji s nanosenzorima postali su neizostavne ugradbene komponente i samo-senzibilne strukture. Komponente i uređaji nanotehnologije su našli široku primjenu i koriste se u danas najviše u mobilnim telefonima, inteligentnom streljivu, mjeračima ubrzanja i tlaka, žiroskopima, magnetometrima, mikroogledalima, minijaturnim robotima, zupčanicima, pumpama za fluide, generatorima mikrokapljica, optičkim skenerima, uređajima za analizu i dobivanje slika, kemijskim analizatorima, sondama za ispitivanje površine i dr. Proizvodnja i uporaba stalno raste i u 2017. godini je proizvedeno više od 9 milijardi MEMS uređaja, što predstavlja prosječan godišnji rast od 34%, [3]. Prednost su njihove dimenzije, (npr. čip s 32 senzora nešto je manji od jednog i pol centimetra), a i bitno su jeftiniji od drugih analitčkih instrumenata koji bi se mogli iskoristiti za slična mjerenja. Dodatne prednosti nanotehnologije su mala potrošnja električne energije i dugi životni vijeki, [4]. Sve je to podloga za dinamična istraživanja mogućnosti njihove primjene u budućnosti pa tako i ova prezentirana u ovom radu.

B. Antikorozivna zaštita i galvanizacija oplate broda za aplikativnu tribologiju

Prema [5], kod čeličnih konstrukcija čiji je najvažniji element željezo prisutan je problem korozije pri čemu nastaju željezni oksidi koji uzrokuju gubitak oblika i čvrstoće čelične konstrukcije. Jednadžbama od (1) do (5) opisana je reakcija koja se odvija u slučaju vlažne i kisele okoline u procesu korozije pri čemu željezo stvara Fe^{2+} ione (2), a reakcijom vode s ugljičnim dioksidom stvara se ugljična kiselina koja stvara kiseli medij za korozijske procese koji su podloga za analize zaštite materijala u različitim tehnološkim postupcima proizvodnje.

$$4H^+ + O_2 + 4e^- \leftrightarrows 2H_2O \quad (1)$$

$$Fe \rightarrow Fe^{2+} + 2e^- \quad (2)$$

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \quad (3)$$

$$2Fe + O_2 + 4H^+ \rightarrow 2Fe^{2+} + 2H_2O \quad (4)$$

$$4Fe^{2+} + O_2 + (4 + 2x)H_2O \rightarrow 2Fe_2O_3 \cdot xH_2O + 8H^+ \quad (5)$$

Produkt korozije je hidratizirani oblik željeznog oksida. Elektrokemijska reakcija na površinama koje se smatraju elektrodama, (katoda i anoda), je podloga za antikorozivnu zaštitu pri čemu je uz objekti koji se štite, potrebna i pomoćna elektroda u električnom i elektrolitnom kontaktu. Pomoću ostvarenog električnog kontakta između katode koju predstavlja određeni objekt i električki pozitivne anode ostvaruje se anodna, (6), odnosno katodna, (7) reakcija.

$$Me \rightarrow Me^{z+} + ze^- \text{ (anodna reakcija)} \quad (6)$$

$$Oks + ze^- \rightarrow Red \text{ (katodna reakcija)} \quad (7)$$

Smanjenje korozije na prihvatljivu razinu ili potpuno zaustavljanje korozijskih procesa moguće je onda katodnom zaštitom opisanom elektrokemijskim ekvivalentom koji predstavlja konstantu proporcionalnosti između količine tvari i količine elektriciteta, (8).

$$E_e = M/z \times F \quad (8)$$

Gdje je: Ee - elektrokemijski e kvivalent, M - molarna ili atomska masa, z - broj razmijenjenih elektrona u korozijskoj reakciji a F - Faradayeva konstanta, (26,8 $Ahmol^{-1}$).

Drugi efikasan način zaštite je pomoću elektrokemijskih reakcija postupkom galvanizacije. Metalni materijal, (Me), na koji se nanosi prevlaka spaja se katodno, s topljivim ili netopljivim anodnim. Zatvorenim strujnim krugom uronjenog materijala, katoda, u elektrolitne otopine i uronjenih anoda, [6], odvija se redukcija hidratiziranih metalnih iona i redukcija vodika, (9) i (10). Na anodi se otapa metal i izlučuje kisik elektrolizom vode, (11) i (12).

$$[Me(H_2O)_x]^{n+} + ze^- \rightarrow Me + xH_2O \quad (9)$$

$$2H^+ + 2e^- \rightarrow H_2 \quad (10)$$

$$Me + xH_2O \rightarrow [Me(H_2O)_x]^{n+} + ze^- \quad (11)$$

$$4OH^- \rightarrow O_2 + 2H_2O + 4e^- \quad (12)$$

Galvanizaciju gore opisanim relacijama karakterizira debljina nanošenog sloja, (13).

$$d = I \times t \times M \times \eta / F \times z \times P \times \rho \quad (13)$$

Gdje je: F - Faradayeva konstanta, (96490 C/mol), P - površina katode, cm^2, ρ - gustoća prevlake, z - broj elektrona, M - molarna masa, g/mol, I - jakost struje, t - vrijeme galvanizacije, a η - katodno iskorištenje struje.

Brodovi kao objekti koji plove, površina uronjena u vodu u triboloških je uvjetima s vodom koje u elektrokemijskom smislu definira električni otpor. To je jedan od parametara ovisan o količini otopljenih soli, (morska voda sadrži 3 do 4% soli, bočata voda 1 do 3%, riječna bočata voda 0,5 do 1,8%, a riječna voda 0,05 %. U katodnoj zaštiti analiziraju se parametri polarizibilnosti metala u morskoj vodi kao elektrolitu i veličina zaštitne struje u zavisnosti o zaštitnom premazu. Zaštitni premaz mora imati svojstva koja omogućuju primjenu katodne zaštite pri čemu nije važno koji se sustav zaštite koristi s obzirom da utjecaj ima samo veličina potencijala. Za proračun zaštitne struje važno je poznavati površinu podvodnog dijela broda koja se može izračunati na temelju stupnja uronjenosti, a što je u funkciji o količini tereta ukrcanog na brod, (14).

$$P_0 / m^2 = L_{VL}/m \times (B_{VL}/m + 2 \times T_{VL}/m) \times \delta \quad (14)$$

Gdje je: P_0 - površinu podvodnog dijela broda, L_{VL} - duljina broda na vodenoj liniji, B_{VL} - širina broda na vodenoj liniji, T_{VL} - dubina konstrukcije, δ - stupanj uronjenosti broda. Zaštitna struja se onda može odrediti sumiranjem, (15).

$$I_z = \Sigma j_{zi} \times P_i \quad (15)$$

Gdje je: P_i - površine pojedinačnih elemenata, j_{zi} - gustoće truja pojedinačnih elemenata a I_z - sumirana ukupna zaštitna struja.

Pojedine komponente koje se štite imaju različite gustoće zaštitne struje. Zaštitna struja za premaze koji se uobičajeno koriste iznosi nekoliko mA m^{-2} i naravno zbog brojnih mehaničkih i kemijskih oštećenja ta se vrijednost, u funkcijskoj ovisnosti o vremenu, povećava i do 20 mA m^{-2} u samo godinu dana. Sustavi katodne zaštite s galvanskim anodama dimenzioniraju se na srednju gustoću struje od 15 mA m^{-2}, a sustavi s vanjskim izvorom struje na 30 mA $m^{-2,}$ što ukazuje da efikasnost nije potpuna. Vrijednosti su u funkciji i s oštećenjima zaštitnih premaza. To multiplicira problem kod taloženja algi i školjki ili u slučaju ledolomaca i brodova koji plove u području ledenjaka pa se zaštite dimenzioniraju na gustoću struje od minimalno 60 mA m^{-2}, [5]. Sve to ukazuje kako projektiranje i izvedba zaštite nije jednostavna a i njena efikasnost podložna nizu parametara

C. Antikorozivna zaštita unutar zatvorenih spremnika

Pitanje antikorozivne zaštita obrađeno u prethodnim podpoglavljima odnosi se na vanjsku stranu broda. No antikorozivna je zaštita potrebna i s unutarnje strane zatvorenih posuda a koje se mogu nalaziti na brodovima. To su raznovrsne konstrukcije spremnika, cjevovoda, balastnih tankova, pumpnih stanica, itd. Sustav zaštite za njih ima svoje specifičnosti i niz drugih ograničenja. Za materijale od kojih su spremnici izrađeni i mediji koji će u njih biti pohranjeni kao i tribološka ovisnost potrebno je ustanoviti mirujuće potencijale i područja zaštitnih potencijala za svaki dio sustava kao i sve elektrokemijske reakcije koje se odvijaju kako ne bi došlo do smetnji u procesu. Veličina površine koju je potrebno štititi obrnuto je proporcionalna raspodjeli struje. Zaštitne prevlake moraju biti otporne na elektrokemijski utjecaj, a elektrode koje se koriste ne bi smjele biti od plemenitih metala ili materijala podložnih koroziji zbog opasnosti od stvaranja zapaljive smjese plinova, ovisno o uvjetima primjene. Za rješavanje svih tih pitanja potrebno je u samom početku pripreme projektiranja provesti posebne mjere, ali i predvidjeti odgovarajuća mjerenja te tijekom eksploatacije pripremiti način mjerenja i broj mjernih mjesta. S obzirom na raznovrsnost primjene ne samo na brodovima već i u kemijskoj i energetskoj industriji postoji niz ograničenja i standarda koji za specifične situacije propisuju uporabu određenih elektroda ovisno o njihovoj primjeni. Stoga su sustavi antikorozivne zaštite za ovakve potrebe još složeniji, [6]. Cjelokupnu problematiku zorno opisuje Tablica I.

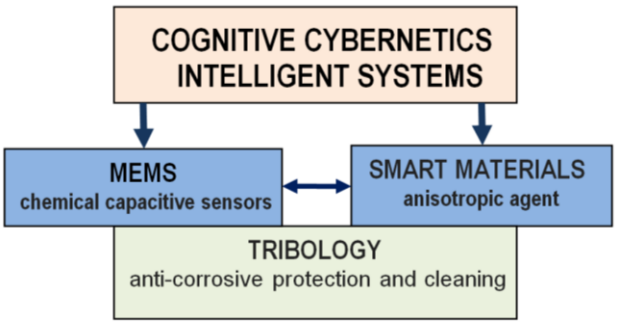
Uz sve navedeno bitan je parametar i vrsta izolacije prostora spremnika koji moraju biti električki odvojeni od drugih instalacija kako bi se mogli upotrebljavati sustavi s galvanskom anodom. U izračunu zaštitne struje mora se uzeti u obzir otpor rasprostiranja konstrukcije i otpor rasprostiranja anoda. Usporedba sustava za katodnu zaštitu konstrukcija u moru izvedenih s galvanskim anodama i s vanjskim izvorom struje za što nema ograničenja, ali postoji problem prezaštićivanja pojedinih dijelova konstrukcije kako bi ostali dijelovi bili adekvatno zaštićeni. Kod primjene ovakvih metoda koriste se inertne anode za koje je bitan parametar vijek trajanja koji treba biti što dulji uz otpornost na različite fizikalno-kemijske utjecaje i velika strujna opterećenja.

TABLICA I. USPOREDBA SUSTAVA ZA KATODNU ZAŠTITU KONSTRUKCIJA U MORU IZVEDENIH S GALVANSKIM ANODAMA I S VANJSKIM IZVOROM

Red. br.	**Parametri analize**		
	Svojstva koja utječu na izbor sustava	***Galvanske anode***	***Vanjski izvor struje***
1	Održavanje	Potrebno	Potrebno
2	Troškovi instaliranja	Prilični	Veliki
3	Anodna masa	Velika	Mala
4	Broj anoda	Veliki	Mali
5	Vijek trajanja	Ograničen	Uz održavanje
6	Izlazna struja	Ograničena, samoregulirajuća	Podesiva (ručno ili automatski)
7	Raspodjela zaštitne struje	Zadovoljavajuća, radi velikog broja anoda	Slabija radi manjeg broja anoda
8	Potrebna posebna kvaliteta premaza u blizini anoda	Općenito nije potrebna	Potrebne su posebne mjere
9	Cijena za uobičajenu duljinu zaštite	Općenito uvjetovana za objekte preko 10 godina	Uvjetovana za velike objekte preko 20 godina

II. BUDUĆNOST APLIKATIVNE TRIBOLOGIJE UZ INTELIGENTNE SUSTAVE KOGNITIVNE KIBERNETIKE

Futuristički prijedlog rješavanja izložene problematike ponudila je obrada uz pomoć inteligentnih sustava kognitivne kibernetike, [7 - 8], slika 1.



Slika 1. Koncept rješavanja problema korozije pametnim materijalima i nanotehnologijom uz pomoć inteligentnog sustava kognitivne kibernetike

Naglasak se stavlja na budućnost uporabe pametnih materijala koji će se proizvoditi s istovremenom pripremom za zaštitu i integraciju s MEMS komponentama. Uz prezentiranu kratku problematiku kemijskih procesa, pretraživačkim agentima u sustavu kognitivne kibernetike načinjen je izbor iz presjeka postupaka proizvodnje i zaštite s odabrana tri primjera:

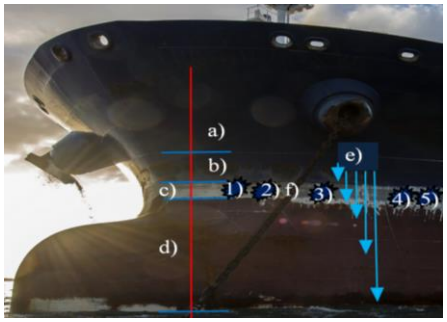
- Postupak kojim se kemijskim putem nanose slojevi u parnoj fazi, za krajnji produkt ima tanki i stabilni sloj prevlake na obrađivanom materijalu, (engl. *Chemical Vapour Deposition* - CVD). Postupak uključuje istodobno stvaranje pare, prijenos, nukleaciju i nastanak zaštitnog sloja na površini osnovnog materijala čime nastaju izuzetno čisti homogeni slojevi, čiju je strukturu moguće kontrolirati na atomskoj ili nanometarskoj razini.

- Fizikalni postupak pomoću kojeg se nanose prevlake u parnoj fazi na nižim temperaturama, (engl. *Physical Vapour Deposition* - PVD). Materijal koji se nanosi dobiva se na fizikalni način te se naparivanjem prenosi u parnu fazu i naknadno taloži u obliku tankog filma. PVD prevlake mogu biti monoslojne ili višeslojne ovisno o njihovoj debljini, i spadaju u podskupine oksidne i neoksidne keramike, dijamantu sličnog ugljika i drugih spojeva koji stvaraju tvrde slojeve. Ove prevlake osim dekorativnih svojstava, otporne su i na trošenje, postojane u agresivnim uvjetima i smanjuju koeficijent trenja.

- Litografski više stupanjski postupak galvanizacije i polimernog repliciranja X-zrakama, (njemački, *Roentgen Litographie*, *Galvanik*, *Abformung* - LIGA), tehnika je kojom se debeli slojevi fotootpornog materijala obrađuju X ili UV zrakama kako bi se elektrolitičkom depozicijom dobile matrice za formiranje trodimenzionalnih mikrostruktura s velikim omjerom površine i volumena. Materijali koji se koriste u LIGA procesima su polimetili, epoksidne smole, te neki drugi materijali osjetljivi na UV zračenje, [9] i [10].

Navedenim postupcima obrade anizotropnog sredstva u procesu nagrizanja postoji mogućnost izbora željenog pravca, brzine nagrizanja i kvalitete dobivene površine na što se utječe odabirom kemijskog sastava i strukture materijala [11-12]. Također odabir postupka nagrizanja može se provoditi s plazmom ili reaktivnim ionima primjenom dopunske energije radio frekvencija što se može preslikati i na neke eksploatacijske procese, [13-14].

U konkretnom primjeru razrađena je teorijska podloga oslonjena na tribologiju za potrebe čišćenja i zaštite velikih brodova, slika 2.



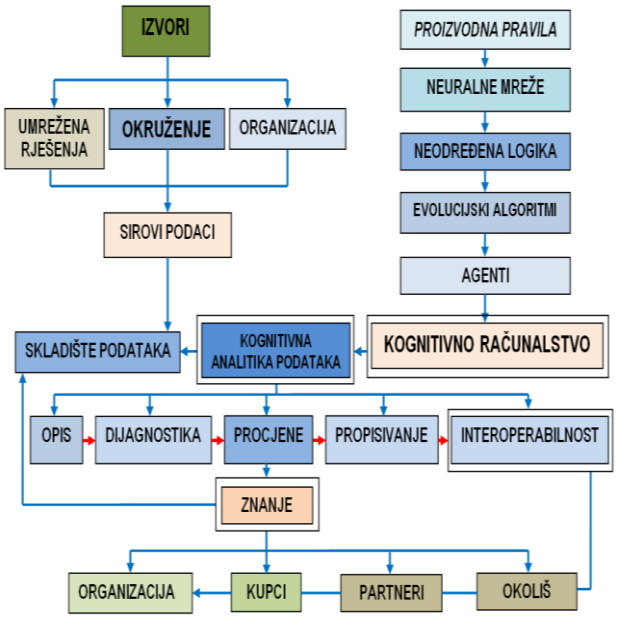
Slika 2. Prikaz razrade tribološkog čišćenja i antikorozivne zaštite broda

Kretanje broda promatra se kao: piezo, (mehanička), kemijska i termo reakcija u kojoj su dodirne površine triboelemenata budućnost pametnih materijala.

U eksploatacijskom smislu punjenje broda teretom, definirana su granična stanja, i na slici 2. prikazana je: od d) prema a), njegova aplikativna tribološka površine. Ona je jenako definirana i za pražnjenje. Na slici je oznaka d) za najplići gaz broda, (najmanja površina podvodnog dijela broda), oznaka a) najdublji gaz broda, (najveća površina podvodnog dijela broda), oznaka c) najučestalija dubina broda, (najučestalija površina podvodnog dijela broda – plovidba s teretom), oznaka b) najplići gaz broda, (najmanja površina podvodnog dijela broda – nakon istovara tereta) i oznaka f) od 1) - 5) kontaminirane površine broda pri najučestalijem gazu broda koje se uz pomoć pametnih materijala i MEMS tehnologije same čiste, a inteligentnim sustavom obrađuju i koriste za učenje, [15–20].

Implementacija strategija kognitivne kibernetike u rješavanju problema kao što je navedeno u ovom radu, započinje postavljanjem strateškog cilja koji se provodi težnjom prema uspjehu kojeg opisuje „Lean“ proces, (engl. - *lean, leaning*). Prijevod za imenicu daje objašnjenje i ukazuje na sklonost koja u nekom procesu oslikava tendenciju, težnju i namjeru, te se u smislu tehnoloških izazova i promjena ostvaruje kroz razvoj i inženjerstvo, na način prihvaćanja mogućnosti dinamike inovacija koje se mogu iskoristiti. Danas su takvi procesi omogućeni uz pomoć koju pružaju kognitivna analitika podataka i umrežena kibernetička rješenja, [21].

Primjenom kognitivnog računalstva iz izvora, (organizacija, okruženje i umrežena rješenja), razradom aplikativnih programskih podrški uz zadanu filozofiju kognitivne kibernetike, primjenom proizvodnih pravila utvrđen je trend kojima se osigurava integrirano znanje za podršku prilikom rješavanja problema neovisno o vrsti problema, sustava upravljanja ili procesa u kojem se pojavljuje, slika 3.



Slika 3. Interoperabilnost kognitivne analitike podataka u rješavanju

Filozofija djelovanja oslonjena na znanje uz pomoć kognitivnog računalstva osigurava niz prednosti koje omogućuju skladištenje, raspoloživost i prijenos podataka. Dijagnostikom, procjenama, propisivanjem i interoperabilnošću moguća je primjena znanja na sve sfere rješavanja problema i integriranje svih disciplina. Povezivanjem projektiranja, proizvodnje, održavanja i razvoja stvara se preduvjet za precizniji i brži tijek čuvanja zapisa, analize informacija i prepoznavanja svih mogućnosti za osiguranje racionalizacije s implikacijama na same korisnike, sve uključene i okoliš. Integriranost kognitivne kibernetike uključuje marketing, financije, promet, energetiku i pripremu, što rezultira efektima:
- upravljanja aktivnostima,
- upravljanje resursima uz praćenje troškova,
- upravljanje arhivom.

Upravljanje aktivnostima podržava svakodnevnu optimizaciju svih operacija, od upravljanja, uvođenja korektivnih mjera i podržavanja planova preventive. Upravljanje resursima uz praćenje troškova podržava praćenje unutarnjih poslova i troškova poslovnih zahtjeva. Upravljanje arhivom osigurava brzo i lako obnavljanje i uporabu važnih informacija kao što je prezentirano u konkretnom primjeru ovog rada.

III. ZAKLJUČAK

U sljedećem periodu naglasak istraživanja, biti će usmjeren na mogućnosti uporabe virtualnih polja pomoću inteligentnih sustava kognitivne kibernetike, koji omogućuju lako uvođenje složenih i ulančanih ključeva pretraživanja i to sveobuhvatno od jednostavnih upita do složenih operacija s bazama podataka, njihovom izdvajanju, obradi i prikazu kao što je navedeno u ovom radu. Akcent stavljen na znanje kroz obrade, uporabe, upravljanja i učenja iz baza podataka profilira i posebno ističe potrebu za specijalističkim ljudskim resursima uz koje njihov inventivan spoj iskustvenih metoda promatranja, i proračuna inteligentnim sustavima u koracima od analize koncepta, formalizacije, implementacije, validacije i konkretizacije vodi optimizaciji.

U prezentiranoj problematici to su svojstva materijala od kojih su napravljeni nanosenzori MEMS uređaja a koji će se u budućnosti koristiti u antikorozivnim zaštitama objekata, (npr. brodova). Na tim spoznajama odgovarajućim izborom materijala i postupaka obrade, optimizirat će se njegove performanse, s ciljem proširenja područja primjene nove generacije MEMS uređaja. Dobivanje „super-slojeva“ novih materijala u cilju zaštite, sprječavaju se neželjeni efekti. Razvoj novih polimernih materijala, modifikacijom unutar strukture polimera, jedan je od važnijih pravaca daljnjih istraživanja. Unaprijeđenjem pomoću filozofije kognitivne kibernetike, (objektno orijentiranih sustava), nezaustavljivo se korača u univerzijaciju algoritamskih sustavnih politika koje tehnološkim promjenama ostvaruju sve ciljeve prosperiteta i primjenjivi su u svim grana gospodarstva, znanosti i obrazovnja.

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PAPERS

Influence of GDPR on social networks used by omnichannel contact center

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***Abstract* - First part of paper addresses the impact of General Data Protection Regulation (GDPR) on data collection by most popular social networks. GDPR will start to apply on May 25th 2018, and it aims to change the way in which organizations treat data protection. Regulation requires organizations, including social networking service providers (SNSP), operating within the EU to know where personal information of their users is located, how can it be used and when does it have to be deleted. The paper clarifies the rights of the users and the obligations of the SNSP. It analyzes 10 most popular social networks and explores what personal information they collect as well as problems related to the application of GDPR. Second part of the paper presents the use of social networks in omnichannel contact center. Omnichannel is a business model which combines various communication channels in order to improve customer experience. Since modern social networks are abundant with personal user information, it is necessary to determine which of them may be collected and used by omnichannel contact center, while respecting the principles of GDPR.**

Keywords - GDPR; social networks; SNS; personal data; privacy; omnichannel contact center; communication channel

I. INTRODUCTION

Social networks have quickly developed into widely used communication channels where users make their profiles for self-actualization, but are often unaware of the potential commercial value of shared data. Utilizing social networks to provide customer service becomes more and more popular. Users can start conversation with service provider on one social network and quickly switch to the other in order to get more prompt, accurate or customized service. They expect an impeccable experience between online and physical purchase, but also between modern and traditional communication channels. To meet their requirements, organizations are moving away from a traditional (i.e. phone based) contact center model to omnichannel service centers [1], which provide greater customer loyalty and higher satisfaction.

Omnichannel service centers integrate a variety of communication channels, including email, chat, SMS, and social networks. This paper focuses on social networks and analyzes the influence of GDPR on personal data they collect. In order to work properly, social networks need to collect certain personal information about the participants, and they have to ensure that unauthorized access to sensitive personal information is correctly restricted. Nowadays, information technology is considered a major threat to privacy [2] because it enables extensive surveillance, large databases and ultra-speed distribution of information. Those developments require a strong and more coherent data protection framework in the Union [3], so the old Data Protection Directive 95/46/EC (DPD) is to be replaced with the new Regulation - GDPR.

II. RELATED WORK

There is no information on previous research studying influence of GDPR on social networks, nor about the use of GDPR affected social networks in omnichannel contact centers. Most research about online security focuses on social network permissions, type of data being collected by online applications and data sharing with third parties, so the recent work in these areas will be presented.

Research conducted by privacy enforcement authorities [4] found that the majority of apps does not provide sufficient information for the user to understand why it is necessary to grant the requested permissions, which were found to be excessive in relation to the functionality of the applications. Furthermore, the exerting privacy rights are still a frustrating experience most of the time, according to the results of assessed behavior of vendors of 150 smartphone apps and 120 popular websites. Other research [5] deems privacy policies to be hard to read and understand, especially since level of user's knowledge and skills with digital technology and media can vary within and across countries depending on gender, age and social background. Statistics from countries within and outside EU [6] show that most users of social networking sites do not read the privacy policies of the sites or the applications from third party stakeholders that use their data. Zang et al. [7] monitored HTTP(S) transmissions of popular apps and found that many apps share personal data with third-party websites. Furthermore, Balduzzi et al. [8] found that attackers can query the SNSP for registered e-mail addresses on a very large scale. They can automatically crawl the user profiles that they map to e-mail addresses, and collect personal data about each user.

So far, there is little work on this topic and the area should be better explored since GDPR will have a great impact on social networks and thus omnichannel service.

III. GENERAL DATA PROTECTION REGULATION

GDPR represents the new European Data Protection Framework. It is directly applicable in all EU Member States without any need for further implementation in national legislation. The Regulation replaces the DPD and the previous national laws transposing the DPD into Member State legal system, and its main purpose is to harmonize data protection laws within Europe in order to protect personal data [3].

The Regulation applies to processing of personal data, whether automated or manual, if the data is stored or is intended to be stored in the storage system. „Processing means any operation which is performed on personal data, such as collection, recording, organization, structuring, storage, adaptation or alteration, retrieval, consultation, use, disclosure by transmission, dissemination or otherwise making available, alignment or combination, restriction, erasure or destruction. [3]“ In omnichannel contact center, data processing can be, for example, collecting, analyzing, storing and deleting personal data collected by users of certain social network. The principles defined in the GDPR are compulsory for organizations operating within the EU and for organizations worldwide, including SNSP, that collect and process personal data of users from the EU. Personal information is any information which could be used to identify an individual, such as user's name or surname, e-mail, physical address, information related to his cultural or social lifestyle etc. Under the GDPR it is strictly forbidden to collect and process user's personal data concerning the information about the race, political commitments, religious commitments, as well as the data concerning user's genetic, health or sexual orientation.

The following subchapters will address the principles of processing the personal data, the rights of the owners of personal data and the responsibilities of SNSP prescribed by GDPR.

A. The principles of processing the personal data on which the Regulation is based

As stated in Article 5 (1) of Regulation [3]:

- Data should be processed lawfully, fairly and in a transparent manner in relation to the data subject. Users should know how their personal data is being collected and used and by whom, the purpose and duration of data processing.
- Data collected for one purpose cannot be processed for any other purpose. For each purpose of processing it is necessary to get a special consent.
- Data should be adequate, relevant and limited to the purpose of processing. Data that is not necessary for the purpose of processing should not be collected.
- There should be a possibility for user to modify incorrect data.
- Data storage should be limited to the shortest possible timeframe. Deadlines for deletion and destruction of data should be defined.
- Data should be protected against unauthorized or unlawful processing, loss, destruction or damage.
- The most important novelty is the accountability principle, which means that SNSP are accountable and responsible for how personal data is handled, processed or used.

B. The rights of the owners of personal data

GDPR should give more power to users over their personal data and less power to SNSP that collect and use these data. Under the Regulation [3], users have:

- **The right to information and access to information** - User can at any time request access to information that the SNSP has about him, and the SNSP must allow him access to that information. User has the right to receive information about how his personal data is being processed, the right to access his personal data, the foreseen storage period, the right to correct, delete or restrict processing of his personal data, the right to complain etc. The SNSP must ensure a copy of the user's personal data free of charge if so requested by user.
- **The right to rectification** - users can request correction of the information the SNSP has about them if it is out of date, incomplete or incorrect.
- **The right to erasure** - users may request from the SNSP to delete all their personal data and to stop sharing it with third parties, and the SNSP should delete user's data if it is no longer needed for the intended purpose, if the user withdraws the consent, if he complains, or if the personal data has been processed irregularly.
- **The right of data portability** - users may request relocation of data, and the SNSP should handle their data to the other SNSP and then delete it. Personal data should be transferred by a structured form.
- **The right to object and automated individual decision-making** - user can file a complaint regarding the processing of his personal data, including the creation of a profile. When data is processed for direct marketing purposes, user can file a complaint to the processing of data. User has the right to forbid decision making based on automated data processing and profile creation.

C. Responsibilities of SNSP

GDPR [3] prescribes following responsibilities:

- Appropriate measures should be taken to ensure that processing is carried out in accordance with the Regulation.
- Before processing personal data, it is necessary to carry out an impact assessment of the processing activity if it is considered that processing will cause a high risk to users' rights.
- Appropriate measures should be taken to ensure an adequate level of security of processing, confidentiality, integrity, availability and

resilience of processing services. It is necessary to ensure regular testing and evaluation of the effectiveness of organizational measures. It is desirable to use pseudonymization and encryption of data.

- If the personal data breach occurs, the supervisory authority should be notified within 72 hours of the violation if a violation of personal data is considered to be a risk to the users rights.
- Personal data protection officer should be appointed.
- The development of a Code of Conduct that will contribute to the correct use of the Regulation should be encouraged, as well as the establishment of a mechanism for certifying data protection.

There are rigorous fines for those organizations which will not comply with GDPR, so SNSP will have to revise their business processes and consent forms with extra care to secure their compliance with Regulation. They will have to map all personal data, determine what data they need to keep, establish procedures for handling personal data, develop and implement security measures etc. There is a lot of work to be done, but SNSP who show that they value user's privacy will keep more loyal users.

IV. ANALYZE OF MOST POPULAR SOCIAL NETWORK SITES AND TYPE OF PERSONAL DATA THEY COLLECT

For the purpose of understanding data processing activities of omnichannel contact center, it is first necessary to identify which personal data are being collected by social networks.

A. *Personal data on social networks*

Data on the most popular network sites worldwide was gathered from the Statistics portal Statista [9], where they were ranked by number of active accounts as of September 2017. The research covered 10 most popular social network sites [Figure 1]: Facebook, YouTube, WhatsApp, Messenger, WeChat, QQ, Instagram, QZone, Tumblr and Sina Weibo. Social network sites are generally characterized by a large number of users or their strong engagement. Most of them (Facebook, YouTube, WhatsApp, Messenger, Instagram, Tumblr) are used worldwide, while few of them (WeChat, QQ, QZone, Sina Weibo) are present mainly in Asian countries.

It was analyzed which personal user data these social networks collect. According to GDPR [3], 'personal data' means any information relating to an identified or identifiable natural person ('data subject'); an identifiable natural person is one who can be identified, directly or indirectly, in particular by reference to an identifier. Most data that is found in social networks is related to personal lives, so it represents personal data. Application Programming Interface (API) documentation and Privacy policy of above mentioned social networks were analyzed to determine which personal data are being collected. Although the deadline to align with GDPR is near, none of above mentioned social networks has fully adjusted their privacy policy nor revised their consent forms. According to actual privacy policy, users can partly control access to their personal data by placing restrictions on who may view their personal data. However, social networking APIs integrate third-party content into the site [10] and give third-party developers access to user data, thus enabling popular site enhancements, but also posing serious privacy risks by exposing user data to third-party developers. Moreover, third-party applications can also request data about the user, his friends or members of his family.

Hasan et al. [11] stated that most social networks collect following information about users:

a) *interests* - user's professional interests or interests in hobbies, entertainment, sports and commercial products,

b) *knowledge, background and skills* - information can be used to detect professionals in a certain domain,

c) *goals* - what user desires to achieve in short or long term,

d) *behavior* - users may have repetitive behaviors that can be monitored,

e) *individual characteristics* - age, gender, e-mail, demographic information etc.,

f) *context* - environmental, personal, social, spatio-temporal.

Each of these attributes contain user's personal data. Next step of the research was to select 15 types of collected personal data found in API and privacy policies of analyzed social networks. Selected types of personal data mostly correspond to above described attributes, and they are shown in Table 1. If the social network collected set type of personal data, it was awarded plus (+), and if it did not collect it, it was assigned minus (-). The research discovered that 100% of social networks collect IP address, device identifiers and location information of their users, while 90% of them collect username, e-mail address, phone number, photo, age and gender. 80% of social networks collect date of birth and credit or debit card number, 70% collect address, 60% collect name and surname, and 30% collect political affiliation and

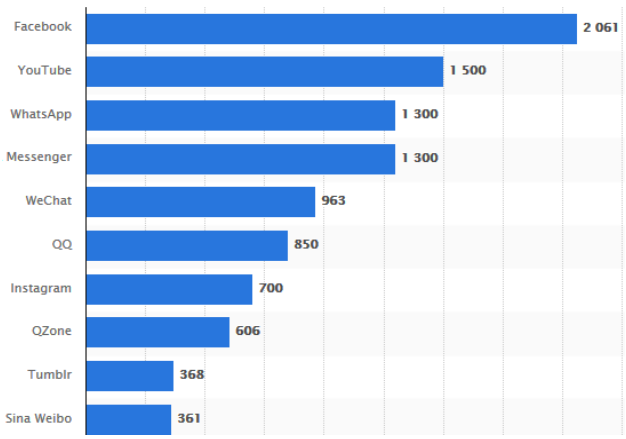

Figure 1. Number of active users in millions [9]

religious commitment. Among analyzed social networks, Facebook and Messenger collect 100% of selected personal data, followed by Sina Weibo, YouTube, WeChat, QQ and QZone (more than 80%). Social network with the least personal data is WhatsApp (53%). None of SNSP gives user a choice to use their service without providing personal data, nor to opt out or withdraw the consent.

Table 1. shows personal data common to the most popular social networks, by which one can easily define unique identificators, i.e. the data that is unique in its basic context, to connect those data into single user interface used by omnichannel contact center. User identification and data synchronization will be described in more detail in chapter V.

B. Users consent

Article 6.1 of the GDPR [3] identifies six legal basis of lawfulness of processing, and SNSP has to determine which one is appropriate for a particular processing activity, taking into account the purpose of the processing, type of personal data and data subject, as well as the intended use of data:

1. Consent for the processing of personal data for one or more specific purpose,
2. Processing is necessary for the performance of a contract,
3. Processing is necessary for compliance with a legal obligation,
4. Processing is necessary in order to protect the vital interests of user or another natural person,
5. Processing is necessary for the performance of a task carried out in the public interest or in the exercise of official authority vested in the controller,
6. Processing is necessary for the purposes of the legitimate interests pursued by the controller or by a third party, except where such interests are overridden by the interests or fundamental rights and freedoms of user.

In this paper, emphasis was placed on consent, although it is not the only applicable legal basis for personal data processing. Consent can only be an appropriate lawful basis if user is offered control and a choice with regard to accepting or declining the terms offered or declining them without harm [12].

There are four types of actions that might constitute a breach of privacy security [13]:

1. Data Gathering: The collection of personal data contrary to the wishes of the user.
2. Data Misuse: The use of personal data in ways contrary to the wishes of the user.
3. Data Sharing: The voluntary disclosure of personal data to third parties in ways contrary to the wishes of the user.
4. Security Breach: The unauthorized accessing of personal data.

What is common to all these breaches is the lack of user's consent. Consent is permission to collect, store and process personal data that users give to SNSP. Consent systems must be pre-adapted so that they have short and readable terms, and the spaces to be marked must be empty. However, if not necessarily, user's consent should not be a condition for access. Consent expresses freewill, specific, informed and unambiguous user's agreement on processing his personal data. „There must be a positive opt-in [14] - consent cannot be inferred from silence, pre-ticked boxes or inactivity.“

In order to collect personal data, SNSP has to inform user about the purpose of data processing. SNSP should be capable to prove at any time that the user has given the consent for processing his personal data for this exact purpose. Users can at any time deny the right to collect, store or process their personal data. Of course, except for the minimum information necessary to provide the services that are the subject of the contract. However, the practice is still far away from the theory. The research found that social media users can't turn down privacy policies and in most cases they have minimum impact on personal data disclosure. Furthermore, privacy policies are far too complicated for ordinary user and collect more data than necessary.

Table 1. Type of personal data collected by social networks

Type of personal data	Facebook	Youtube	WhatsApp	Messenger	WeChat	QQ	Instagram	Qzone	Tumbir	Sina Weibo
Name and surname	+	+	+	+	-	-	+	-	-	+
Username	+	+	-	+	+	+	+	+	+	+
e-mail address	+	+	-	+	+	+	+	+	+	+
Phone number	+	+	+	+	+	+	+	+	+	-
Photo	+	+	+	+	+	+	+	+	-	+
Date of birth	+	+	+	+	+	+	-	+	-	+
Address	+	+	-	+	+	+	-	+	-	+
Age	+	+	+	+	+	+	-	+	+	+
Sex	+	+	-	+	+	+	+	+	+	+
Political affiliation	+	-	-	+	-	-	-	-	-	+
Religious commitment	+	-	-	+	-	-	-	-	-	+
Location	+	+	+	+	+	+	+	+	+	+
Credit / debit card number	+	-	-	+	+	+	+	+	+	+
Device identifiers	+	+	+	+	+	+	+	+	+	+
IP address	+	+	+	+	+	+	+	+	+	+

C. Privacy policy

Bechmann [6] stated that most users don't read either privacy policies or app permissions. According to research made by Gross at Acquisti [15], only a minimal percentage of users changes the highly permeable privacy preferences and in general, fully identifiable information is available to anybody registered at certain social network. Additional personal data are made available to any user able to obtain at least one unique identificator. Despite concerns [16] raised about the disclosure of personal data on social networks, it seems that the benefits users expect from public disclosure surpass its perceived costs, so they continue to disclose them. Moreover, most of them consider themselves as 'numbers' [6] to the organizations and not as individuals and this is why they are not concerned with data disclosure. GDPR should help protect their privacy, as SNSP will have to respect the following principles:

1) they may not collect more data than necessary,
2) they may not use personal data of users for purposes other than specified,
3) they may not keep user's data if they are no longer needed,
4) they may not disseminate user's data to third parties

unless the user allows it with his consent.

V. INTEGRATION OF SOCIAL NETWORKS WITHIN THE OMNICHANNEL CONTACT CENTER

Omnichannel contact center encompasses multiple social networks and, as stated above, each of them has its own privacy policy and collects various types of personal data. Personal data common to the most popular social networks can serve as unique identificators to connect all users data into single interface used by omnichannel contact center. In our research, the identificators are linked to the user login to a particular social network. Each social network can have several identifiers, which can be used to link all user data to a single user interface within omnichannel contact center, under the condition of having a user's consent. The first step is to collect unique identifiers of users on different social networks. The second step is to collect additional profile data whose identifiers are collected in the previous step, and the third step is to determine the degree of user profile matching so that each individual user determines the degree of match between his potential profiles on different social networks. To make the communication through these social networks work, it is inevitable to get user's consent as a correct lawful basis, since contract should no longer be a conditional service [12].

A. Types of users consent

Depending on the purpose of collecting, processing and using personal data, three types of users consent were defined:

1. In the first type of consent, the following user's personal data shall be used to support communication through social networks:
   a) social network contact data (such as e-mail, phone number, Skype, Youtube, Instagram or Facebook contact information, and similar),
   b) public communication on social networks (contact center will collect data published on social networks and use it for delivery of its services),
   c) personal communication between the user and the contact center (contact center will store communication to provide users with better support).

Each purpose requires a new consent, and the user should have the option to mark the box in front of the option he wants to approve. What is mandatory according to GDPR is that data subjects should be given enough insight into the logic of a model and the significance of that logic to have the context necessary to opt out [15].

2. In the second type of consent, the user's personal data will be used to support communication through social networks and for profiling, which should be particularly emphasized:
   a) all three options from the first type of consent are included,
   b) contact center makes user profile.

The information in a user profile [8] may include various attributes of a user such as geographical location, academic and professional background, membership in groups, interests, preferences, opinions, etc. The greater the wealth of information in user profile, the higher the likelihood of accurate merging of user profiles from different social networks. However, the information contained in user profile is personal and thus there are privacy issues related to user profiling. GDPR will limit the creation of user's profiles which are used in decision making. Articles 13-15 require that users should be given a variety of information about their rights regarding the storage and processing of their personal data, including the purposes of the processing. If user's personal data is being used for making their profiles, then they have to get acquainted with the background of decision making, and also with the possible outcomes for the user. It is necessary to inform users of certain elements that are crucial to make a choice [12]. SNSP might additionally want to provide a list of the benefits of automated processing versus the downsides of opting out to help users make their decision [17].

3. In the third type of consent, the user's personal data will be used to support communication through social networks, for profiling and marketing.
   a) all four options are included from the second type of consent,
   b) contact center uses personal data for marketing purposes, to inform user about special offers and novelties that may be of interest to him.

If the user has given consent to use the service, the form for contracting the service will be automatically filled based on his profile data. But, if the user has not given consent, the empty form will be open for contracting it. Once the consent is given, contact center will easily transfer personal data from user's profile to the storage system. It can then collect unique identifiers of individual users on different social networks and collect additional profile data in line with given consent. The user should also be given the option to deny to give his consent. In this case, he will be redirected back to the public profile without saving his personal data.

B. Future research

Social networks are collecting and processing large amounts of personal data under very complex terms of service. After the GDPR enters into force, omnichannel contact center will have to adapt to new data processing rules. It will encounter the problem of unambiguous identification of users from different communication channels, as well as the problem of data storage and protection from unauthorized access. In this paper, a simple scenario of communicating with users and getting their consent was described, but further research is needed to address mentioned problems. Namely, the research covered only one communication channel, i.e. social networks. In order to solve the problem of identifying users, as well as transferring, synchronizing and storing personal data, it is necessary to explore the impact of GDPR on other communication channels used by omnichannel contact center (telephone, SMS, e-mail etc.). Since SNS represents a form of electronic communication, future research should include overview of NIS Directive and E-Privacy Regulation. Namely, processing of personal data pursuant to NIS Directive shall be carried out in accordance with GDPR [17]. Regarding the enforcement of E-Privacy Regulation, it relies on the supervisory authorities and the consistency mechanism of the GDPR, and complements and particularizes the GDPR [18].

VI. CONCLUSION

The aim of this paper was to examine the influence of GDPR on social networks used by omnichannel contact center. For that purpose, an analyze of most popular social network sites was carried out. API documentation and privacy policy of above mentioned social networks was analyzed to determine which personal data is being collected. As an outcome, data analysis uncovered that 7 out of 10 social network sites collect more than 80% of user's personal data. If they want to use social networking services, users can't turn down privacy policies, and in most cases they have minimum impact on personal data disclosure. GDPR should introduce novelties in terms of offering users an understandable and simple frame to specify their privacy settings towards other users, SNSP and third parties. In order to collect user's personal data from SNSP, omnichannel contact center will have to get a consent in a form of a clear affirmative action. Users will get acquainted with the background of a system in order to decide whether to give or withdraw the consent. According to GDPR, personal data should be collected while respecting the principles of lawfulness, fairness, transparency, purpose limitation, data minimization, accuracy, storage limitation, integrity, confidentiality and accountability [3]. The process of collecting, using and storing data will become more challenging, but it will also enable contact center to build trust with users since the level of security of their data will be increased.

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GDPR in access control and time and attendance systems using biometric data

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Abstract – The new General Data Protection Regulation (GDPR) begins to fully apply on May 25, 2018, and EU Member States have to transpose it into their national law by 6 May 2018. By this Regulation (i.e. by a binding act directly applicable), the European Union regulates the questions of personal data protection in a significantly different and more up-to-date way than regulated by the previous regulations. For the first time, biometric data, are also defined as personal data obtained by a special technical processing related to physical, physiological characteristics, or characteristics of an individual's behaviour, which provide or confirm the unique identification of the individual, such as face recognition or fingerprint identification. Given that these data are very commonly used in access control and time and attendance systems, in this paper, we would like to present the novelties that the GDPR brings, and which will have to be respected by everyone whose access control system or time and attendance systems are based on biometric data.

I. INTRODUCTION

The new General Data Protection Regulation (GDPR) [1] begins to fully apply on 25 May 2018. This is a new act that regulates the matters of personal data protection in the EU countries in a very different way. Let's remember that the first modern act relating to this area is the Convention on the Protection of Individuals regarding the automatic processing of personal data [2] of the Council of Europe (Convention 108). This is the Convention of the Council of Europe, but since all EU members are also members of the Council of Europe, the Convention has been generally applied and applies within the EU.

The Convention in force was opened for adoption on 28 January 1981, in Strasbourg, and entered into force on October 1 1985 after its fifth ratification. Despite the exceptional significance of the mentioned Convention, its provisions are partially out of date, in practice, due to the flow of time - at the time when it was written there was no high-speed internet in the present sense, there was no cloud computing, there was a lack of personal data not as nearly in the way it's done now.

The European Union has reformed the area of personal data protection in 1995 when the Directive 95/46/EC of the European Parliament and of the Council of 24 October 1995 on the protection of individuals with regard to the processing of personal data and on the free movement of such data [3] came into force. This Directive, together with Convention 108, is the foundation for the adoption of national personal data protection laws, the establishment of national regulatory agencies and the existing personal data protection model, which has been developed by so far.

Let us also mention how some other regulations, relating to the areas of personal data protection have also been adopted e.g. in electronic communications, (but they are not essential to our paper).

Since the adoption of Directive 95/46/EC has passed many years, and it has begun to show some disadvantages, and legal practice has also shown that some standards can be regulated in a better manner. That is the reason why it all started with the adoption of a new regulation, and after a couple of years the GDPR was adopted.

Here we have to point out on another difference between the current legal framework and the GDPR. On the contrary to Convention 108 which was supposed to be fully incorporated into national regulation as an international convention, and to Directive 95/46/EC which had to be transposed into domestic acts ''the GDPR is a binding legislative act. It has to be applied in its entirely across the EU, while a directive is a legislative act that sets out a goal that all EU countries have to achieve. However, it is up to the individual countries to decide how. It is important to note that the GDPR is a regulation, in contrast to the previous legislation, which is a directive." [4]

In this paper, we shall analyse the GDPR rules in relation to today's common collection of biometric data for the purpose of access control and time and attendance systems. GDPR explicitly defines biometric data where: "'biometric data' means personal data resulting from specific technical processing relating to the physical, physiological or behavioural characteristics of a natural person, which allow or confirm the unique identification of that natural person, such as facial images or dactyloscopic data" (GDPR, Article 4, and explicitly limits their application).

II. DACTYLOSCOPIC DATA

Dactyloscopy is a contemporary, safest and most widespread method of determining persons' identity, on the basis of friction ridges (friction ridges on the surface of the inside of the fingers, palms and soles of the feet). Friction ridges are formed even before birth and do not change during life, they are strictly individual (there are no two

persons with the same friction ridges). Also, fingerprints are easily classified in practice. [5] After being applied for almost a century in police and criminology in practice, the use of dactyloscopic data has become extremely popular in access control and time and attendance systems.

With the GDPR's entry into force, several important questions are being raised: can the organization use our data undisturbed? Do we have to agree to biometric identification, or are we entitled with the right to alternative? How is the organization obliged in keeping our data? In this paper, we shall try to provide answers on some of these questions, without any pretense that our conclusions are final – because we believe that legal practice within this area will be developing in years to come.

It is legitimate to ask the question of the importance of storing the dactyloscopic data. Mathematically, they should be unique to each person. As they are unique, and easy to read, it seems almost ideal in access control and time and attendance systems However, this uniqueness and easy reading can also represent a potential security risk. Today, fingerprints can be easily forged. There are even instructions on how to forge a person's fingerprints, such as on the Internet's page: "How to Fake Fingerprints?" [6]. This practice is not even illegal as long as fake fingerprints are not misused!

In a situation where there is great confidence in fingerprint identification, but which can be relatively easily forged, there is a serious security problem. What happens in the case of misuse? While the fingerprint identification is taken as common and "safe", how much time and resources will it take in cases of misuse to prove that a false fingerprint was used? We consider that the attention which the GDPR has dedicated to biometric data is therefore, quite appropriate.

III. THE EXISTING SOLUTIONS

Manufacturers of modern smartphone devices commonly use fingerprint recognition to access more expensive devices. By simply pressuring the sensor is easier than entering a code or by using a similar identification method. However, it seems they were aware of the dangers of collecting of biometric data, so they placed them on the separate chip, on the device itself. Here's an example for Apple:

"The chip in your device includes an advanced security architecture called the Secure Enclave, which was developed to protect your passcode and fingerprint data. Touch ID doesn't store any images of your fingerprint, and instead relies only on a mathematical representation. It isn't possible for someone to reverse engineer your actual fingerprint image from this stored data.

Your fingerprint data is encrypted, stored on device, and protected with a key available only to the Secure Enclave. Your fingerprint data is used only by the Secure Enclave to verify that your fingerprint matches the enrolled fingerprint data. It can't be accessed by the OS on your device or by any applications running on it. It's never stored on Apple servers, it's never backed up to iCloud or anywhere else, and it can't be used to match against other fingerprint databases." [7]

This kind of technological solution introduced years before the entry into force of GDPR can be characterized as very useful. But here it's about a well-known smartphone manufacturer who invests tremendous resources in securing the use of its devices. An omission in the field would cost a company billions of dollars.

And what about hundreds of different devices and manufacturers of various solutions for access control and time and attendance systems? What kind of security systems do they have and what do we have to look for from them? First of all, to answer these questions, first we have to analyse the provisions of GDPR on the protection of biometric data.

IV. GDPRG AND BIOMETRIC DATA

The processing of biometric data is defined by the Art. 9 of the Regulation, under the title "Processing of special categories of personal data", therefore, among the data that must be additionally protected, as emphasized in the paragraph 53 of the Preamble of the Regulation: "Special categories of personal data which merit higher protection". It gives an additional responsibility for processing and storage of biometric data.

The basic provision is that processing of such data is not permitted (Art. 9, Para 1): "Processing of personal data revealing racial or ethnic origin, political opinions, religious or philosophical beliefs, or trade union membership, and the processing of genetic data, shall be prohibited for biometric data for the purpose of uniquely identifying a natural person, data concerning health or data concerning a natural person's sex life or sexual orientation."

Subsequently, (Para. 2) lists an entire range of exceptions, which we fully quote: "Para. 1 shall not apply if one of the following applies: (a) the data subject has given explicit consent to the processing of those personal data for one or more specified purposes, except where Union or Member State law provide that the prohibition referred to in paragraph 1 may not be lifted by the data subject; (b) processing is necessary for the purposes of carrying out the obligations and exercising specific rights of the controller or of the data subject in the field of employment and social security and social protection law in so far as it is authorised by Union or Member State law or a collective agreement pursuant to Member State law providing for appropriate safeguards for the fundamental rights and the interests of the data subject; (c) processing is necessary to protect the vital interests of the data subject or of another natural person where the data subject is physically or legally incapable of giving consent; (d) processing is carried out in the course of its legitimate activities with appropriate safeguards by a foundation, association or any other not-for-profit body with a political, philosophical, religious or trade union aim and on condition that the processing relates solely to the members or to former members of the body or to persons who have regular contact with it in connection with its purposes and that the personal data are not disclosed outside that body without the consent of the data subjects; (e) processing relates to personal data which are manifestly made public by the data subject; (f) processing is necessary for the establishment, exercise or defence of legal claims or whenever courts are acting in their judicial capacity; (g) processing is necessary for reasons of substantial public interest, on the basis of Union or Member State law which shall be proportionate to the aim pursued, respect the essence of the right to data protection and provide for suitable and specific measures to safeguard the fundamental

rights and the interests of the data subject; (h) processing is necessary for the purposes of preventive or occupational medicine, for the assessment of the working capacity of the employee, medical diagnosis, the provision of health or social care or treatment or the management of health or social care systems and services on the basis of Union or Member State law or pursuant to contract with a health professional and subject to the conditions and safeguards referred to in paragraph 3; (i) processing is necessary for reasons of public interest in the area of public health, such as protecting against serious cross-border threats to health or ensuring high standards of quality and safety of health care and of medicinal products or medical devices, on the basis of Union or Member State law which provides for suitable and specific measures to safeguard the rights and freedoms of the data subject, in particular professional secrecy; (j) processing is necessary for archiving purposes in the public interest, scientific or historical research purposes or statistical purposes in accordance with Article 89(1) based on Union or Member State law which shall be proportionate to the aim pursued, respect the essence of the right to data protection and provide for suitable and specific measures to safeguard the fundamental rights and the interests of the data subject."

Due to its importance, we also list the remaining two paragraphs:

''3. Personal data referred to in Para. 1 may be processed for the purposes referred to in point (h) of Para. 2 when those data are processed by or under the responsibility of a professional subject to the obligation of professional secrecy under Union or Member State law or rules established by national competent bodies or by another person shall also be subject to an obligation of secrecy under Union or Member State law or rules established by national competent bodies.

4. Member States may maintain or introduce further conditions, including limitations, with regard to the processing of genetic data, biometric data or data concerning health."

Therefore, Member States may introduce stricter regulation of this category of data.

When we analyse a very extensive article with a large number of exceptions – it's immediately apparent that the most of them are related to the collection of biometric data for the needs of different states, or for health purposes. Only a few of the provisions can be applied for the purposes of this paper - access control and time and attendance systems.

V. BIOMETRIC DATA IN CORPORATIVE ENVIRONMENT

As a model for the purpose of this paper, we used a company with time and attendance system based on biometric data but also an information security system ISO/IEC 27001 [8], which provides additional fingerprint identification used in access control systems when entering the server room [9] as a specially protected area.

If we look closer to the provisions of the Regulation, in such a corporate environment, only Para. 9. Art. 2. (a) and (b) can be used. The case where an employee or associate who should be allowed to access control system, gives permission for use of their own biometric data, specifically, in this case fingerprints, is quite simple. In Para. 9. Art. 2 (a) of the Regulation it's stated: "the data subject has given explicit consent to the processing of those personal data for one or more specified purposes". So, if the employee explicitly authorizes the use of their fingerprints for access control to control their working hours (explicit approval should then be interpreted as a written approval) - then there is no obstacle to collect their biometric data.

The problem arises if an employee refuses to sign such an approval or withdraws an approval which has already been given. Art. 7 Para. 3 of the Regulation specifically states: "The data subject shall have the right to withdraw his or her consent at any time." And what happens then? The company no longer has the right to use biometric data, here fingerprints, and cannot force an employee to give them permission, nor can punish them, if he/she withdraws their approval. Nor can bind a work relationship with a consent in the sense of this provision, because it explicitly states: voluntary consent. The sanctioning of employees for non-compliance of a voluntary consent is not acceptable, and the dispute related to such a sanction would probably not be favourable for the employer. That leaves us with the provision of the Article 2, para. 9, (b), '' processing is necessary for the purposes of carrying out the obligations and exercising specific rights of the controller or of the data subject in the field of employment and social security and social protection law in so far as it is authorised by Union or Member State law or a collective agreement pursuant to Member State law providing for appropriate safeguards for the fundamental rights and the interests of the data subject.

It's hereby stated that the processing of biometric data is allowed for the purposes of the labour law, and time and attendance systems belong in this category. However, then it should be defined by the particular regulations, or by the collective agreement.

Consolidated Version of the Treaty on the Functioning of the European Union [10] Art. 288 states: "A regulation shall have general application. It shall be binding in its entirety and directly applicable in all Member States." In addition, the literature states that the "Member States and their national bodies are banned from interpreting of the Regulation, as well as the modification of its content". [11]

However, when the Regulation states that a national regulation may elaborate or otherwise amend its provisions, then a national state may do so. It's particularly interesting the provision on the processing of biometric data, and it can be regulated by a collective agreement. In that case, if control of time and attendance system is allowed by using fingerprints, either by national regulation or by a collective agreement, is allowed, this could become binding for the employees. The employees could express doubts and request for surveillance if they consider that the safety protection of their biometric data are not fulfilled.

Specifically, the arrangement of biometric data collection for the purpose of time and attendance system on the national level, by regulations or by collective agreement naturally applies only to that country - but in case of multinational corporations the problems might occur - each EU country may have this issue differently resolved or not to have a solution at all, if it has not introduced the national regulation.

Furthermore, this solves only the question of time control, but what happens to the access control system inside the facility, where control is allowed or identified on biometric data? Labour law does not speak of it for it does not enter the work processes. In case that an employee refuses to provide their biometric data, it's possible that in

the dispute, court may stand aside the employee, taking into account that there is possible other way of access control systems, e.g. by entering an access password. There is still no case law of European Court of Justice, but who would be ready for 2-3 years of trial, whereby strong trade unions will surely stand on the side of employees. Access control system and time and attendance system by using biometric data, specifically fingerprints is widespread all around the world. By entering into force by the GDPR – such method of identification can in large measure be in question. How will the GDPR development continue on national levels, and even within collective agreements – for now it's far too early to predict.

Let us also mention a view of the literature (about Directive 95/46/EC): "Sensitive personal data may be processed to comply with employment law obligations, whether such law derives from statute or court or tribunal precedent and whether such processing is carried out by an employer or anyone else. It is highily unlikely that the phrase 'imposed by law' could be taken to include contractual obligations – an employer will thus be unable to legitimize sensitive personal data processing by including a relevant provision in the employment contract." [12]

VI. BIOMETRIC DATA IN GOVERNMENT ENVIRONMENT

Both the state-owned companies and the civil services will face the same challenges, same as the private companies, mentioned in the previous chapter. However, when processing classified data, we consider that the provision of the Article 9, Para 2 (g) may apply, and it states: "processing is necessary for reasons of substantial public interest, on the basis of Union or Member State law which shall be proportionate to the aim pursued, respect the essence of the right to data protection and provide for suitable and specific measures to safeguard the fundamental rights and the interests of the data subject".

Classified data can be considered as data protected for the sake of public interest (which is in the definition of classified information, and corporate and private data are protected by the business secrets). Therefore, it is considered that persons who have access to such data may be required to accept biometric verification or biometric data as part of their duties. That is to say, for a degree of secrecy (TOP SECRET, SECRET, CONFIDENTAL) they should undergo security checks and receive the appropriate certificate, at least that is the case in Croatian legislation. [13]

VII. CONCLUSION

Several authors have already noticed how the GDPR has put biometric data into a special, sensitive group. For example, Ross states: "As the GDPR considers biometric data to be a special category of sensitive personal data, processing and protecting it must proceed under the framework reserved for sensitive personal data generally. While the GDPR broadly prohibits the processing of sensitive personal data, it recognizes certain bases to justify its processing, chiefly, the explicit consent of the data subject, the performance of specific contracts or processing for certain specific purposes." [14] An interesting observation is also made by Bailey: "Because the EU member states have not been able to reach a clear consensus about the use of biometric data, however, the legal requirements applicable to the use of biometrics can still vary between the member states. This means that the GDPR cannot entirely live up to its promise of completing the internal market by fully harmonising the requirements applicable to the processing of personal data, at least where the processing of biometric data is concerned." [15] We find similarity in the other documents and analyses, for example: "Using biometrics for access control in the workspace, such as facial, iris, or finger print scanners, appears problematic as well, as employers cannot rely on consent, and no other exception to the general prohibition to process biometric data appears applicable. Member states are permitted to create their own rules concerning biometric data, however." [16]

Others warn that the use of fingerprints has become common, such as for the use of mobile phones: "The rationale that gave rise to the development of using biometrics in this way is that in 2015 there were 100 million people using mobile phones equipped with a fingerprint reader and this feature was becoming a more widespread offering amongst manufacturers." [17] Reason is simple, as we said, there are no two persons with the same friction ridges, studies have shown that modern automatic fingerprint verification system can successfully distinguish even identical twins. [18] However, safety has a different side - malicious attacker can relatively easily use a false fingerprint.

Finally, what we would like to emphasize is that even other countries out of the EU region also have the similar regulation as the EU.: "Australia has taken an approach similar to the GDPR. Under the Australia Privacy Act 1988, amended in 2014, biometric information are to be used for purposes including verification or identification, and biometric templates are explicitly defined as sensitive personal information." [19]

Given that there is no legal, administrative and judicial practice concerning this problem, finally, we can only give a few basic recommendations. First of all, the most important thing is that fingerprint data is placed in special categories of personal data that are specifically protected. For their use, there should be a voluntary consent of employees - however, employees shouldn't be discriminated if they deny the consent. As for employing the new employees, they should be warned in advance, of the obligation to provide such a consent, but there is no case where we can be sure of the outcome of the dispute, if one of the employees interpret it as a discriminatory measure and ask for protection. In the case where there is an employee's voluntary consent, the data should be kept appropriately – e.g. by the model used by Apple. Any further recording which would allow copying of fingerprint data – certainly isn't allowed. Naturally, companies can avoid the whole problem by using other methods of identification, e.g. by numeric codes, cards and similar. This is also required with the existence of a parallel video surveillance, which is also needed with fingerprint identification, because as we have already written – those are relatively easy to forge. The fact is that fingerprint readers have become widespread, popular and cheap, but on the other hand fingerprints are included in special categories of personal data, which are additionally protected – which has created a number of potential problems in practice, and

we shouldn't forget the penalties for violating the GDPR provisions, which are exceptionally high.

For now, it's impossible to find concrete answers which are required by the practice, because the legal practice will start to create only with the beginning of the application of GDPR. However, it's certainly necessary to further analyse this topic from the legal and technological point of view. In the meantime, we recommend companies to apply technological systems, which will protect employees' biometric data, and by obtaining voluntary consent to use the information, but also a possible application of the other identification systems if the employee's permission cannot be obtained. Certainly, we hope that national regulators will understand the importance of this issue and use the powers of GDPR to resolve this issue by a national regulation, either within the framework of the labour legislation, or within the supplementary regulations on personal data protection.

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Transposition of EU Network and Information Security Directive into National Law

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ABSTRACT - Information system attacks and data breaches are becoming a common occurrence. EU Commission has reported over 80% of European enterprises have suffered at least one case of information system attacks in the last year. Appropriate level of information security is a prerequisite to development of information society services and the common digital market. The European lawmaker as well as Member States have previously tried to regulate information security requirements and obligations with varying degrees of success. The new European Network and Information Security Directive, essentially the new European legal framework of information security, attempts to secure essential and digital services in order to limit damage from cyber threats and improve availability and integrity of information society services in the EU.

Key words: information security, NIS Directive, essential services, digital services

I. INTRODUCTION

Current data on the character and reach of information systems attacks as well as current research in the field of cybercrime show how information system attacks and data breaches are increasingly becoming a common occurrence. [1]

Apart from complex attacks demanding a high level of technical knowledge by the perpetrator, massive attacks committed by script-kiddies and other low-skilled perpetrators are also on the rise. [2] Increasingly, unsuspecting users' computers and Internet-of-Things (IoT) devices are used to facilitate attacks without the knowledge of their owners or legitimate users. According to the data published by ENISA, in the previous years a significant number of attacks have used sophisticated malicious programs, especially ransomware, to either access data or to restrict legitimate users' access to their data. In other reports, the EU Commission has reported that over 80% of European enterprises have suffered at least one case of information system attacks in the last year. The total number of detected attacks in 2015 has increased almost 40% from the year before. [3]

A high level of information security is a prerequisite to development of information society services. The European lawmaker, and the Croatian one as well, have tried to regulate and prescribe the high level of information security through normative intervention for years. The new General Data Protection Regulation is just the first of many EU regulations implementing good information security practices into law. [4]

A pure normative approach or the idea that one can regulate the issue of information security primarily through legal and administrative measures have predictably yielded insufficient results. However, an efficient and universally accepted legal and administrative regulation concerning information security is a requisite for transnational cooperation and a condition required to ensure that all actors participating in information society services, notably electronic commerce, all kinds of electronic communication and data exchange adopt efficient measures required to prevent future security incidents.

These and other concerns have motivated the EU Commission to adopt a string of regulatory measures that aim to raise the level of information security and increase resilience of key European information society services to most categories of cybernetic attacks.

Among the measures discussed, a central position belongs to the new EU NIS Directive - the Directive on security of network and information systems adopted by the EU Parliament in July of 2016, and entered into force in August of 2016. [5] Among other provisions, the Directive establishes a network of national CSIRT (Computer Security Incident Response Teams) in the EU Member States in order to facilitate quick response to cyber threats wherever in the EU they may appear. The Directive also establishes a coordination body to ensure strategic cooperation and efficient data exchange on potential threats. The purpose of this body is to create an atmosphere of trust and coordination mechanisms required for adequate response.

The Directive anticipates over half a billion euro in research and innovation programs by the EU in the field of information security in the period up to 2020. The EU expects that private sector enterprises participating in information security and neighbouring markets to invest three times as much resources in the same period.

II. INFORMATION SECURITY IN THE EU LEGISLATIVE

Ensuring adequate level of information security is becoming a requisite part of all European policies, especially those concerning economic and social development, i.e. automation of transport, generation and distribution of energy, advances in data communication and general IoT initiatives. [6]

For example, the aforementioned GDPR already includes provisions detailing responsibilities of data controllers and data processors with regard to personal data, especially in the context of reaction to data breaches, communication of data breach incidents to data subjects and regulatory bodies etc.

Similar provisions are contained in the proposal of the new E-privacy Regulation, a lex specialis for telecoms, over-the-top services and general electronic communication industry. These measures introduce established information security practices and refer to information security standards broadly recognized by communications, financial and other industries.

Historically, the EU has adopted several documents aimed at raising the level of information security and increasing cyber-resilience. The Croatian Parliament has implemented these documents in national legislation in addition to existing laws.

Chronologically, first of these initiatives was the above mentioned European Cybersecurity Strategy. Adopted in 2013, the Strategy defined the following primary goals:

- activities towards strengthening resilience to cybernetic attacks,
- activities towards curbing the spread of cybercrime,
- development of common European defence policy in cyberspace,
- development of industrial and technological resources in cybersecurity
- and the development of coherent common international policy of regulating EU cyberspace with fundamental European values in mind.

In 2015, the Commission adopted the European Agenda on Security 2015-2020. In light of the fact that seemingly unstoppable rise of cybercrime demands a coordinated response by all Member States, the Commission proposed that Member States intensify:

- Implementation of suggested policies concerning cyber security
- Activities fostering prevention of attacks to information systems
- Combating various forms of fraud and counterfeiting, especially concerning new electronic payment services and financial instruments
- Improving transborder cooperation in criminal proceedings and investigations against cybercriminals especially in the areas of digital evidence, discovery and juristdiction

In 2015, the newly appointed European Commission adopted another long-awaited policy document - The Common Digital Single Market Strategy, whose purpose was to stimulate European competition in the field of digital content products and services and to finally unify the fragmented European digital distribution market. In this regard, one of the key goals of the Strategy was to adopt measures to ensure strengthening the trust in the common European market and regulation framework.

Another document adopted by the Commission was the 2016 Communication under the title Strengthening Europe's Cyber Resilience System and Fostering a Competitive and Innovative Cybersecurity Industry, based upon earlier EU Cybersecurity Strategy and the Digital Single Market Strategy. [7] The Commission outlined the measures expected to:

- strengthen Member States cooperation in the field of information security through education, training and exercises,
- improve development of the common market for services and products related to information security and
- to create a framework for public-private partnership with information security industry to develop and improve EU research and innovation resources.

These documents laid out ground work for a first EU-wide law concerning information security, implemented as a Directive (rather than a Regulation, such as the GDPR enacted in May 2016).

III. RISK MANAGEMENT AND INCIDENT REPORTING

In order for the Member States to ensure adequate level of information security, responsibilities in operational security of network and information systems lie with operators of critical information infrastructure systems as well as operators of essential and digital services.

The Directive calls for adoption of a culture of risk management - a need to adopt adequate risk assessment measures and security measures appropriate to information security risks not just prescribed by regulatory requirements, but also through voluntary industry practices based on raised awareness on the potential risks. This goes especially for operators of so called essential services, who will have to take appropriate measures and to report serious incidents to relevant national authorities.

With regard to risk management, the measures these operators will have to undertake include those targeted at preventing risk, those aimed at ensuring the security of network and information systems and efforts to adequately handle information security incidents - to prevent and minimize the damage and ensure availability and integrity of data.

With regard to incident reporting, Article 14 of the Directive regulates that Member States shall ensure that operators of essential services notify, without undue delay, the competent authority or the CSIRT of incidents having a significant impact on the continuity of the essential services they provide. This provision mirrors the obligation data collectors have under the GDPR.

The Directive identifies operators of essential and digital services - private businesses or public entitites with an increasingly important role for modern societies and national economies. Thus, Article 4 defines operators of essential services as public or private entities that meet the criteria of Article 5 of the Directive. Digital service providers are legal persons providing a digital service.

The Article 5 of the Directive lays down the criteria for identification of operators of essential services. Directive regulates the term (9th of November, 2018) by which Member States need to identify the operators of essential serivces with an establishment on their territory. The criteria for the identification of essential services is contained in the provisions of Article 5.p.2 of the Directive which states that an entity is considered to be providing essential services if a service is essential for the maintenance of critical societal and or economic acitivities, provision of the service depends on network and information systems and an incident would have significant disruptive effects on the provision of the service.

The scope and meaning of the term significant disruptive effects is subject of Article 6 of the Directive. Directive offers Member States criteria to qualify an information

security incident as one having a disruptive effect on the provision of the service under attack. An attack is considered to have disruptive effect on an essential service with regard to the number of users relying on the service and users affected, with the impact that incidents in terms of degree and duration could have on economic and societal activities or public safety, market share of that entity, geographic spread with regard to the area that could be affected by the incident etc.

Directive regulates that Member States will need to regularly update the list of essential services, starting in 2018 and every two year henceforth, as well as national measures allowing identification of operators of essential services, number of operators of essential services identified for each sector defined by the Directive and indication of their importance in relation to the sector etc.

The sectors defined by the Directive are energy (transport and distribution of electricity, oil, gas etc.), transport (air, rail, maritime and river, road transport), banking and financial market infrastructure, healthcare, water (Supply and distribution) and digital communication infrastructure (internet exchange points, domain name system service providers, top level domain name registries.

Directive also defines digital services as services within the meaning of Article 1 of the Technical Standards and Directive 2015/1535 for the provision of information in the field of technical regulations and of rules on Information Society services. Article 1 of that Directive defines Information Society service as any service normally provided for remuneration, at a distance, by electronic means and at the individual request of a recipient of services.

Article 16 of the Directive regulates that Member States shall ensure digital service providers identify and take appropriate and proportionate technical and organisational measures to manage the risks posed to the security of network and information systems which they use in the context of offering digital services.

These measures need to ensure a proportional level of security of network and information systems appropriate to the risk posed and have to reflect the security of systems and facilities, incident handling, business continuity management, monitoring, auditing and testing and compliance with international standards in information security.

IV. Raising National Information Security Competence

European Commission has adopted a series of measures to raise Europe's preparedness to ward off cyber incidents. Increasing resilience of key European information service providers to cyber attacks is of paramount importance for normal economic and social development.

The new NIS Directive is the first piece of EU-wide legislation on cybersecurity with measures to ensure a high common level of network and information security across the EU. Its goals are: raising the level of national competences regarding information security, improve Member States cooperation and improve risk management and incident reporting.

In more detail, the NIS Directive provides legal measures Member States need to implement into their national legal systems in order to boost the overall level of cybersecurity in the EU as follows:

- Member States need to ensure preparedness by requiring them to be appropriately equipped, e.g. via a Computer Security Incident Response Team (CSIRT) and a competent national NIS authority;
- Cooperation among all the Member States is of paramount importance. Higher level of operational cooperation can be accomplished by setting up a cooperation group, in order to support and facilitate strategic cooperation and the exchange of information among Member States.
- Member States need to set a CSIRT Network, in order to promote swift and effective operational cooperation on specific cyber-security incidents and sharing information about risks;
- Across the EU, Member States need to adopt a culture of security across sectors which are vital for EU economy and society, especially those that rely heavily on ICTs, such as energy, transport, water, banking, financial market infrastructures, healthcare and digital infrastructure.
- Member States need to improve risk management as well as establish an obligation to report information security incidents by the digital service providers and other essential service providers

A question central to discussion on EU information security has to be what Member States can do in order to advance their capabilities and competences in the field of information security. How and where do competent information security experts come from, how is this knowledge acquired and disseminated, how can Member States go about fostering development of new products and services in this field and how to ensure that critical information infrastructure remains safe?

Internet is by definition borderless and agnostic to national jurisdiction. Networks and information systems are essential for electronic commerce. Any disturbance in essential internets services, for whatever cause, can affect Member States and the EU as a whole. This is why the security of network and information systems has to be a priority, otherwise the normal function of the common market is in jeopardy. Securing and protecting information systems and infrastructure situated and operating in every Member State is not attainable without a broad consensus, cooperation and equivalent levels of competence between the Member States.

With this in mind, the Directive foresees formation of a Working Group with participants-representatives from Member States, EU Commission and the European Network Information Security Agency (ENISA). In order to foster better strategic cooperation among the Member States with regard to network and information security, and in order for the Group to be effective, it is imperative that all Member States develop at least a basic level of competence and adopt a national strategy to ensure a high level of security of critical network and information systems.

Such strategy should include:

- Strategic objectives, priorities and governance framework
- Identification of adequate measures on preparedness in cae of attack in order to facilitate quicker response time to attacks and rapid return of access to data and servicer should the attack be successful

- Cooperation methods between the public and private sectors
- Awareness raising, training and education
- Research and development plans related to NIS Strategy with regard to products and services of use to maintaining network and information security
- Risk assessment plan
- List of actors involved in the strategy implementation

Member States are expected to assign one or more national competent authorities for the NIS Directive to follow and monitor the application of the Directive at the national level. They will also designate a single point of contact which will function as a liaison for cross-border cooperation.

Finally, and from the operational perspective, probably the most important provision of the Directive concerns the obligation of Member States to form one or several Computer Security Incident Response Teams - CSIRTs. CSIRTs or CERT (Computer Emergency Response Teams).

The main tasks of these teams include monitoring incidents at a national level, providing early warning, alerts, announcements and dissemination of information to relevant stakeholders about risks and incidents, responding to incidents, providing dynamic risk and incident analysis and situational awareness and participating in the network of the national CSIRTs (CSIRT network).

In reality, within most of the Member States there is already a network of CSIRT teams in place, usually connected to security agencies, academic internet service providers (ISPs) etc. Likewise, most of the Member States have adopted, as a standalone document or a part of wider security strategy, a national information security strategy.

The problem here is obvious from the standpoint of the NIS Directive provisions - a profound lack of cooperation and, perhaps, of trust between Member States that prohibits or hampers EU-wide cybersecurity measures, incident response and analysis. This is why the Directive calls for an increased level of cooperation between Member States.

V. Essential and Digital Services

The Directive identifies operators of essential and digital services - private businesses or public entitites with an increasingly important role for modern societies and national economies. Thus, Article 4 defines operators of essential services as public or private entities that meet the criteria of Article 5 of the Directive. Digital service providers are legal persons providing a digital service.

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These measures need to ensure a proportional level of security of network and information systems appropriate to the risk posed and have to reflect the security of systems and facilities, incident handling, business continuity management, monitoring, auditing and testing and compliance with international standards in information security.

VI. Some thoughts on transposition into Croatian law

Information security and related concepts were first introduced into Croatian body of laws in 2007 with adoption of the Information Security Act (OG 79/07).

In return, this Act codified the Croatian interpretation of measures contained in the European Cybersecurity Strategy of 2001. The provisions of this Act apply to public institutions and government bodies alone and do not apply to private sector bodies.

The Act introduces relevant information security standards (i.e. ISO 27000 family of standards) and defines categories of classified data, the process of classification

and use of such data etc. Institutional framework is also developed with introduction of national CERT as well as the Information Systems Security Bureau.

Along with Security and Intelligence System Act (OG 79/06, 105/06), Data Secrecy Act (OG 79/07, 86/12), Regulation on Information Security Measures (OG 79/07) and the National Cyber Security Strategy of the Republic of Croatia (OG 108/2015), the Information Security Act represents the Croatian legal framework of information security. [8]

Regardless of legislative efforts, comparative experiences in legal regulation of information security imply that merely implementing information security into law does not necessarily lead to adequate implementation of information security procedures and behaviours in order to protect confidentiality, integrity and availability of data. Successful management of the so called CIA triad depends on systemic education and application of information security standards and good practices. [9]

Implementation of information security standards into law should not only reflect a political purpose (i.e. at the time of Croatia's accession process to the EU). [10] Instead, it should reflect a genuine realisation of the importance of information security in information society.

With this in mind, Croatian lawmaker needs to decide on the future course in developing the national legal framework of information security with regard to the new EU Directive.

Several scenarios are possible, including a probable revision or complete rewrite of the Information Security Act which would position the Information Security Act as a central and encompassing regulation in this field – something similar to the regulation concerning personal data protection, and the role of the Personal Data Protection Act (OG 103/03, 118/06, 41/08, 130/11, 106/12).

Another solution would be a purely sectorial approach, regulating essential services or digital services with regard to information security through relevant telecommunication sector, finance or transport regulation.

Finally, a hybrid model is also possible with both a separate information security act as well as implementation of information security provisions into leges speciales.

VII. CONCLUSION

Fifteen years have passed since the EU first tackled the issues of information security. A relatively short time considering the usual speed of legislative development, and an eternity considering the speed of IT development, proliferation of new business models based on the use of digital content, especially personal data.

Of course, legal and technical challenges regulation of the kind information security now faces have been observed before. Just like in the case of personal data protection regulation, real world spread and use of technology have advanced faster than regulatory systems' ability to cope.

New technologies such as wide spread broadband, affordable and accessible mobile data connections and the rise of Internet-of-things have empowered the users and gave rise to numerous new information society services.

These new services, especially social networks, geo-location services, data distribution networks and content streaming services present a huge challenge for both personal data protection as well as information security. Today, a scenario where hackers walk in into a financial or government institution premises and wirelessly circumvent existing information security infrastructure is not only possible, but also very likely. Successful attacks compromise information systems and users accounts and open up new avenues of attack onto other, connected services. New forms of communication open up new social engineering vectors and opportunities for identity theft.

The new European information security laws represent an attempt to introduce consistent provisions concerning the regulation of essential and digital services and to ensure their resilience to cyber attacks across legal systems of the Member States underlining the importance of these services to economic, administrative and social life in general in times of transition to information society.

However, the state of this transition, especially the state of the EU digital market and innovation in IT industry in general characterize the EU as a second tier competitor. Asian competitors, especially China, Japan and South Korea, as well as the United States, continue to lead in innovation, research and development of new services and products.

A strong internal market as a proving ground for development of truly global and innovative services is a conditio sine qua non, as illustrated by the almost uniform distribution of leading internet services mostly out of US and China. In that regard, the NIS Directive represents another effort in Commission's proclaimed goal of effecting the European Digital Single Market and fostering innovative information services based in the EU.

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Stabile Usage of Export Regulatory Standards in Data Security Process

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***Abstract* - The amount of data that contemporary companies generate is rapidly increasing. Due to data explosion, security and privacy are becoming crucial concerns for companies. Therefore, companies must ensure security to remain a priority, and set the rules that will keep company at a desired security level. In addition to their internal security rules, a company may need to comply with one or more standard defined by external parties. Weak implementation of strict standards may lead to procedural gaps where the critical point is delivering the data to customers. In this paper, we define terms and concepts behind the security standards that are related to encryption algorithms and describe the correlation between security and regulatory standards while exporting sensitive data to customers. In addition, we provide a case study to demonstrate how weak implementation of export regulatory standards can lead to human errors, where lack of security competence can trigger high level damage after commercial product roll up. Finally, we show how minor modification in the implementation of standards can mitigate the security breach.**

Keywords - Cryptography; Protocols; Algorithms

DISCLAIMER - some companies, products and services are mentioned in this tutorial. Such mention is for example purposes only and should not be taken as a recommendation or endorsement by the authors.

I. INTRODUCTION

To mitigate the risk of losing data, the companies introduce security frameworks that define a life cycle for managing the security of data and technology within the company. The updates of security frameworks need to be prioritized during the product development or otherwise desired security level will not be reached. There are known methods to enforce security rules, however the implementation often does not comply with the defined standards which may result in severe security breach [1].

In the first part of the paper we provide an overview of cryptographic algorithms used in Ericsson company. Also, we explore future emerging environments where cryptographic solutions are yet to be adopted.

In the second part of the paper, we specially focus on security aspects of complex product development process in a large company where various teams need to cooperate and communicate to produce the product and deliver it to their customers. For instance, companies that operate internationally and offer their products abroad, should obey certain regulations according to the export rules [2]. This is especially important in case the exported product is using cryptography and product's usage is restricted. Failing to meet the export rules can cause large penalties for exporting companies. As part of the paper, we deliver a case study that analyses the Panama case [3], where Ericsson company paid large fines due to export rules violations. We also identify the main cause that led to violation of export rules as a weak implementation of security standards within the company and miscommunication between teams responsible as well. Finally, we propose a better implementation of security standards that would prevent the export violation in Panama case to happen.

Section 2 provides an overview of cryptographic algorithms currently used in company Ericsson during the product design phase. Section 3 will introduce some future contexts where cryptographic solutions need to be adopted. Section 4 describes the behaviour of products at commercial roll up and export where data security must follow specific regulatory standards. Section 5 brings the case study where human behaviour in process of export control is main part of discussion. Finally, Section 6 concludes the paper.

II. CRYPTOGRAPHIC ALGORITHM

An overview of cryptographic algorithms used in Ericsson telecommunication company can be found in their Technology Review [4], where is stated that algorithms developed by 3GPP and GSMA for confidentiality, integrity, authentication, and key derivation have evolved dramatically since they were first introduced. The original algorithms deployed in 2G/3G networks were kept secret and designed to meet the restrictions related to encryption of that time but found to have weaknesses. The encryption algorithms developed for 3G and LTE have been made available for public analysis. They use well-known and standardized algorithms such as AES, SNOW and SHA-3 and to date, no weaknesses have been found.

Commonly used algorithms, will be briefly mention in the next three sub-chapters [5].

A. Symmetric algorithms

Symmetric algorithms encrypt and decrypt a message using the same key. However, there is certain risk in handling same keys. Once a key gets in the wrong hands, there is no going back. A person who possesses the key can read all past messages and create new messages that are indistinguishable from valid data. Several symmetric algorithms have been used in the past: Blowfish, DES, 3DES (Triple DES), AES.

The first three algorithms are generally considered obsolete and are followed with comments in literature, as "*should be avoided due to poor security*", "*has been phased-out from standard due to poor security*" or even "*considered weak, not to be used today*".

Ericsson [4] conducted a study about usage of symmetric algorithms and concluded that processes of encryption and integrity protection are separated. By instead combining them, newer AEAD [6] algorithms achieve huge performance gains over their legacy counterparts. For example, when AES is used in Galois Counter Mode (AES-GCM), AES has outstanding performance on modern processors and is today's solution for many high-end software applications.

B. Asymmetric Algorithms

Asymmetric algorithms use different keys for encryption and decryption. The encrypting key is called the public key while the decrypting key is the private key. In a public key encryption system, any person can encrypt a message using the receiver's public key. That encrypted message can only be decrypted with the receiver's private key. The receiver has confidence that the message came from the right source, because only someone who holds private key could have produced a working signature. There are two dominantly used asymmetric algorithms today: RSA and Elliptic Curve. In addition, a Diffie-Hellman protocol is commonly used today for key exchange over a public channel.

Diffie-Hellman is not quite suitable for establishing identity as it needs to be protected from Man-In-The-Middle Attack [7]. RSA is most commonly used today, while Elliptic Curve appears to be on its way to become the next standard [8].

An example of asymmetric algorithms usage is described in [4], where is stated that data encrypted with the public key can only be decrypted by the private key and signatures created with the private key can be verified with the public key. Typically, public-key algorithms like RSA are used for authentication and key exchange during session setup and not for the protection of data traffic.

Improved security and performance can be accomplished with Elliptic Curve Cryptography (ECC). ECC can achieve better performance by using smaller key size. The key sizes used in asymmetric algorithms need to be longer than those used in symmetric algorithms of comparable strength. The ECC signature algorithm ECDSA (with the NIST p-256 curve) uses significantly smaller key sizes than RSA (256 bits compared with 3072 bits) and delivers significantly better performance in use case where both signing, and verification are needed. New faster ECC algorithm Ed25519 [9] will further improve the performance of ECC.

C. Hash Algorithms

Ordinary hash functions are not suitable for digital signatures because they are easily reversible. Instead, there are special cryptographic hash functions which produce hashes that are hard to reverse [5]. In other words, given a hash, it's hard to generate a document that produces that hash. Cryptographic hash functions include: MD5, SHA 1, SHA 2 family (SHA-128/-192/-256), SHA 3 family. MD5 has been found to contain weaknesses and is therefore no longer recommended for use. SHA 1 is a little stronger but should still be phased out now. SHA 2 is secure, but its disadvantage is that the NSA invented it. SHA 3 is secure and was invented using an open selection process.

III. USAGE OF ALGORITHMS IN THE FUTURE [4]

ICT industry is in the process of abandoning the use of several legacy algorithms and protocols including 3DES, RC4, CBC-mode, RSA, SHA-1 and TLS 1.1, changing them with newer, more secure, and faster algorithms such as AES-GCM, ECC, SHA-2, SHA-3 and TLS 1.2 and later versions.

One company has recently initiated an upgrade of the 3GPP security profiles for certificates and security protocols such as TLS, IPsec and SRTP [10]. That will lead to security strategy that should be implemented using efficient and tested algorithms that will offer a cryptographic strength equivalent of at least 128-bit security for AES, as minimum requirement for wireless technologies as IoT or Cloud storage.

Messaging patterns that are used in IoT device communication nowadays are *store-forward* and *publish-subscribe*. Those devices are communicating using middleboxes, which limits the possibility for end-to-end security. The solution is usage of fully trusted intermediaries, which make access to IoT data sensitive services difficult for enterprises and governments. The aim of object security is to provide end-to-end protection of sensitive data, while enabling services to be outsourced at the same time.

Homomorphic encryption [11] is one of the key breakthrough technologies that came from cryptographic research. In contrast to AES, this approach allows operations to be performed directly on encrypted data without using the data in its decrypted form. To support arbitrary computations on encrypted data using fully homomorphic encryption, some performance issues still need to be overcome. However, many specialized methods like partially homomorphic encryption,

deterministic encryption, order-preserving encryption, and searchable encryption, allow a specific set of computations to be performed on encrypted data with a sufficient performance so that they can be applied to real-life scenarios. Research [12] has shown a performance increase of orders of magnitude, which makes it suitable for high-throughput scenarios. By using homographic encryption, clients with large datasets, such as network operators, health care providers and process/engineering industry players, would be able to outsource both storage and analysis of the data to the cloud service provider. Once outside the client's network, data is encrypted, thereby preserving confidentiality, and allowing the cloud provider to perform analytics directly on the encrypted data.

In post-quantum cryptography era, the existing algorithms that are considered secure nowadays, will become weak to special attack algorithms invented and are ready for a quantum computer to execute on. As an example of such attacks, Grover's algorithm can be easily used to break symmetric cryptographic algorithms. Grover's algorithm inverts a function using only $\sqrt{N}$ evaluations of the function, where N is the number of possible inputs. For a symmetric 128-bit key algorithm, such as AES-128, Grover's algorithm enables an attacker to find a secret key 200 quintillion times faster, using roughly 264 evaluations instead of 2128. The quantum computing therefore weakens the effective security of symmetric key cryptography by half. Research [4] state that situation for public-key algorithms is even worse; for example, Shor's algorithm for integer factorization directly impacts the security of RSA. With Shor's algorithm, today's public-key algorithms lose almost all security and would no longer be secure in the presence of quantum computing.

Although current research is far from the point where quantum computing can address the size of numbers used today in crypto schemes, the ability to perform quantum computing is increasing. In 2014, ETSI organized a workshop on quantum-safe cryptography and in 2015 the US National Security Agency (NSA) said it would initiate a transition to quantum-resistant algorithms, as the potential impact of quantum computing has reached the level of industry awareness [13].

IV. CRYPTOGRAPHY EXPORT CONTROL

An encryption functionality can be provided by a software, encryption chips, integrated circuits, application specific encryption toolkits, executable or linkable modules, e.g. that alone are incapable of performing complete cryptographic functions, and any encryption commodity that is designed or intended for use in or in the production of another encryption item [14]. So, it is visible that awareness of encryption is increasing and there has been a surge in the number of companies that want to encrypt products over the entire product life-cycle. The market for encryption of products is growing and more developers are building software that integrates data security using encryption. This raises important questions about the legal frameworks that regulate the distribution of encryption technology.

Part of data security concept, responsible for distribution and standards defined by external parties and internal company trade compliance directives is called Export control. Export control must guarantee that product using cryptography is not delivered to certain end-users or for certain end-uses without permission from a competent authority. For example, dual-use items (items that have both commercial and military or proliferation applications) [15] should be subject to effective control when they are exported.

One of few agreements which regulates export of cryptography internationally is called the Wassenaar Arrangement. The Wassenaar Arrangement (WA) [16] has been established to contribute to regional and international security and stability, by promoting transparency and greater responsibility in transfers of conventional arms and dual-use goods and technologies, thus preventing destabilising accumulations. Participating States seek, through their national policies, to ensure that transfers of items do not contribute to the development or enhancement of military capabilities which undermine these goals and are not diverted to support such capabilities. The aim is also to prevent the acquisition of these items by terrorists. Participating States apply export controls to all items set forth in the List of Dual-Use Goods and Technologies and the Munitions List, with the objective of preventing unauthorized transfers or re-transfers of those items. To assist in developing common understandings of transfer risks, Participating States regularly exchange information of both a general and a specific nature. Participating States are required to report their arms transfers and transfers/denials of certain dual-use goods and technologies to destinations outside the Arrangement on a six-monthly basis. In some cases, shorter reporting time-frames apply. In fulfilling the purposes of the Arrangement as described above, Participating States have, inter alia, agreed to many guidelines, elements, and procedures as a basis for decision-making through the application of their own national legislation and policies. The decision to transfer or deny the transfer of any item is the sole responsibility of each Participating State. All measures with respect to the Arrangement are taken in accordance with national legislation and policies and are implemented based on national discretion. For specifics on Export Controls in Participating States National Contacts.

Usage of export regulations is mainly defined and communicated to authorities through specific Product Classification codes, called Export Control Classification Number (ECCN) and Harmonized System Tariff (HST).

A. Export Control Classification Number code [17]

Export Controls regulates the shipment or transfer, by whatever means, of controlled items, software, technology, or services, as classification of controlled goods is mandatory part of export.

The ECCN code refers to Export Control Classification Number (the U.S. term for an export classification code). The export of cryptographic technology and devices from the United States is severely restricted by U.S. Law. The ECCN code is national code specific to the United States, although it has a similar form as used in other countries because most countries participate in multilateral export control regimes like the mentioned WA. Accordingly, regulations were introduced as part of munitions controls which required licenses to export cryptographic methods. The regulations established that cryptography beyond a certain strength would not be licensed for export except on a case-by-case basis. This policy was also adopted elsewhere for various reasons. The ECCN code identifies the relevant category and paragraph of a classification, as they are maintained under the EAR's Commerce Control List [18].

ECCN code structure contains 3 parts: Category, Product area and Type of control, described on Figure 1

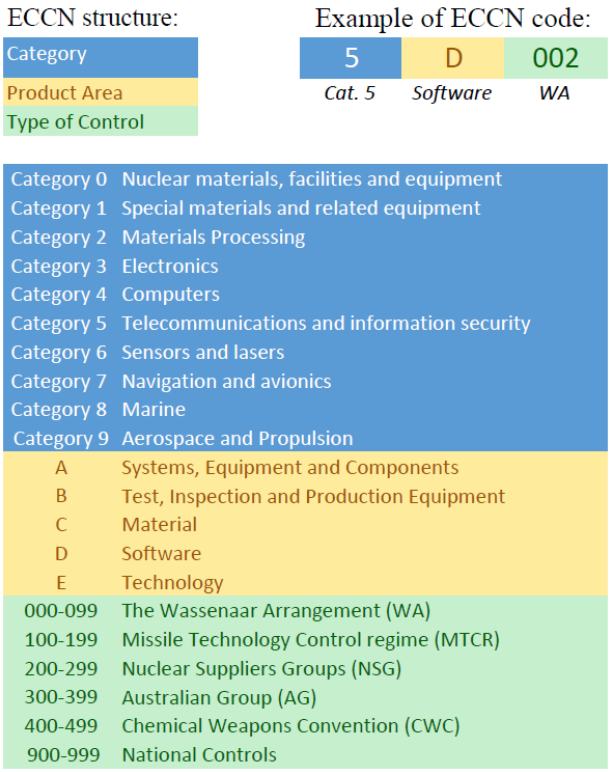

Figure 1 ECCN code structure

B. Harmonized System Tariff (HST)

The Harmonized Commodity Description and Coding System [19] generally known as Harmonized System (HS) is a multipurpose international product nomenclature developed by the World Customs Organization (WCO). All goods that cross international borders must be classified with an HS code.

The HS is a complete classification system (i.e. it covers all merchandise). It was designed as a core system so that countries adopting it could make further subdivisions according to their tariff and statistical needs. Goods in trade generally appear in the HS in categories or product headings in a progression beginning with crude and natural products and continuing in further degrees of complexity through advanced manufactured goods.

Developed and managed by the WCO, the HS Code:

- consists of 5,000 commodity groups covered in 99 Chapters containing 21 Sections;
- is identified by a six-digit code;
- is arranged in a legal and logical structure; and
- is supported by well-defined rules to achieve uniform classification all over the world.

HS code structure contains 4 parts: Chapters, Headings, Subheadings, and Country-specific details[1] described in Figure 2, where example of code used in telecommunication sector is shown.

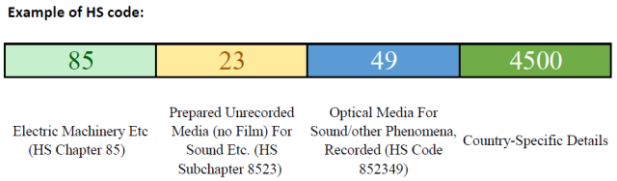

Figure 2 HS code structure

V. CASE STUDY

Order process in companies is formed according to the customers wishes. Products are packaged in groups to meet reusable functions of sales process, common in customers' orders. Those reusable groups of products are called packages. When package reaches general availability state then every aspect of product security should already be implemented. This means that mandatory cryptographic algorithms should be known, export control information on package level should be strictly defined, export control codes should be stated and approved by trade responsible and set as package data. The key point is export control procedure involves several roles, usually spread over few different departments. If there is no correct communication between included parties export control process is prone to human errors. A critical part is related to setting the right security data on the package level. Failing to set the appropriate security data on the package level for some reason can lead to a high level of damage while exporting goods. A known example is the case of Panama where Ericsson company paid $1.7 Million to settle 262 violations of the Export Administration Regulations (EAR).

A. Issue

In a company as Ericsson, Trade department (TC) handle export regulations deployment and control security information's connected with each package [20]. The TC department is well known by handling strict security policy and managing trade information on high

[1] The remaining numbers may include national tariff rates (generally 8-digits) or a 10-digit number may be used for statistical use, quotas, and analysis. In the United States, for example, the full 10-digit number is called the Harmonized Tariff Schedule of the United States (HTSUS) code. Not all countries, such as India, have full 10-digit codes.

level and is not responsible for setting data on package level or releasing packages. The department that is responsible for release is the Product Packaging department (PP), where technical responsibility and crucial structure knowledge is situated.

In the Panama example, a problem occurred when Ericsson de Panama knowingly implemented a scheme to route items from Cuba through Panama, repackaged the items to conceal their Cuban markings. Then, they forwarded the items to the U.S. for repair and replacement and then returned the items to Cuba. Classified under Export Control Classification Numbers 5A002, 4A994, 5A991, 5B991 or designated EAR99, the items' distribution to Cuba were controlled for national security, antiterrorism, encryption, and sanctions reasons. In this case the issue was that products didn't have right export control data set. However, issues can also appear if there is no adequate amount of communication between departments involved in the trade process.

The PP department is mainly involved in pre-sale phases but is not familiar with mandatory trade knowledge. As not obligated to contact TC department when release of product is ongoing, the product can be automatically moved to the commercial phase with predefined trade data without trade responsible confirmation. In such a scenario, the released package has non-confirmed or lack of export control strength, where transport of such product can lead to high level of damage.

B. Solution

The guidelines for handling cryptography found in company documentation advise as follows:

- All non-public information, especially about customers, partners or suppliers must be encrypted to ensure proper and effective use of cryptography and to protect the confidentiality, authenticity and integrity of information;
- No individuals in company shall take steps to bypass encryption or decrypt information for which they are not authorized to access. Equipment used to generate, store and archive keys must be protected;
- Systems that are providing cryptographic functionalities must reveal used algorithms. If possible, standard cryptographic algorithms and libraries should be used;
- Some countries restrict usage of cryptographic technology, others restrict the import of encrypted data and still others restrict or prohibit the use of encryption within their borders. Local laws and legislation regarding the use of cryptographic technology must be respected;

Cryptographic keys must be treated as company's confidential asset. They must be provided on request from an authorized security function within company and be part of export control process, where coordination between TC and PP departments is crucial in providing stabile usage of export regulatory standards in data security process.

PP and TC responsible should do the release of the package together when all predefined rules are confirmed:

- All design information and substructure should be created and connected with the package;
- All trade information and documentation should be released and connected with the package;
- When the package is ready for release, release confirmation should be confirmed by PP and TC responsible by setting unique state of the package; TC responsible should set a new added trade (TC) code and PP responsible should set a common design code for release;

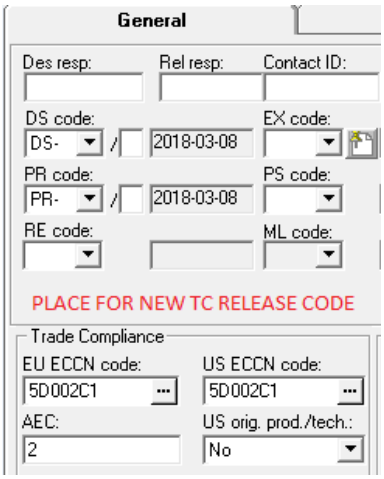

Figure 3 Package data update with TC code

- When the trade code and the design code are set product can be released.

Packages released by following the above-mentioned rules are secured of lack of release information. Therefore, huge damage triggered when the order reaches customers would be avoided.

C. Lesson learned

It's important that there is a regular time for reporting both progress and potential pitfalls between the teams. This keeps people on track and gives everyone the discipline of a team check-in. Export control process is all about knowing guidelines, elements, and procedures, that are strictly connected with agreements and trade rules, but team spirit and communication is something that lies in human hands and should be mandatory in trade work.

VI. CONCLUSION

The top priorities in data secure process is to define stable security and privacy framework as the key to protect the privacy of individuals and company's knowledge. Companies must take steps to ensure that they follow encryption regulations in all countries where they do business and at the same time must adopt best practices

to maximize information security, despite restrictions on cryptography use.

Overcoming these concerns is a non-negotiable element of the product export process, where encryption techniques are applied across the entire product line system. This, together with new, more complex communication services places new demands on cryptography usage [5].

Implementation of security policy should be applied to all company's product/packages that are ready for commercial usage. As described in case study, key role is sharing knowledge and information between all parties included in export process. In mentioned example, passing information between TC and PP department should be defined as part of release process where more stable and security driven packages will be placed and sent to customers.

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A Decision Matrix Model to Identify and Evaluate APT Vulnerabilities at the User Plane

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***Abstract*—While advances in cyber-security defensive mechanisms have substantially prevented malware from penetrating into organizational Information Systems (IS) networks, organizational users have found themselves vulnerable to threats emanating from Advanced Persistent Threat (APT) vectors, mostly in the form of spear phishing. In this respect, the question of how an organizational user can differentiate between a genuine communication and a similar looking fraudulent communication in an email/APT threat vector remains a dilemma. Therefore, identifying and evaluating the APT vector attributes and assigning relative weights to them can assist the user to make a correct decision when confronted with a scenario that may be genuine or a malicious APT vector. In this respect, we propose an APT Decision Matrix model which can be used as a lens to build multiple APT threat vector scenarios to identify threat attributes and their weights, which can lead to systems compromise.**

Keywords-APT; Phishing; spear phishing; threat; security

I. INTRODUCTION

Almost all information security breach incidents involve some element of human error [1], as end users in the workplace are "the weakest link" in IS security [2, 3]. Thus, the human factor is the most critical element in the security system for at least three reasons; it is the weakest link, it is the only factor that exercises initiatives, and it is the factor that transcends all the other elements of the entire system [4]. Thus, the user at the workstation may become an unwitting propagator of APT in the network. Since APT threat vectors via spear phishing carry zero-day payloads which can evade anti-malware solutions, detection at the point of entry (the user plane) provides effective prevention of the threat. In this respect, this paper aims to provide a model to identify the APT vector attributes and the relative weights assigned by the user in differentiating between a malicious APT threat vector and a genuine online communication. The model can assist IS security managers to identify the attributes and relative weights assigned by users in determining the nature of an APT threat vector.

Mostly targeting organizations with substantial intellectual property value [5, 6], APT has been used to penetrate government and corporate organizations worldwide by way of the unintentional mistakes of computer users. Consequently, APTs pose a grave threat to cyberspace because they bypass all the conventional cyber defence mechanisms [7]. Intervention is required at the 'user plane' (the dimension where the user interacts with the workstation) in order to assist the user to make a correct decision when confronted with a genuine or malicious APT vector. This necessitates the need to identify and evaluate the attributes and relative weights that users allocate to the APT threat vectors. In this regard, awareness and user conditioning of APT vectors can lead to proactive detection at the human intervention phase of APT attacks. Results of this study will help users ultimately move towards a proactive prevention (before it enters the network) mode, rather than a reactive detection (after it enters the system) mode, at the human intervention phase of APT attacks.

II. APT CHARACTERIZATION

APT attacks are typically carried out via communication channels, such as email or instant messaging, by masquerading as legitimate and trustworthy communications [8]. Other attack vectors include use of infected USBs, fraudulent websites, advertisement banners, and freeware [9]. Out of the 156 million phishing emails (a key part of the APT) sent every day to global Internet users, 16 million make it through spam filters, resulting in 8 million scam emails being opened, and 80,000 people falling victim to the loss of personal identity and information [10]. A 2015 survey on the probability of the sources of successful APT attacks placed social networking sites highest at 95%, followed by Bring Your Own Device (BYOD) combined with rooting or jailbreaking at 89% [11]. Since, mobile devices have been described as a phisher's paradise [12], results of this work can be extended/modified to BYOD and/or mobile devices to identify new attack patterns on organizational IS through mobile devices.

While APTs have drawn increasing attention from the industrial security community, the academic community has neglected these threats and, as such, an objective approach to the APT issue is lacking [5]. Much research has been done in the area of intrusion detection but little in its application to APTs [6]. In this respect, research on APT countermeasures focuses mainly on detection and mitigation within the network rather than on prevention. APT poses a serious challenge for current detection methods because these methods depend on known signatures of attacks and APTs make heavy use of unknown security holes for attacks [13] [14]. Thus, the defensive tools, procedures and other controls commonly put in place to handle commodity

security threats are often ineffective against targeted APT-style attacks [15].

Research on cyber threat modelling by Nicho and Kamoun [16] and Giura and Wang [17], have demonstrated that it is not only possible to model cyber-attacks patterns, but also to implement simulations to pursue self-paced security training and awareness [18, 19]. Similarly researchers at Carnegie Mellon University have successfully modelled insider threat scenarios to train users to make decisions on how to prevent, detect, and respond to insider threat actions, and to see the impacts of their decisions in terms of key performance metrics [20]. APTs being highly advanced networked entities [6] that employ multiple attack techniques [21, 22] to monitor, administer, and steal information from the target over a long term [23], modelling APT threats from a user perspective can help in their detection.

III. APT Detection and Mitigation

Since APTs follow a multistep attack process that is executed with more stealth and targeted specifically to achieve a specific goal, most often espionage [13], it is very difficult to detect them [24]. Research on APT detection and mitigation has mainly been conducted in a reactive mode driven by cause-and-effect mechanics [25], rather than on the human intervention proactive detection method. In this respect, an intrusion detection system (IDS) has been designed to detect the possibility on the initial intrusion and thereby minimize the amount of damage from the APT attack [26]. Moon, et al. [27] proposed a multi-layer defence system to prevent APTs traversing a network by analysing information from network, server, end-user, and logs (the defence in depth approach). Due to the enormous data generated through logs, using security log analysis has been proposed by Jeon, et al. [28] to locate suspicious activity inside the network.

Research has been done on user behavior prior to and during the attack phase. The predominant factor in the success of spear phishing attacks is their deceptive nature and the attacker taking advantage of basic human psychology [29]. The sophistication and the use of multiple attack techniques, including social engineering and automated tools, makes it much more insidious [22]. Once APT attackers have identified the employees, they will use social engineering techniques to obtain valid user credentials. Thereafter, they will use spear phishing emails that appear legitimate to trick employees into divulging sensitive information or clicking on a link or attachment that contains malicious codes [30]. Moreover, phishers have also started to use psychology in their emails that plays on urgency, greed or trust [31]. Viewing user behavior from a psychological perspective, a significant body of research has implicated the mode of cognitive processing individuals employ as a determinant of the likelihood of their falling prey to a phishing attack [32]. While advances in the automated detection of phishing websites have resulted in improved security tools and models, these automated means are not fool-proof and users must be vigilant in protecting themselves from APT threat vectors [33]. Therefore, little can be done to protect against APT threat vectors, except to educate staff not to freely click on links or to open attachments sent within emails [34]. Hence, identification of the APT threat vector attributes assumes significance.

Since APT enters through the unintentional mistakes of employees, Lin, et al. [35] proposed a virtual time control mechanics-based method that efficiently detects nontrivial anomalous codes that may be neglected by conventional sandboxing techniques. Internal network traffic and client data analysis at multiple network locations using both signature and anomaly detection methods derived from the intelligent data analysis field has been proposed by De Vries, et al. [36]. Similarly, Vert, et al. [6] employed finite angular state transition velocity machine (FAST-VM) and its vector based analytic algebra to detect APTs inside the network. FAST-VM has analysed 10,000,000 state variable vectors in around 24 ms which demonstrates the application of "big data" to the area of cyber security [37]. Meanwhile, Chandran, et al. [38] proved the effectiveness of random forest algorithm methodology to detect the presence of APTs in infected machines. To reduce false positive and false negative rates, Siddiqui, et al. [39] proposed a model that analyses traffic patterns inside a network using a machine learning classification approach. Hu, et al. [40] came up with an expert system (ES)-based APT detection game using both the miss detection rate and false alarm rate of APT detection.

Despite several models being introduced and deployed by the cyber security sector, these models mostly target the network, physical, and application planes (see figure 1). There are few papers which address the decision making of the user in terms of differentiating between a genuine online communication and one that is masquerading as a genuine IS communication. Since, APT employs increasingly sophisticated evasive techniques to avoid detection at different technical layers of the networked cyber defence mechanisms, focusing on the threat vulnerabilities at the user and pre-user plane provides the most effective preventive measure against the growing APT threats.

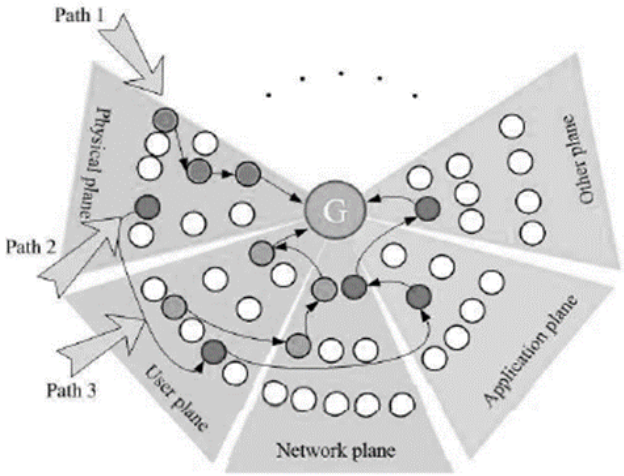

Figure. 1. Attack patterns [11]

IV. THE MODEL

APTs follow multiple paths to reach their goal; namely, the physical plane (hardware), user plane (users' system), network plane (internal network), application plane (application gateways), or any other emerging planes [17] (see figure 1). However, the human intervention happens when the APT vector moves from the 'delivery' phase of the APT vector to the 'exploitation' phase (inside the victim machine). APT attacks can be thwarted during this transition between the two phases through reinforcement of human behaviour. This requires knowledge of relevant information on the part of the user to take correct decisions. From an insider threat perspective, Rich, et al. [41] proposed an insider threat decision matrix to differentiate between a genuine and a fraudulent transaction (executed by a malicious insider). We modified the model to suit the APT scenario to present the attributes and weights the workstation user evaluates when deciding between a normal IS communication process and a malicious APT vector.

The task of the computer user is to make a judgement as to whether an email is an APT targeted one or a genuine email. In this regard, the user, acting as a negative or positive gatekeeper, uses their existing knowledge of APT vectors to make a decision on whether to proceed processing the IS communication or to avoid it. APT threat scenarios can be modelled to incorporate the decision-making process by the user, based on the attributes of the APT vector, the relative weights given to the attributes by the user, and a pre-determined threshold where a vector is considered suspicious. Considering that an APT vector can be denoted with a 'positive' sign, while a normal IT process is denoted as 'negative', we use 'true' when the user is able to detect and differentiate between an APT vector and a genuine process, while 'false' represents the inability to detect and differentiate.

The ensuing APT decisions (table 1) comprise four types of user decisions. Both 'true positive' and 'true negative' denote correct identification of real attacks (APT) and genuine processes (like a genuine email/link/attachment/ drive) respectively. However, 'false positives' denote false alarms where a genuine process has been identified as an APT vector, while false negatives are APT vectors that go undetected and create significant losses in terms of data breach for the organization. In this regard, a phishing study found that 97 percent of people failed to correctly identify infected sample test emails [42].

Out of the four decisions, the false negatives being dangerous and potent, this research aims at reducing this element while increasing the true positive value through increased awareness of APT vector descriptive attributes. Figure 2 illustrates variables affecting the users' decision to ascertain the authenticity of a process. This demands not only knowledge of the attributes of APT vectors and genuine processes, but also knowledge of the relative weights placed on these attributes by the user. Users base their judgment regarding each process (whether APT or genuine) by comparing 'y' against a mental threshold 'z' (where 'z' is the information on all attributes/weights of APT vectors and genuine IS processes in the mind of the user). If the value of 'z' is low, it leads to an error in judgement, while a high value for 'z' can lead to correct decisions as the user is more informed. However, a substantial high value of 'z' can also lead to false positives. Thus, policy-makers trying to find an optimal threshold value face a trade-off between the negative consequences of false positives and false negatives [43]. An optimal value can be ascertained through re-adjusting the suspicion threshold 'z', based on a set of noticed results [41]. Subsequently, understanding APT attacks in a simulated environment provides an optimal value through modelling of multiple APT vector attributes and attribute weights.

Table 1. APT decisions

	+	-
True	True Positive (Attack detected; correct judgement)	True Negative (Genuine IS process identified; correct judgement)
False	False Positive (False alarm; genuine IS process detected as APT)	False Negative (APT vector enters masquerading as genuine IS process; error in judgement)

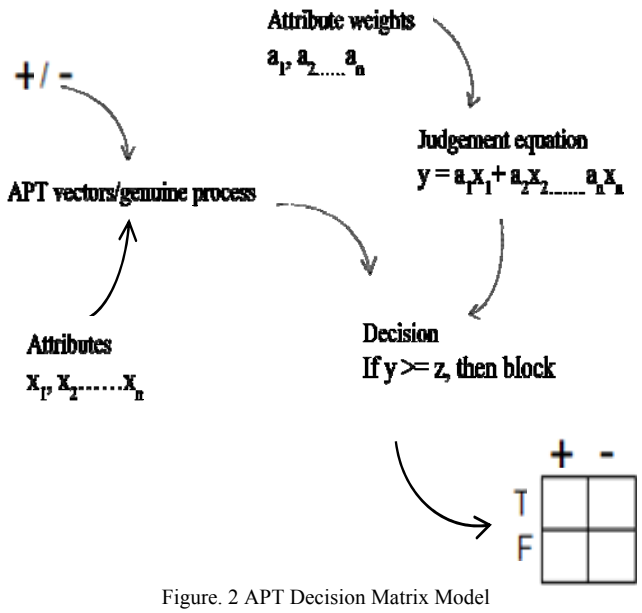

Figure. 2 APT Decision Matrix Model

The model, as well as the attributes (x), the relative probability (a), the aggregate average probability value of the decision (y), and the mental threshold (z) can be illustrated using a phishing scenario given below:

"You receive an e-mail from your credit card company informing you that your account has been deactivated

because of suspicious activity. The message requests you to click a web link and log in to verify your account information. Following the instructions, you are directed to what appears to be the "Online Update" page of your credit card company. Here you are asked to enter your name, password, account number, social security number, and PIN. It all seems legitimate: the logos look proper, the web address of the page looks convincing, and the format of the site is the same as you remember. However, this is a scam; the e-mail is a fraud, and now a cyber-criminal has your personal information. He or she can now use or change your account or open new accounts in your name. You have become a victim of a growing crime called phishing" [44].

Attributes (x): While the above scenario refers to phishing attacks, the email characterization is identical to a spear phishing email where the attributes can be key words, instructions, and/or visual observations (table 2). While the computer user's knowledge of the attributes of a spear phishing email attack vector varies, a few obvious attributes are listed. The significance of 'x' lies in the fact that extension of this research from an empirical perspective, not only aims to explore a taxonomy of attributes for distinct types of spear phishing vectors, but also attempts to identify the varied levels of knowledge displayed by the computer user when confronted with a suspicious looking email vector.

Table 2. Attributes

Attribute types	Attributes	Notation
Source	Credit card company	X_1
Instructions	Click a web link	X_2
Instructions	To log in	X_3
Instructions	Verify a/c information	X_4
Instructions	Enter card information	X_5
Consequence	Deactivate	X_6
Observation	Online update form	X_7
Observation	Bank web site replica	X_8
Observation	Bank web page replica	X_9

Relative weights (a): This refers to the weights in terms of probability of the attributes of the spear phishing attack vector assigned by the computer user to the attributes. This highly variable value depends on the knowledge of the user regarding the attack vector. Thus, it is to be noted that network security personnel may assign an appropriate value of 0.9 to a definite attack vector attribute, while a novice or a risk-taking computer user might assign a low value of 0.1. In this respect, the significance of 'a' lies in the fact that extension of this research from an empirical perspective can uncover the variations of 'a' for an 'x' by different users.

Decision based on probability (y): It was observed in a normal spear phishing scenario facing a computer user that no one single attribute influences the computer user to take a decision to block or allow a spear phishing attack vector. Hence, an incidental composite of attributes along with their weights 'a', aggregated into an average, influence the computer user to determine if the email is most probably a spear phishing attack vector. This can be expressed by the equation where the value of 'y' ranges from 0 to 1:

$$y = \frac{1}{n} \sum_{i=1}^{n} x_i$$

Here again, the significance of identifying the value of 'y' lies in the fact that extension of this research from an empirical perspective can uncover the variations of 'y' for multiple attributes 'x' by different users or strata of users.

Mental threshold (z): Over time, a computer user accumulates knowledge of a spear phishing vector's attributes. Based, on this tacit knowledge, the computer user has a variable mental value 'z' (0 to 1, with a maximum value of '1' that indicates a definite threshold probability value), where any value above 'z' is regarded as a threat vector while anything below 'z' is regarded as genuine email. However, it is to be noted that this value 'z' change over the course of time due to the learning curve of computer use and the changing dynamics of online threats. This threat value can also be expressed as $z = \frac{1}{n} \sum_{i=1}^{n} x_i$, where x_i characterize those attributes and weights accumulated as tacit knowledge. Finding the value of 'z' assumed significance, since extension of this research from an empirical perspective, attempts to identify the varied levels of tacit knowledge displayed by the computer user when confronted with a suspicious looking email vector. It would also be interesting to find out the initiatives that need to be undertaken to increase the value of 'z' since an increase in 'z' increases the accuracy of identification of threat vectors.

V. Conclusion and Future Work

The research project aims to explore and analyse APT threats and vulnerabilities affecting the user. In addition, it explores the decisions taken by users in identifying and evaluating the attributes of multiple APT vectors. The project aims at using the APT Decision Matrix model in identifying and analysing multiple types of APT specific human errors, oversights and decisions that ultimately lead to systems compromise. Apart from the extensions of the research mentioned above, this study can result in a taxonomy of APT threat vector attributes that can assist managers to draft procedures for computer use and to prevent misuse; draft and execute APT defensive awareness and training programs; and to assist senior managers to frame organizational wide security policies.

Three limitations are evident in the paper which we aim to overcome. First, different weights can be attributed by

different users for an APT vector attribute. Second, the threshold ‘z’ can be different for different users. Third, the perception of risk of an APT attack is different for different organizations which can lead to different attribute weights. Hence, taking these factors into account, a generic statistical value can be obtained by simulating multiple APT threats using a large sample

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Brute-force and dictionary attack on hashed real-world passwords

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Abstract - An information system is only as secure as its weakest point. In many information systems that remains to be the human factor, despite continuous attempts to educate the users about the importance of password security and enforcing password creation policies on them. Furthermore, not only do the average users' password creation and management habits remain more or less the same, but the password cracking tools, and more importantly, the computer hardware, keep improving as well. In this study, we performed a broad targeted attack combining several well-established cracking techniques, such as brute-force, dictionary, and hybrid attacks, on the passwords used by the students of a Slovenian university to access the online grading system. Our goal was to demonstrate how easy it is to crack most of the user-created passwords using simple and predictable patterns. To identify differences between them, we performed an analysis of the cracked and uncracked passwords and measured their strength. The results have shown that even a single low to mid-range modern GPU can crack over 95% of passwords in just few days, while a more dedicated system can crack all but the strongest 0.5% of them.

Keywords – password cracking; password security; brute force attack; dictionary attack; hashed passwords

I. INTRODUCTION

Password based authentication remains the most common way of granting access due to its simplicity, despite many well documented flaws. While progress has been made from the technical point of view, the weakest link remains the human factor. This was already pointed out nearly 40 years ago, when Morris and Thompson addressed the issue of UNIX password security, identifying numerous issues and proposing several countermeasures. They concluded that the algorithm (in that case DES), used in the encryption of plaintext passwords, was too fast, which made them prone to brute-force attacks. To put things into perspective, back then, cracking a 6 lowercase character password using an average CPU took 107 hours, while today it takes roughly 20 seconds. They also pointed out, that user-created passwords were not only short, but also predictable, and were thus likely to appear in dictionaries [1].

A decade later, a follow-up study by Feldmeier and Karn found out that password creation habits remained weak, while cracking methods and the algorithm speed improved. They concluded that in order to improve password security, password entropy should be increased. Several additional solutions were suggested, such as password meters, pre-assigned strong passwords and salts. An alternative login method in form of smart cards was proposed as well, but such method is plagued by another set of flaws [2].

Zviran and Haga observed that characteristics of user created passwords did not change in the internet era. Passwords are still weak and easy to guess, mainly because users keep employing predictable patterns and common words, such as names and birth dates. Furthermore, the level of data importance or sensitivity does not affect password composition. They concluded that the length, change frequency, and selection method are not related to writing down a password, while its composition is. A set of guidelines for selecting and implementing user-selected passwords and mechanisms that monitor their implementation was also proposed [3].

Klein went into details on what to put into dictionaries, suggesting permutations, keyboard patterns, names, changing character cases and covering foreign languages. Perhaps the most useful advice was using word pairs, although such dictionaries can become quite large. He used a relatively small, but diverse dictionary that contained phrases ranging from sport teams to names of asteroids. To improve security, smart cards and password checkers were suggested yet again [4].

For the past four decades, the battle against user habits and laziness has remained in full swing. With advances in technology, even longer passwords are becoming more vulnerable, the dictionaries grow larger each day and all precautions cannot deter users from making bad decisions. A study on password meters concluded that they increase password strength for the important accounts, while for the unimportant accounts they make no observable difference [5]. Additionally, password policies can be more of a help to the attacker, because they reveal the minimal search space. Given that the users most often try to satisfy rules with as little effort as possible and thus use predictable patterns, an adversary can prioritize such passwords in their attack while ignoring weaker ones. Another important aspect of password security is frequent password change, but despite educating the users about the problem, the majority still does not change their password once it has been set [6].

The aim of this study is to crack as many passwords used by the students to access the university's online

grading system as possible, in order to demonstrate just how predictable and weak they really are. We were interested in the differences between the used cracking techniques, their success and time consumption. Finally, we performed the analysis and compared cracked and uncracked password characteristics and measured their strength with bits of entropy.

II. DATA ACQUISITION

185,643 passwords in MD5, SHA-1 and SHA-256 hashed form (and later in plaintext) were acquired, of which 151,136 were unique. They were created between 1980 and 2013 and were used to access the university's online grading system. Two default password patterns were identified. The main reason for duplicates are passwords, generated with the first pattern, consisting of two lowercase letters, derived from the students' first and last names, followed by four letters. The newer, improved pattern consisted of one uppercase, one lowercase letter, and six digits, all in random order. There were 154,505 (83.23%) default passwords, of which 144,250 (77.7%) matched the old pattern, and 10,255 (5.52%) the new one. Therefore, only 31,138 (16.77%) passwords were user-generated.

Previous works using this data found user habits to be in correlation with those described in [1], [2] and [3]. Password strength did somewhat improve over time, but unfortunately not enough to match the technology. Students who changed the default password mostly used short, simple, and predictable patterns [7]. An attempt to crack the passwords was made but was flawed in more than one way. Each attack mode was performed on the entire set of passwords, while the additional letters did not include 'đ' or 'ć', only Slovenian 'š', 'č' and 'ž'. Dictionary used was not adapted to suit the language used by the users but was instead build using large English wordlists. Lastly, only brute-force and dictionary attacks were performed, skipping attacks such as combinator or hybrid and rules [8].

Ethical concerns were addressed as well. Mentioned passwords are no longer in use, while additional data, such as gender, year of birth and course of study, had been anonymized by the university security service's personnel. The use of such personal data without prior or written consent of a subject (e.g. student) is allowed for the purpose of research under Article 11 (2), Article 13 (2), and Article 32 (3) of the Data Protection Directive [9].

III. EXECUTION OF THE ATTACK

User-generated passwords were predominantly created by Slovenian students, therefore some of them contained language-specific letters, that are considered special characters, such as "š" (used 181 times), "č" (used 160 times) and "ž" (used 74 times). Letters "ć" (used 13 times) and "đ" (used 4 times) were considered due to significant number of foreign students, mainly from former Yugoslav countries. In order to crack passwords that contained such letters, custom charsets were constructed.

All attacks were performed using hashcat v4.0.0 due to its flexibility and portability. In the first part of the experiment, a personal computer with a mid-range GPU, AMD Radeon R9 280X, 8GB of RAM (DDR3 1600, PC3 12800, 9-9-9-24, CAS9) and i5-4670k (@4GHz) with Windows 10 Pro (x64) OS was used. Benchmark hashrate for MD5 hash function using this system was approximately 8,900 MH/s. In the second part, we used a more dedicated system. With three nVidia GeForce Titan X Pascal, 64GB of RAM (DDR4 2400, PC4 19200, 16-16-16) and i7-6700k (@4GHz) with Linux Mint (x64) OS, the combined hashrate during benchmark reached approximately 88,500 MH/s.

All the executed attacks are gathered in Table I. They are grouped by the method of the approach and the results are also summed for each category. Sequence number denotes the order in which the attacks were executed, and the system column marks the computer used for the given attack. Some of the attacks were not completed and ran until they were interrupted. Few of the times are estimated due to the missing final report of the process, since they were paused and then resumed on another occasion. In the following chapters, each approach is described, and the more important results are singled out. It should also be pointed out, that most of the attacks could be combined during the more systematic approach.

A. Brute-force approach

Perhaps the most well-known, this attack mode heavily relies on the raw computing power instead of cleverness of the attacker. Cracking the old default pattern, for instance, took approximately 20 seconds for all 144,250 records (and some other passwords that matched the pattern), while the improved pattern was also later cracked in a single attack but took 10 hours and 20 minutes. This time could be significantly shorter if the attack covering all the possible arrangements of the letters and digits would be performed separately, because such detailed mask takes below one second to complete. Next, incremented attack was performed up to six characters in length, taking 2 minutes and 12 seconds and yielding 12,056 passwords. That was followed by the mask for digits only, from length seven to twelve characters, which took 3 minutes and 18 seconds and cracked 656 passwords. For further attacks on the remaining passwords, three custom charsets were constructed. First consisted of lowercase characters, including language specific letters mentioned earlier, digits and the most common special characters, while the second included uppercase letters as well. Third also contained letters from multiple less common foreign languages. All were missing a common special character asterisk ('*'), which later turned out to be a significant mistake, because the only two uncracked passwords left with the length of 7 contained said character, and there were 10 more in the longer uncracked passwords.

The first few attacks that cracked a large amount of the dataset provided an insight into user generated passwords and used patterns, which were later considered in the construction of the dictionaries. Weak passwords, like phone numbers, license plate numbers, birthdates and student IDs were all cracked as well.

TABLE I. ALL PERFORMED ATTACKS WITH UNIQUE PASSWORD COUNTS AND TIMES OF EXECUTION

Seq. no.	System	Attack	Count	%	Time
ALL Attacks			**150,213**	**100.00**	**~35 hours 44 min**
		Brute-force	**147,401**	**98.13**	**~32 hours 21 min**
1	1	Old pattern (2 lowercase letters followed by 4 digits)	115,498	76.89	20 sec
2	1	Increment to length six (mixedalphaspecialnum)	12,056	8.03	2 min 12 sec
3	1	Digits only from length 7 to 12	656	0.44	3 min 17 sec
4	1	Increment to length 8 (lowercase custom charset)	7,094	4.72	22 min 6 sec
5	1	Length 9 and 10 (mixed custom charset, special pattern)	2,071	1.38	Aborted after ~30 min
6	1	Increment to length 9 (foreign languages charset)	36	0.03	Aborted after ~15 min
14	1	Improved pattern (mixedalphanum length 8)	9701	6.46	10 hours 20 min
16	2	Length 10 lowercase English alphabet	67	0.05	49 min 33 sec
17	2	Length 10 lowercase English alphabet and digits	222	0.15	~20 hours
		Dictionary	**284**	**0.19**	**2 sec**
8	1	674,096-word dictionary	248	0.17	1 sec
10	1	14,457,264-word dictionary	36	0.03	1 sec
		Combinator	**1,012**	**0.67**	**2 min 34 sec**
7	1	14,652-word dictionary combined with itself	202	0.13	1 sec
12	1	674,096-word dictionary combined with itself	810	0.54	2 min 33 sec
		Hybrid	**697**	**0.46**	**2 hours 20 min 6 sec**
9	1	14,652-word dictionary, length 4 mask, custom charset, both sides	73	0.05	6 min 40 sec
11	1	674,096-word dictionary, length 4 mask, custom charset, both sides	590	0.39	6 min 26 sec
14	2	2.15GB dictionary, incremented mask to length 5, both sides	34	0.02	2 hours 7 minutes
15	2	**Rules** (2.15GB dictionary, all included hashcat rules)	**127**	**0.08**	**50 min 13 sec**
13	1	**Online database**	**692**	**0.46**	**~10 min**

B. Dictionary attacks

A straightforward dictionary attack is limited to exact matches, but is still surprisingly successful, as users tend to choose simple and predictable passwords. As suggested in [3] and [4], used words included most common names and surnames from several languages, pet names, band names, car manufacturers, sports teams, famous people, and colors. These specific phrases were added to a large wordlist containing most common passwords in several languages, among others, obtained in several well-known leaks, forming a 14,457,264-word (134MB) dictionary for a straightforward attack. For the hybrid and combinator attacks, two more dictionaries were made. First contained 674,096 above mentioned common words from multiple languages (6.83MB), with leaked wordlists omitted. A second, smaller 14,652-word (92KB) dictionary contained the same common words (this time only Slovenian), all possible combinations of letters and numbers up to 4 characters (including full years) and special characters in order to build word pairs for use in other dictionary attack modes.

Hashcat enables concatenating two dictionaries on-the-fly, forming word pairs for the combinator attack. We avoided using two large wordlists because of processing power constraints. The main idea for building the previously mentioned smaller (674,096-word) dictionary was to construct such word pairs. By using this approach, some common patterns were covered, such as words followed or preceded by a year, or some other characters.

Another possibility when building a dictionary is to construct a single, larger wordlist by appending all words from one dictionary to all words in another. This newly constructed dictionary can then be used in any subsequent attacks. That allows us to cover passwords which contain combinations of three words by performing a combinator attack, or two words with additional characters before or after the passwords when executing a hybrid attack. The smallest (14,652-word), 92KB dictionary was combined with itself, resulting in a 2.15GB wordlist.

Dictionary attacks with the exception of larger hybrid approaches are much faster than the basic brute-force method. The majority of performed attach took only up to 15 minutes. Straight mode for instance, took only 1 second with the largest of the dictionaries, suggesting that a significantly larger dictionary could have also been used. Even the dictionary in the combinator attack could be larger when considering the time. Third approach using wordlists is hybrid with masks and therefore similar to

brute-force method. Such attack takes existing wordlists and appends or prepends characters specified by the mask. With an option to increment said additions, this attack covers similar patterns as the combinator attack, but is more flexible, because it includes unusual diminutives and otherwise unpredictable strings.

C. Rule-based attack

Rules can be applied to words from dictionaries and are used with hybrid, combinator and straight dictionary attacks to provide even more options. They can be defined with a complex set of functions and some most popular are already included in hashcat. In our case, only the latter were used.

This attack was performed near the end, when only the strong password remained uncracked. By substituting certain letters with special characters or numbers (among many other rules), even some of the more clever user generated passwords were found. This method is fast even with large wordlists and can be performed in a matter of minutes or even seconds. However, in our case, the time of the combined attack was longer due to the number of rules and the complexity of a few of them. Some rules are more successful than others (such as those in d3ad0ne.rule and dive.rule), but in total they yield surprisingly good results.

D. Pre-computed wordlists

Perhaps the simplest approach is not to do any work but to simply look up cracked hashes. This method is also immune to calculation speeds of different hash functions. Online, freely available, precomputed wordlists and rainbow tables are huge, and they are growing each day. Among others, the 190GB, 15-billion-entry lookup table available on crackstation.net [10] or over 829.726 billion decrypted MD5 hashes on hashciler.co.uk [11] exist, with the latter also being used in our case. This method is easily prevented by using passwords in combination with salts, however no such procedure was used in this case, therefore enabling the use of this method. Unfortunately, such wordlists work best on passwords created by English speaking users due to language used in leaked databases.

IV. ANALYSIS

Out of the 185,643 passwords, 953 (0.51%) in total remained uncracked, out of which 923 (0.5%) are unique. This is a very unsettling result, especially considering the effort that was put into the attack. The number of cracked passwords could be even higher, if not for the mistakes described later in this chapter. Even the alarming number of uncracked passwords could be considered weak by most standards, although their measured strength was reasonably high.

We measured password strength with bits of entropy. Entropy is a measure of randomness of a system, and is one of the most common measures used in literature. [12-14] If, for instance, the passphrase is made of M symbols, each chosen at random from N possibilities, each equally likely, the entropy is $M*\log_2(N)$. Table II contains the values obtained for our set using the previously mentioned formula. Surprisingly, the password with the most bits of entropy was cracked, which is unusual at the first glance. Upon further inspection it became clear why: it consists of 29 lowercase letters 'l', making it the longest among all by 9 characters. It was obtained from the online database. Password with the most bits of entropy among the uncracked is "duiebvz fnikhrgh,l", while the weakest is "ansm*63". The latter remained uncracked due to the already mentioned mistake made while constructing the charsets. The weakest of all the passwords is a single zero with 3.3219 bits of entropy. Other passwords, containing only digits are extremely weak as well, since the search space is only ten characters.

Provided that the old, weak default pattern with the entropy of 32.1453 represents over three quarters of the passwords, the average for cracked passwords is skewed towards that value. Entropy of the improved default pattern is 49.3594 bits, making it better, but still not strong enough, given the fact that it was cracked in its entirety. A Mann-Whitney U test showed that the entropy of cracked passwords was significantly lower than the entropy of the uncracked passwords ($U = 423{,}581$, $p < 0.000$).

Another thing to consider while attempting to crack passwords stored in the hashed form is the used function. In our case, the original passwords were stored in the plaintext form, making the analysis of the uncracked passwords possible in the first place. Needless to say, this is the worst possible way of storing them. Another thing to add is that the uncracked passwords were only revealed after the attack was over. However, this bad practice also made it possible to compare the resilience of different hash functions, or in other words, their cracking times, as seen in Table III. Widely used MD5 function is among the fastest, but when it comes to cracking, that is all but desirable. Another very commonly used function is SHA-1. Despite being twice as slow by our measurements, it is just as unfit for storing passwords, as all passwords could still be cracked in less than a day. Third considered function was the bCrypt with a work factor 5. It is among the recommended functions when it comes to password hashing. The estimated time was on an entirely different level, as illustrated by the hashrates for each hash function while cracking the second pattern on a personal computer:

TABLE III. PASSWORD ENTROPY

Passwords	Entropy		
	Average (Std. Dev.)	***Min***	***Max***
All	33.3296 (6.8033)	3.3219	143.6717
Cracked	33.1495 (6.2913)	3.3219	143.6717
Uncracked	68.2320 (11.0076)	43.6017	118.5293

TABLE II. HASH FUNCTIONS ESTIMATED CRACKING TIME

Hash function	Estimated time (desktop PC)	
	Brute-force *(second pattern)*	***Dictionary*** *(6.83MB)*
MD5	10 hours 37 min	6 sec
SHA-1	21 hours 43 min	7 sec
bCrypt (5)	>10 years	308 days 18 hours

TABLE IV. UNIQUE CRACKED AND UNCRACKED PASSWORDS COMPARED BY PASSWORD LENGTH

Length	Passwords			
	Cracked		Uncracked	
	Count	*%*	*Count*	*%*
All lengths	150,213	100.00	923	100.00
1-4 characters	1471	0.98	0	0.00
5 characters	1316	0.88	0	0.00
6 characters	124999	83.21	0	0.00
7 characters	3047	2.03	2	0.22
8 characters	14964	9.96	3	0.33
9 characters	2044	1.36	13	1.41
10 characters	1357	0.90	31	3.36
11 characters	482	0.32	242	26.22
12 characters	276	0.18	207	22.43
13 characters	154	0.10	145	15.71
14 characters	60	0.04	118	12.78
15 characters	26	0.02	97	10.51
16 characters	14	0.01	22	2.38
17+ characters	3	0.002	43	4.66

- MD5: 5708.6 MH/s
- SHA-1: 2792.0 MH/s
- bCrypt: 4761 H/s

One more thing to mention is adding salt to a password before calculating the hash. Salt is a random string that is appended or prepended to a password and is usually stored in the database next to it. It should be long and not reused. When it comes to cracking, this approach prevents the use of lookup and rainbow tables, but the speed itself is not affected, due to hash function remaining unchanged and the salts being known.

Next, Table IV clearly shows the importance of the password length. If not for the previously mentioned mistake, every single password up to the eight characters in length would be cracked. A reasonable minimal length is at least 12 characters, provided that they are chosen randomly from a sufficiently large character pool. Additionally, Table V suggests, that using just lowercase letters and digits is only sufficient, when the length exceeds a certain threshold and the phrase is not predictable. Obviously it is not recommended, except in some specific cases, like in the method mentioned in conclusion.

On the other hand, uncracked passwords still contained many less common combinations of names and surnames, which exposes a flaw in the dictionaries. Results could be even better if the wordlists also contained a phone book or some similar larger list of names and surnames, since it appears that names are even more prevalent than previously thought. In cracked passwords,

TABLE V. UNIQUE CRACKED AND UNCRACKED PASSWORDS COMPARED BY CHARACTER SETS

Character sets	Passwords			
	Cracked		Uncracked	
	Count	*%*	*Count*	*%*
loweralphanum	124,775	83.07	587	63.60
mixedalphanum	10,211	6.80	1	0.11
loweralpha	7912	5.27	196	21.24
numeric	6468	4.31	1	0.11
upperalphanum	272	0.18	0	0.00
loweralphaspecialnum	92	0.06	54	5.85
loweralphaspecial	76	0.05	18	1.95
specialnum	12	0.01	0	0.00
special	4	0.003	0	0.00
upperalpha	1	0.0007	0	0.00
mixedalphaspecialnum	0	0.00	7	0.76

for instance, nine out of top ten base words are names (and the other is "nokia"). What's more, other common words were overlooked as well, such as dialect words, certain band names, less common car manufacturers or models and even movie titles. Those are generally already in the available dictionaries, but unfortunately mostly in English and therefore do not cross the language barriers. Nevertheless, a dictionary building method, described in [4] should be followed more closely.

With this in mind, the number of uncracked passwords could be even lower than it already is. Beforehand, a much higher password strength was expected, at least near the end of the attack. Because of that, some of the choices for attacks were a step in the wrong direction, like adding too many unused special characters in the character sets or including Greek letter passwords among others in the largest dictionary. After the surface examination of the uncracked passwords, an estimated 200 more passwords were somewhat weak and could be cracked with a better approach.

Sex of the users was considered as well, as seen in Table VI. In total, the ratio between male and female users is surprisingly even. A total of 91,902 (49.5%) passwords

TABLE VI. PASSWORDS COMPARED BY THE SEX OF THE USER

			Sex		Total
			Male	*Female*	
Cracked	Yes	*Count*	91,902	92,788	184,690
		% of total	49.50	49.98	99.49
	No	*Count*	593	360	953
		% of total	0.29	0.19	0.51
Total		*Count*	92,495	93,148	185,643
		% of total	48.83	50.17	100.00

by males and 92,788 (49.98%) passwords by females were cracked. Further, we performed a Mann-Whitney U test, and observed that the cracked passwords created by the male students had significantly higher entropy values than the passwords by female students (U = 4,227,514,906.5, p < 0.000). Among the uncracked passwords, the male users are better represented. Their passwords represent almost two thirds of the uncracked passwords compared to just a third for the female users. There was no significant difference in the entropy of uncracked passwords between the sexes, however (U = 102,806, p = 0.337).

Spearman's rank-order correlation test determined that there is a significant, albeit weak relationship between the year of the student's enrollment at the university, and the entropy of their password (r_s = 0.201, p < 0.000). This finding supports the conclusion that textual passwords are slowly improving over time, likely due to user education.

Finally, we divided our sample into five groups based on the students' field of study: humanistics, natural, social and technical studies, and transport. We discarded some of the older entries that did not include the field of study, bringing the total to 178,518 passwords. Then, we carried out the Kruskal-Wallis test, which showed that there are significant differences between the social studies and all the other groups (i.e. social-transport: $\chi^2(2)$ = -8,741.49, p < 0.000) in terms of password entropy, whereas there were no significant differences between any of the other groups. The mean rank for social studies was 32.56, followed by 33.93 for transport, 34.02 for humanistics, 34.037 and 34.044 for technical and natural sciences, respectively.

V. CONCLUSION

Even though additional sophisticated approaches could be employed, the results of the executed attack speak for themselves. Not only was the alarming amount of the passwords cracked, but the attack was also completed in a relatively short time period. Furthermore, the available wordlists grow larger by the day while the computers get faster, allowing for these attacks to become even easier over time.

Another key thing to remember is that these passwords were generated and used by the students, who are to some degree expected to be aware of security-related issues, and possess more cognitive ability than the average user. In other words, they should in theory pick stronger, more secure passwords. This is either not the case, or the passwords created by the average users are even weaker. Additionally, the age of the user and the year of the creation could also be considered in the analysis.

From the results it seems that the length is the main difference between the strong and weak passwords, so perhaps the solution to at least some textual password issues could be a less known method called Diceware. The goal is to create a long and hard to guess, yet secure passphrase using a random predefined 7776-word list available in multiple languages. Words are prepended with five numbers from one to six. Each word is then picked by rolling the dice five times. Number of words can vary, but the recommended minimum is six words, while for more security a length of up to nine words is advised. Each word in the passphrase yields 12.9 bits of entropy. This can be further increased by adding special characters in random word and random place by rolling the dice. The source also states, that a physical dice must be used due to true randomness [15]. Password policies could make picking such passphrases more complicated, because no uppercase letters or digits are used.

All things considered, it appears textual passwords are here to stay for foreseeable future due to their simplicity and widespread use, however ever-increasing computing power could raise the bar of reasonable security beyond what users would consider practical. While less practical but more secure alternatives like the graphical passwords or biometry could be the solution, the life of textual passwords could be extended if stronger hash functions such as bCrypt were more commonly employed to protect them.

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Efficiency and Security of Docker Based Honeypot Systems

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Abstract

Honeypot is a computer, a group of computers, an application or just a single service with the main task of attracting malicious agents. It is actually bait, used to detect or mitigate attacks or simply to divert the attacker from the real services. The challenge in creating honeypots is how to create an agile and flexible Honeypot infrastructure.

In this paper we assert that, as regards to efficiency, containers are more suitable for this kind of task compared to other technologies. However, we analyse the security of Honeypot implementations inside of containers based on Docker, which is the de facto standard for containers and a widely used implementation.

Keywords: Honeypot; security; infrastructure, X86, hypervisor, micro service, orchestration

1. Introduction

Scientists and experts in the field of computer security often use Honeypots in their work, using it with high or low degree of interaction. Honeypots have a unique characteristic, which deems any interaction as an illegal action, as it does not contain any actual services. Honeypot is actually nothing but a "fake" service, acting as a bait with the aim of attracting a malicious attacker, gathering as much data as possible about malicious actions and potentially activating a predefined action. However, setting up just one Honeypot is often not enough to attract an attacker, so usually a network of Honeypots is used, often distributed geographically. However, some challenges are then encountered, which need to be taken into account [1]:

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- security
- flexibility
- limited number of IP addresses

Another frequent issue is that the potential attackers recognise the nature of the Honeypot and avoid it [2].
This paper will use an analysis to show the security deficiencies of Docker containers on which such Honeypots are based.

2. Problem domain

Nowadays microservices and its implementation in containers especially, has begun to be a mainstream architecture and technology for modern IT infrastructures. It brings many advantages in difference to traditional physical or virtualized servers but also brings new risks.
So we are facing a question, are container based systems secure enough to be used for the construction of honeypots that will be used against highly motivated and sophisticated malicious actors.

3. Previous research

Several authors already researched container efficiency. However, the emphasis of the previous research was more on the efficiency of the use of computing resources (CPU, memory, disk access or network connectivity), comparing it to the efficiency of implementation on physical computers, whether virtual or another container implementation. Morabito, Kjallman and Milla Komu [3] provided a comparison of hypervisors (in particular KVM) and "light" virtualisation based on containers (Docker and LNX). Using the standard efficiency testing tools, they have shown that the same operations use the resources more efficiently than hypervisors, while a physical computer has almost the same results as the containers. Miguel G. Xavier, Marcelo V. Neves, Fabio D. Rossi, Tiago C. Ferreto, Timoteo Lange, Cesar A. F. De Rose [5] have also compared the efficiency of Type I hypervisors (Xen)

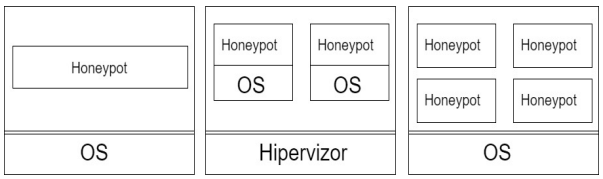
and containers (OpenVZ, VServer and LCX) in the context of HPC (High Performance Computing),where the containers again surpassed the hypervisor. The authors also tested the isolation: however, they analysed the mutual influence of containers with regard to density, i.e. degradation of efficiency, while security was not taken into account. Amr A. Mohallel, Julian M. Bass, Ali Dehghantaha [7] researched the vulnerabilities appearing in using containers, but their focus was on implementation, namely they detected the vulnerabilities using Nessus and ranked them for implementations in virtual machines and implementations using containers, in particular Docker. Amith Raj MP, Sahithya J Pai, Ashok Kumar, Ashika Gopal analysed the existing security mechanisms in Docker (RHEL SELinux, Ubuntu Apparmor) and concluded that using such mechanisms makes Docker completely safe for use. Authors Yang Luo, Wu Luo, Xiaoning Sun, Qingni Shen, Anbang Ruan, Zhonghai Wu researched the Channel Attacks on containers. Authors present the weaknesses of security mechanisms and the shared infrastructure. They are focused on the analysis of deficiencies in the capabilities of containers. Authors Stipe Kuman, Stjepan Groš and Miljenko Mikuc [15] at the other hand presented emulation of ICS (*Industry Control System*) systems as Docker containers. Their focus is on detection of malicious events inside of ICS systems, less about how Honeypots implemented inside of the container are secure.

4. Honeypot architecture

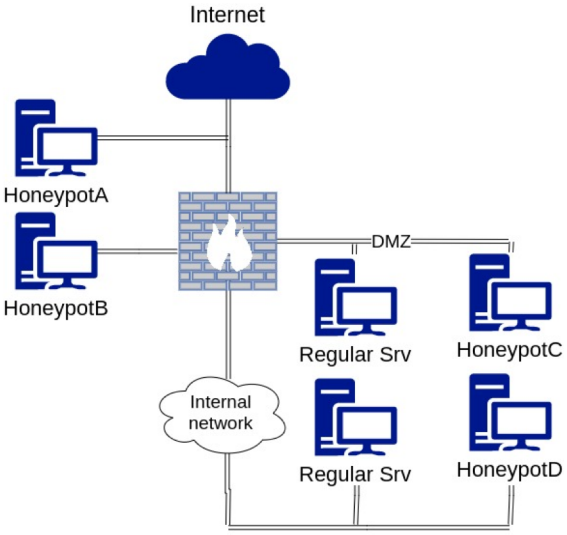
Regardless of the Honeypot type, its main function is to gather as much information as possible about an attacker, either by keeping the attacker within a "sandbox" or to react in a certain way to the attacker's actions. Such model is sustainable if it is efficient enough, if it does not endanger its host operating system and, as one of the most important Honeypot characteristics, regardless of the implementation, it needs to remain hidden to the attacker.

4.1 Honeypot implementations

Honeypots as independent systems are implemented either as physical computers or physical devices (Picture 1). They usually have greater bandwidth, but are more difficult to maintain and the services are not agile enough. Virtual Honeypots are implemented as virtual instances, whether as virtual computers or lately as micro services, the so-called containers.



Picture 1: Honeypot implementation



Picture 2: Honeynet model

4.2 Honeynet model

To keep Honeypots from being isolated units, they are organized into clusters, called Honeynets (Picture 2). The advantages of such setups are:

- single point of sensor control
- central storage of event information
- ability to correlate events on sensors in real time

However, such a distributed architecture also has some disadvantages, which need to be taken into account:

- infrastructure complexity
- higher security risk
- problem of efficient management

5 Implementation efficiency

5.1 Implementation efficiency for physical computers

It is obvious that an implementation of a Honeypot agent only on physical servers is not efficient. The reason for this is:

- longer time required to implement the agent
- poor flexibility of the agent
- significant unused resources remaining after the implementation

On the other hand, from the perspective of IT security, such implementations have a high level of security. That means that, while compromising the Honeypot agent, the attacker will compromise only the host agent, unless the Honeypot shares the computer with actual services.

5.2 Implementation efficiency for virtualized systems

Having in mind the level of isolation and the fact that each virtualized machine has its own installed operating system, such virtual machine can be considered equivalent to a physical machine. On the other hand, precisely due to the complete operating system, the "footprint" of the agent is relatively large.

Footprint = operating system + Honeypot size

The flexibility of such Honeypots is greater than that of physical implementations, as the technology provides faster growth of instances, reduction of resources or simple cloning of the instances.

5.3. Implementation efficiency of containers

Container technology is not that recent, since the popular chroot mechanism appeared in the 70s in Unix operating systems, where it was used to restrict the scope of processes. Later implementations that occured were FreeBSD's Jail, OpenVZ, Linux Containers LXC, and finally Docker and Rocket, which are the most common container formats today. Compared to physical and virtual computers, the container instances are very light, as they do not contain a complete operating system, and they implement only those functions, i.e. services which are necessary for the purpose of the container. Containers rely on the operating system on which the container management system is based, i.e. all containers share the same operating system kernel.

The advantages of such implementation, compared to physical and virtual servers, are:

- high speed of infrastructure implementation
- small footprint
- large flexibility
- simple orchestration
- high density

However, having in mind the sharing of the operating system, i.e. of the system calls and other system resources, it is questionable whether the isolation level is adequate for a Honeypot implementation.

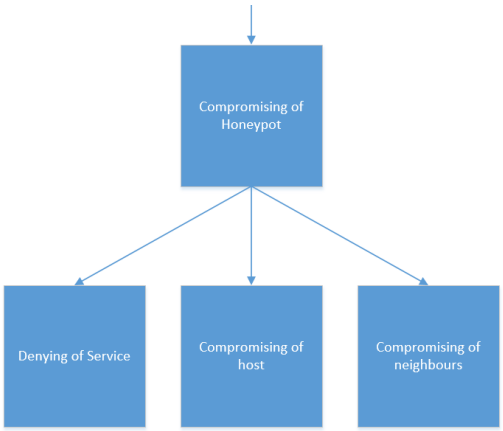
4. Threat model

Because of high density of containers, it is possible to share host between Honeypots and real services, but that is necessary to pay attention for security concerns and potential threats.

From the point of view of the Honeypot, regarding the implementation in containers, it is possible to detect the following threats (Picture 3):

1. Honeypot is compromised, i.e. gaining of access to the container itself
2. Denial of service
3. Host takeover
4. Compromising the neighbouring containers

As a side note, the threats were modelled according to a Docker container implementation without additional configurations. In order for threats 2, 3 and 4 to appear, the condition 1 needs to be met. The attacker needs to primarily access the container itself, by compromising some of the Honeypot vulnerabilities.



Picture 3: Threat model

It should be noted that the threats model does not include the threats to the Docker management service itself, i.e. to the Docker API access.

4.1 Probing stage

Docker makes the attacker's job easier by not hiding too much information about the host system, so it is relatively easy to access the host information by querying (/proc):

- File system structure (diskstats)
- Processor information (cpuinfo)
- Memory information (meminfo)
- Kernel version
- IDs of other containers in the system (keys)

5. Docker container security mechanisms

The container security is based on three basic mechanisms:

- Namespaces
- CGroups
- Capabilities

6.1 Namespace

Namespaces are the first and most important container security mechanism, which prevent the containers to be aware of the host resources, and in particular of the other containers processes or the host resources implementing the containers. In this regard, Docker uses different namespaces, such as as User, Net, mnt, IPC.

6.2 Cgroups

Cgroups are a mechanism that provides the containers with equal use of resources (CPU, memory, IO resources). The goal is to protect the host or other containers from the denial of service actions caused by problematic application behaviour or malicious actions within any of the compromised containers. However, it should be noted that the basic startup of publicly available Docker images largely does not have implemented settings for Cgroups, which will be shown in the examples from the analysis.

6.3 Capabilities

Capabilities mechanism enables a fine granulation of access control to the containers. It enables performance of a predefined set of operations possible within containers, while those are actually controlled outside of containers themselves. The goal is to enable the containers to have only the essential capabilities, in order to reduce the footprint of attack as much as possible. For example, NET_BIND_SERVICE capability enables the container to open a port below 1024, which are considered privileged network ports.

An additional container protection mechanisms are MAC (Mandatory Access Control) mechanisms, such as AppArmor, as implemented in Ubuntu, or SELinux, as implemented in RedHat.
However, with all the implemented protection measures, NIST [9] points out that the containers share the Linux kernel, which is one of the attack vectors on the container infrastructure, which makes them more vulnerable than the standard hypervisor isolation. Additionally, the vulnerability of a shared Linux kernel may have a significant impact on all containers instanced on the host node.

7. Security analysis

For our analysis we used a virtualised Mint 18 operating system (kernel 4.4.0.21) with the following characteristics:

- 2 CPUs, 2.30GHz clock
- 2GB RAM
- 30GB HDD
- 10 GB Swap (SSD)

Docker version that we used was 17.07.0.

Basic Ubuntu Docker images were used:

```
DISTRIB_ID=Ubuntu
DISTRIB_RELEASE=16.04
DISTRIB_CODENAME=xenial
DISTRIB_DESCRIPTION="Ubuntu 16.04.3 LTS"
NAME="Ubuntu"
VERSION="16.04.3 LTS (Xenial Xerus)"
VERSION_CODENAME=xenial
```

The analysis presumes that the attacker has successfully compromised the Honeypot software and has gained root (uid=1) command line access of the container on which Honeypot is implemented.

The aim is to show some of the actions which the attacker may take and the data to be collected for the purpose of compromising of the container, host or the neighbouring containers.

7.1 Denial of service

One of the Honeypot's tasks is to record the logs of the attacker's actions. For the Honeypot, such logs are

usually stored in a permanent storage space directly accessed by the container, or such logs are immediately sent to the central system for processing. Therefore, the attacker may use a known vulnerability in order to deny disk storage to other containers and thus prevent their execution. Another reason is to prevent Honeypot to store the recorded actions and thus simply to remove the traces of attack. Vulnerability actually lies in the fact that there is a limited disk space available.

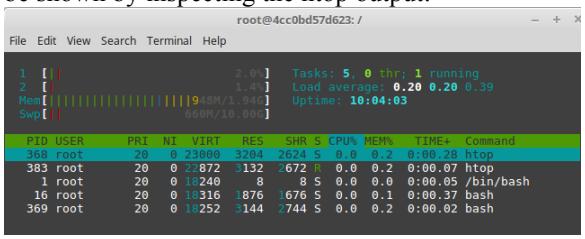
Another type of denial of service as regards the storage space is based on the storage layers, i.e. two containers from the same image on the host [10]. Therefore two containers use the same inodes within metadata, which poses a threat of denial of service in case when the attacker generates "garbage" with the goal of using all available inodes.

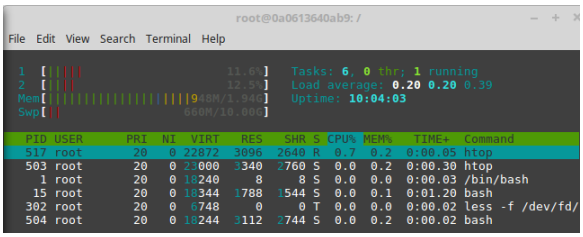
```
root@4cc0bd57d623:/sys/block/ram1# df -i
Filesystem      Inodes  IUsed   IFree IUse% Mounted on
none           1835008 714107 1120901   39% /
tmpfs           253836     17  253819    1% /dev
tmpfs           253836     16  253820    1% /sys/fs/cgroup
/dev/sda1      1835008 714107 1120901   39% /etc/hosts
shm             253836      1  253835    1% /dev/shm
tmpfs           253836      1  253835    1% /sys/firmware
```

```
root@0a0613640ab9:~# df -i
Filesystem      Inodes  IUsed   IFree IUse% Mounted on
none           1835008 714107 1120901   39% /
tmpfs           253836     17  253819    1% /dev
tmpfs           253836     16  253820    1% /sys/fs/cgroup
/dev/sda1      1835008 714107 1120901   39% /etc/hosts
shm             253836      1  253835    1% /dev/shm
tmpfs           253836      1  253835    1% /sys/firmware
```

Picture 4: An example of inode index of two containers

The third threat is the denial of memory and processor resources. Each container user has access to host memory status (/proc/meminfo) and processor resources (/proc/procinfo). The basic container settings do not prevent the container to allocate all the host memory or processor resources, and thus prevent running of other containers on the host. The potential vulnerability can be shown by inspecting the htop output:





Picture 5: An example of memory status of two containers

If the host has the OOM memory protection mechanism turned on, the attacker may theoretically monitor memory usage and keep the memory levels below the OOM cleanup mechanism threshold, but may still use the memory of other containers on the host node.

7.2 Host compromise

All Docker containers share the same host kernel, i.e. system files, with the basic service for creating and managing the containers. This achieves a high efficiency of the system, reduces the system elements redundancy levels and/or facilitates container management. However, with the appearance of vulnerabilities of the kernel or the management service, there comes a threat of the attacker abusing the vulnerabilities of the container, and potentially harm the container host or other containers on the same host.

The kernel is mature enough to reduce the frequency of such attacks, but the MITRE CVE (Common Vulnerabilities and Exposures) vulnerability database analysis shows the possible vulnerabilities which may cause the host to be compromised.

Table 1: An example of known vulnerabilities

CVE	Description
CVE-2016-5195	User gains access outside of container
CVE-2015-3629	Enables the access and creation of files outside of container

7.3 Compromising the neighbouring containers

Basic Docker configuration achieves network communication by creating a "bridged" network interface, and the containers' virtual network interfaces connect to such created "bridge". However, this architecture presents a range of threats arising from such implementations. The simplest threat is the so-called ARP cache poisoning. Upon its instancing, each container has an empty table. However, the attacker is able to spoof his identity by using various attacks (e.g. arp spoofing) and reroute the network traffic.

```
root@0a0613640ab9:/proc/sys/net/ipv4# arpspoof  -t 172.17.0.3  172.17.0.1
2:42:ac:11:0:2 2:42:ac:11:0:3 0806 42: arp reply 172.17.0.1 is-at 2:42:ac:11:0:2
2:42:ac:11:0:2 2:42:ac:11:0:3 0806 42: arp reply 172.17.0.1 is-at 2:42:ac:11:0:2
2:42:ac:11:0:2 2:42:ac:11:0:3 0806 42: arp reply 172.17.0.1 is-at 2:42:ac:11:0:2
2:42:ac:11:0:2 2:42:ac:11:0:3 0806 42: arp reply 172.17.0.1 is-at 2:42:ac:11:0:2
2:42:ac:11:0:2 2:42:ac:11:0:3 0806 42: arp reply 172.17.0.1 is-at 2:42:ac:11:0:2
```

Picture 6: Abuse of bridge implementation deficiencies

```
root@4cc0bd57d623:/proc/net# cat /proc/net/arp
IP address       HW type     Flags       HW address            Mask     Device
172.17.0.2       0x1         0x2         02:42:ac:11:00:02     *        eth0
172.17.0.1       0x1         0x2         02:42:ac:11:00:02     *        eth0
```

Picture 7: Result of abuse of bridge implementation deficiencies

Since the attacker who took over the container is able to view the CPU and memory usage, this opens the possibility for an side channel attacks. The attacker is able to initiate the attack using a specially crafted query sent to certain applications located within a container located on the same host as the Honeypot. By monitoring the CPU usage, the attacker can glean more info about other containers on the system. At the end of 2017 we were faced of processor vulnerabilities Meltdown [13] and Spectre [14] (CVE-2017-5753, CVE-2017-5715, CVE-2017-5754). Because those are vulnerabilities of processors, containers are not immune to Meltdown and Spectre exploits. So well know vulnerabilities allows compromised containers to read memory of other containers and all other running processes on the same host.

8. Conclusion

The basic container characteristics are high efficiency, small footprint and high flexibility, which makes them suitable for creating an infrastructure which can be set up or dismantled quickly.

Although Docker containers are considered secure, the basic implementation which comes with already prepared Dockerfile files or GitHub images does not satisfy the security requirements for building a Honeypot infrastructure, e.g. Cowrie Dockerfile or other available images. An additional problem is that Honeypot's purpose is to attract malicious users, who usually have a very good knowledge of systems penetration, so it is to be expected that they will use all the possible weaknesses of the basic container installations. Docker actually supports powerful security mechanisms, if properly configured: Capabilities, Cgroups, MAC (AppArmor or SeLinux) are very powerful mechanisms, but they all require knowledge for their proper configuration.
Some vulnerabilities can be resolved by using the best practices:

- Use of verified images
- Use of minimal OSs (Atomic, CoreOS, Vmware Photon)
- Isolation at the hypervisor level
- Immunisation of capabilities
- Reduction of resources
- Startup in userspace
- Startup of applications in userspace within Docker
- Using NIST best practices
- Updating the host operating system

What is alarming is the quantity of information exposed by Docker containers to the user, so it is easy for an attacker with the proper knowledge of the host operating system to address these vulnerabilities and abuse them, even in an automated manner inspired by VM detection methods used by malware. Having in mind the known deficiencies of the Honeypot implementations using basic Docker, future research should propose a model which would eliminate all known shortcomings addressed in this article, together with a secure manner of orchestration of containers for the purpose of creating a Honeypot infrastructure based on containers.

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Using Automatic Generation of Relaxation Constraints to Improve the Preimage Attack on 39-step MD4

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***Abstract*—In this paper we construct preimage attack on the truncated variant of the MD4 hash function. Specifically, we study the MD4-39 function defined by the first 39 steps of the MD4 algorithm. We suggest a new attack on MD4-39, which develops the ideas proposed by H. Dobbertin in 1998. Namely, the special relaxation constraints are introduced in order to simplify the equations corresponding to the problem of finding a preimage for an arbitrary MD4-39 hash value. The equations supplemented with the relaxation constraints are then reduced to the Boolean Satisfiability Problem (SAT) and solved using the state-of-the-art SAT solvers. We show that the effectiveness of a set of relaxation constraints can be evaluated using the black-box function of a special kind. Thus, we suggest automatic method of relaxation constraints generation by applying the black-box optimization to this function. The proposed method made it possible to find new relaxation constraints that contribute to a SAT-based preimage attack on MD4-39 which significantly outperforms the competition.**

Keywords*—cryptographic hash functions; MD4; preimage attack; SAT; black-box optimization.

I. Introduction

Cryptographic hash functions have a wide range of applications: starting from various data security [1] and cryptocurrency protocols [2] to theoretical methods for cryptographic resistance justification of different cryptosystems [3], [4]. The Merkle-Damgard construction [5], [6] is considered to be one of the most successful paradigms for constructing cryptographically resistant hash functions. The MD4 hash function [7] is one of the first examples of hash functions based on the Merkle-Damgard construction. The widely known works [8], [9] demonstrated the possibility of constructing collisions for hash functions MD4 and MD5. Thus, these functions have been compromised with respect to the *collision attack*. However, today even MD4 remains resistant to the so called *preimage attack*, which consists in the following: for a known hash value to find a corresponding input message. In this context, the implementation of preimage attacks on truncated variants of MD4 hash function is of interest. The truncated variant of the MD4 hash function is a variant of the original algorithm, which contains fewer steps (non-truncated variant consists of 48 steps). Hereinafter by MD4-k we denote a truncated variant of MD4 with k steps, $k < 48$.

The first successful attack on truncated variant of MD4 with a relatively large number of steps was described by H. Dobbertin in [10]. In this work it was showed that two-round version of MD4, i.e. MD4-32, is not one-way. The main idea of Dobbertin's attack is to use additional constraints on chaining variables at the certain steps of the MD4 algorithm to derive additional information, which leads to fast resolution of the corresponding cryptanalysis equations.

To the best of our knowledge, the attack described in [11] is currently the best known attack on truncated variants of MD4. This attack is a SAT-variant of Dobbertin's attack which used the constraints of Dobbertin's type, in the sense that they were applied to the same chaining variables as in [10]. The resulting system of cryptanalysis equations was reduced to the Boolean Satisfiability Problem (SAT) and then solved using the MINISAT [12] SAT solver. For MD4-32 the SAT variant of the Dobbertin's attack turned out to be very effective. The main novelty of [11] is to use Dobbertin's constraints and state-of-the-art SAT solvers to find preimages for MD4-k, $k = \{36, 37, 39\}$, within a reasonable time. However, it should be noted that the corresponding computational experiment for MD4-39 took a lot of time (about 8 hours on one processor core). In addition, in [11] only the hash values of special kinds were considered. It is surprising that until 2017 there was, apparently, no progress in the practical implementation of the preimage attacks, which would be more effective than the attack from [11].

In [13] we presented a parallel SAT-variant of Dobbertin's attack on MD4-k, $k \leq 39$. One of the main results of [13] is the automatic search procedure of Dobbertin's constraints. For MD4-39 it was achieved a relatively fast solving of the preimage finding problem for the hash value 1^{128} (hereinafter a^n denotes a word which consists of n a symbols).

In the present paper we improve the results from [13] in the following directions. First, we consider the problem of finding relaxation constraints of Dobbertin's type as a problem of black-box optimization over Boolean hypercube. To solve this problem we develop metaheuristic algorithm related to the class of Tabu Search algorithms. Using this algorithm we construct new relaxation constraints of Dobbertin's type for the MD4-39 preimage finding problem. These constraints, which are different from the ones presented in [10] and [11], make it possible to find the MD4-39 preimages for 65-75% of randomly generated 128-bit vectors within one minute of the MINISAT2.2 SAT solver runtime on a single processor core

Intel i7-3770K (3.5 GHz). Whereas using constraints from [10] and [11] MINISAT2.2 is not capable to solve these tasks in several hours.

II. Preliminaries

As it was mentioned above, the MD4 hash function is a cryptographic hash function based on the Merkle-Damgard construction. This hash function can be used to calculate hash values for messages of an arbitrary length. The input message is split into 512-bit blocks. The resulting hash value is written in a special 128-bit register called *hash register*. The hash register is divided into four parts of 32-bit length. According to the Merkle-Damgard construction, the fixed Initial Value (IV) is written to the hash register before hashing the first block of input message. Further, the content of the hash register is iteratively modified. Thus, before hashing the 512-bit block with number $t+1$, the hash register contains the result of hashing of message blocks with numbers from 1 to t. The process of hashing of one 512-bit block is divided into 3 rounds with 16 steps each (thus, 48 steps in total). The content of the hash register is mixed with the input message using the *round functions*. In total, MD4 uses three round functions, detailed descriptions of which can be found in a variety of sources (i.e. [8]). On each step with number $k = 1, \ldots, 48$ a variable called *chaining variable* is associated with one of four parts of the hash register.

Hereinafter, we consider the problem of finding preimage (preimage attack) for the function of the kind:

$$f_{MD4-k} : \{0,1\}^{512} \to \{0,1\}^{128}, \tag{1}$$

assuming that at the initial moment of time the hash register contains IV, corresponding to the specification of MD4. In fact, we consider the problem of finding 512-bit MD4-k preimage for known 128-bit hash value. Herein the main object of further interest is the function f_{MD4-39}.

Let us briefly recall the idea of the Dobbertin's attack [10]. Based on the analysis of the round functions properties, H. Dobbertin proposed to fix with constant K the values of certain chaining variables corresponding to the steps of the algorithm with numbers:

$$13, 14, 15, 17, 18, 19, 21, 22, 23, 25, 26, 27. \tag{2}$$

The substitution of corresponding values into the cryptanalysis equations makes it possible to derive a significant part of the values of variables, which encode the unknown 512-bit input message. This, in turn, leads to a further simplification of the problem. As a result, in 1998 H. Dobbertin managed to find preimages for the MD4-32 hash function on a personal computer. We will refer to *Dobbertin's constraints* to denote the additional constraints of the form $v_i = K$, where v_i is chaining variable at i-th step and i goes through the set of numbers from (2). In general case, similar constraints on various steps of the MD4 algorithm different from (2) can be used. For all such constraints we use the term *relaxation constraints*.

The next step is to use a powerful combinatorial algorithm for solving the cryptanalysis equations with additional relaxation constraints. As it was mentioned above, this idea was proposed in [11] where Dobbertin's constraints were used with constant $K = 0$ and the corresponding cryptanalysis equations were solved using the MINISAT [12] SAT solver.

Let us recall, that SAT (short for "Satisfiability") is a problem of satisfiability of an arbitrary Boolean formula, which consists in the following: for an arbitrary formula F over the set of Boolean variables X to decide if there exists such an assignment of variables from X that makes this formula true. It is usually considered in the variant where F is presented in conjunctive normal form (CNF).

The approach in which modern SAT solvers are used to solve cryptanalysis problems is called *SAT-based cryptanalysis*. To reduce the preimage finding problem (inversion problem) of an arbitrary total discrete function of the kind $f : \{0,1\}^n \to \{0,1\}^m$ to SAT one can use various automatic translation systems, like CRYPTOL [14] or URSA [15]. In our work we use software system TRANSALG [16] specially designed to produce SAT encodings for the inversion problems of cryptographic functions. TRANSALG performs a symbolic execution [17] of a program, which specifies the considered function f. The result of such execution is a CNF $C(f)$ called *template CNF*. By $C(f, y)$ we denote the result of the substitution of a known image y of function f, $y \in Range f$, into CNF $C(f)$. It can be shown that $C(f, y)$ is satisfiable. Asumming that satisfying assignment for $C(f, y)$ is found using SAT solver, a preimage $x \in \{0,1\}^n$ such that $f(x) = y$ can be extracted from this assignment. Using the methods of SAT-based cryptanalysis to find preimages of cryptographic hash functions is called a *SAT-based preimage attack* on this function.

As it was mentioned above, in [13] the parallel version of SAT-based preimage attack on MD4-k ($k \leq 39$) from [11] was proposed. However, in the role of relaxation constraints the same Dobbertin's constraints were used. In the next section we consider the generation of relaxation constrains as a problem of block-box optimization over Boolean hypercube. We also present computational results obtained using new relaxation constraints.

III. The generation of relaxation constrains as a problem of black-box optimization

Let us consider the preimage finding problem for the function of the kind (1) with fixed k and reduce this problem to SAT. Let $C(f_{MD4-k})$ be template CNF for this problem and X be a set of all Boolean variables in $C(f_{MD4-k})$. By $C(f_{MD4-k}, \chi)$ we denote a CNF obtained by substitution of a hash value $\chi \in \{0,1\}^{128}$ into $C(f_{MD4-k})$.

Below we briefly describe the idea of switching variables introduced in [13]. Suppose that there is some set of relaxation constraints $\Re = \{R_1, \ldots, R_Q\}$, where an arbitrary constraint $R_j, j \in \{1, \ldots, Q\}$ is usually a conjunction of some literals, i.e. a formula of the kind:

$$l_1(x_{j_1}) \wedge \ldots \wedge l_{t_j}(x_{j_{t_j}}), \{x_{j_1}, \ldots, x_{j_{t_j}}\} \subseteq X \tag{3}$$

(note that literal $l(x)$ is a formula of the kind x or $\neg x$, where x is a Boolean variable).

Consider a new set of Boolean variables $S = \{s_1, \ldots, s_Q\}$, $S \cap X = \emptyset$. We call such variables *switching variables*. Let us associate with an arbitrary $R_j, j \in \{1, \ldots, Q\}$ of the kind (3) the following CNF:

$$C_{R_j} = (\neg s_j \vee l_1(x_{j_1})) \wedge \ldots \wedge (\neg s_j \vee l_{t_j}(x_{j_{t_j}})).$$

It should be noted that the literals $l_1(x_{j_1}), \ldots, l_{t_j}(x_{j_{t_j}})$ can be derived from CNF $s_j \wedge C_{R_j}$ using the Unit Propagation (UP) rule [18]. Then, this new information will be further propagated according to UP. On the other hand, it's obvious that $\neg s_j \wedge C_{R_j} \equiv \neg s_j$. In this case the constraint R_j does not give any additional information. We say that the constraint R_j is *active* if $s_j = 1$ and *inactive* if $s_j = 0$.

Let S be the set of switching variables. The set of all possible values of variables from S is $\{0,1\}^Q$. Thus, each nonzero Boolean vector $\lambda \in \{0,1\}^Q$ specifies some set of active relaxation constraints from set $\Re$. Our first goal is to learn how to distinguish more effective sets of relaxation constraints from less effective ones (in the sence of increasing the efficiency of the corresponding SAT-based preimage attack). To solve this problem we use the approach similar to that applied in [19], [20] for searching SAT partitionings [21] of SAT-instances arising in cryptanalysis problems. In particular, we introduce a measure of efficiency for an arbitrary set of relaxation constraints from $\Re$ and consider the problem of finding sets of relaxation constrains with good efficiency as a problem of maximization of a specially defined function over Boolean hypercube $\{0,1\}^Q$.

The problem of choosing the adequate measure of efficiency for relaxation constraints is quite non-trivial. At this stage, after a large number of experiments, the measure was defined as follows. Consider an arbitrary vector $\lambda \in \{0,1\}^Q$, where $\{\lambda_{h_1}, \ldots, \lambda_{h_d}\}$ is a set of components equal to 1. Taking into account the above, these components define a set of active relaxation constraints from $\Re = \{R_1, \ldots, R_Q\}$, namely, the constraints with numbers $h_1, \ldots, h_d$. Consider the following CNF:

$$\tilde{C}(\lambda) = C(f_{MD4-k}, \chi) \wedge (\wedge_{j \in \{h_1,\ldots,h_d\}} C_{R_j}). \qquad (4)$$

Everywhere below, we will use notation $\tilde{C}(\lambda) \rightarrow_{UP} l(x)$ to denote that literal $l(x)$ is derived from CNF (4) using UP. By $X^{in} \subset X$ we denote a set of Boolean variables in $C(f_{MD4-k}, \chi)$, which encode an unknown 512-bit input of f_{MD4-k} function.

For an arbitrary $\lambda \in \{0,1\}^Q$ we consider the function

$$\mu(\lambda) = \#\{l(x) | \tilde{C}(\lambda) \rightarrow_{UP} l(x) : x \in X^{in}\}. \qquad (5)$$

In other words $\mu(\lambda)$ is the number of literals from X^{in}, which were derived by UP from CNF (4) as a result of activation of relaxation constraints corresponding to vector λ.

We will consider the maximization problem of (5) over Boolean hypercube $\{0,1\}^Q$. It's obvious that function (5) is a function of black-box type and its analitical properties are unknown. Thereby it is justified to use metaheuristic algorithms for the maximization problem of (5). At this stage, we implemented a special variant of Tabu Search algorithm [22]. In the computational experiments, discussed further, we considered the Hamming neighborhoods of the radius 1 in $\{0,1\}^Q$. The pseudocode of the algorithm is presented below.

Algorithm 1 Tabu Search Algorithm (A1)

```
1:  ⟨λ_center, μ_best⟩ ← ⟨λ_start, μ(λ_start)⟩
2:  initializeLists(L_1, L_2)
3:  repeat
4:      bestValueUpdated ← false
5:      repeat
6:          λ ← getNewPoint(N(λ_center))
7:          markPointInTabuLists(λ, L_1, L_2)
8:          if isCorrectPoint(λ) then
9:              compute μ(λ)
10:             if μ(λ) > μ_best then
11:                 ⟨λ_best, μ_best⟩ ← ⟨λ, μ(λ)⟩
12:                 bestValueUpdated ← true
13:             end if
14:         end if
15:     until N(λ_center) is checked
16:     if bestValueUpdated then
17:         λ_center ← λ_best
18:     else
19:         λ_center ← getNewCenter(L_2)
20:     end if
21: until timeExceeded() or L_2 = ∅
22: return ⟨λ_best, μ_best⟩
```

Let us give more detailed description of the A1 algorithm. The input of A1 algorithm is CNF $C(f_{MD4-39}, \chi)$ encoding the MD4-39 preimage finding problem for a known hash value and starting point λ_{start} with a corresponding set of relaxation constraints of the kind (3). As a starting point, either a random point or some known point can be chosen. The contents of the L_1 and L_2 lists are initialized using function *initializeLists*. At the initial moment the L_1 list is empty, L_2 contains point λ_{start}, λ_{center} is equal to λ_{start} and μ_{best} is the value of the objective function $\mu(\lambda_{start})$.

In the main loop of the algorithm the neighborhood of the point λ_{center}, denoted by $N(\lambda_{center})$, is considered. Function *getNewPoint* chooses any unchecked point from $N(\lambda_{center})$ as a current point λ. Function *markPointInTabuLists* adds point λ to L_2 and then marks λ as checked in all neighborhoods of points from L_2 which contain λ. This allows to avoid re-processing of the same points. If the neighborhood of some point contains only checked points, then this point is moved to L_1.

For current point λ and corresponding CNF $\tilde{C}(\lambda)$ of the kind (4) function *isCorrectPoint* runs a SAT solver for a short period of time. If, as the result, CNF $\tilde{C}(\lambda)$ is proven to be unsatisfiable, then the algorithm moves to the next point from the neighborhood $N(\lambda_{center})$. Otherwise, the value $\mu(\lambda)$ is computed and compared with the value μ_{best}.

In case if we did not improve μ_{best} value in the neighborhood of λ_{center}, new point λ_{center} must be selected from L_2. Function *getNewCenter* chooses a point from L_2 with a value of the objective function which is closest to the known μ_{best}.

The algorithm is completed if a certain time limit is exceeded or the entire search space is processed (in this case L_2 is empty). The output of the algorithm is the point λ_{best} and the corresponding value of the objective function $\mu(\lambda_{best})$.

IV. Computational experiments

In this section we describe computational results for MD4-39 preimage attack using the method of relaxation constraints generation described above. At the current stage, the A1 algorithm is implemented as a single-threaded application. To calculate the value of the function (5) the Unit Propagation procedure, implemented in all modern CDCL solvers, is used.

Everywhere below, the constraints of the kind (3), consisting only of literals with negation, were used as relaxation constraints. Thus, we used constraints of Dobbertin's type with constant $K = 0$.

Let us note here that the structure of the MD4-39 hash function makes it impossible to impose constraints on the first four and the last (preceding the calculation of the final hash value) four steps of the MD4-39 algorithm. According to this, the sets of new relaxation constraints were selected (using the values of the corresponding switching variables) from the set $\Re$ of power $Q = 31$. Thus, the problem of maximization of the function (5) over Boolean hypercube $\{0,1\}^{31}$ was considered.

In the early experiments it was found that some sets of relaxation constraints produce CNFs, for which the UNSAT can be proven quite quickly (within a few seconds). In practical implementation of the algorithm for each set of values of switching variables that specifies a set of relaxation constraints, not only the value of function (5) was calculated, but also short time limit was given to solve the corresponding SAT instance. This step allows to screen out some points without the computation of the objective function.

In the A1 algorithm the following actions are performed: selection of starting search point; screening out the points for which unsatisfiability is proven quickly; accumulation of all record points; exit from local maxima.

The A1 algorithm was run on one core of Intel i7-3770K (3.5 GHz) processor under Linux OS (Ubuntu 16.04). In all computational experiments the MD4-39 preimage finding problem for $\chi = 0^{128}$ was considered. For the points, obtained using the A1 algorithm, with the value of the objective function close to the maximal possible value (i.e. 512), we established that corresponding sets of relaxation constraints define unsatisfiable CNFs. The satisfiability problems of such CNFs were considered as a separate problems, which in some cases required a significant amount of time. Thus, it was necessary to select points from $\{0,1\}^{31}$ for which there was a good chance for the corresponding CNF of the kind (4) to be satisfiable. To find such points the following heuristic was used: first, to select only those points where the value of the function $\mu(\lambda)$ was improved (i.e., record points); second, to select the points with the value of the function $\mu(\lambda)$ from the interval $[256, 320]$. The total number of record points from the number of all points processed in several hours was approximately 2%. The total number of perspective points identified by the heuristic described above was 0.5%. For each point from the perspective set of points the MINISAT2.2 SAT solver was applied to the corresponding CNFs with a small time limit (60 seconds).

As a result of the above actions, two new sets of relaxation constraints were obtained. These sets are specified by the following vectors of values of switching variables from $\{0,1\}^{31}$:

$$\rho_1: \quad 0000000001101110111011101000000$$
$$\rho_2: \quad 0000000000101110111011101100000$$

The application of these sets allows one to find preimages of the MD4-39 hash function for known hash values 0^{128} and 1^{128} within a minute of MINISAT2.2 runtime (whereas using constraints from [11] the solution of the preimage finding problem for 1^{128} requires about 2 hours, and the preimage finding problem for 0^{128} cannot be solved in 8 hours). Corresponding results are presented in Table I, where ρ_{De} denotes the set of relaxation constraints described in [11] and $\rho_{Dobbertin}$ denotes the variant of Dobbertin's constraints from [10] with constant $K = 0$. Below these relaxation constraints are specified by the vectors of values of switching variables from $\{0,1\}^{31}$ (in the similar notation to that of ρ_1 and ρ_2):

$$\rho_{Dobbertin}: \quad 0000000011101110111011100000000$$
$$\rho_{De}: \quad 0000000001101110111011100000000$$

What is particularly interesting is that the application of new sets of relaxation constraints ρ_1 and ρ_2 also allows one to find preimages of MD4-39 for randomly generated 128-bit hash values persistently. To obtain this result, we considered a test set consisting of 500 randomly generated vectors from $\{0,1\}^{128}$. Each vector from this set was taken as a hash value of the MD4-39 hash function. After that the preimage finding problem for this value was solved using constraints ρ_1 and ρ_2. For the prevailing part of the tasks (65-75%) the solutions were successfully found using the MINISAT2.2 SAT solver. The average time of finding one preimage was less than 1 minute. The rest ones (25-35% of the tasks) corresponded to 128-bit vectors for which there were no MD4-39 preimages under constraints ρ_1 and ρ_2. These results are presented in Table II. Note that even in a few hours we did not manage to solve the preimage finding problem for any vector from the test set using constraints from [10] or [11].

V. Conclusion

In the present paper a new SAT-based preimage attack on the 39-step variant of the MD4 cryptographic hash function is suggested. This attack makes it possible to solve the MD4-39 preimage finding problem for a very significant percentage of randomly generated 128-bit vectors, spending on one such vector less than a minute of MINISAT2.2 runtime. The proposed attack is much more effective than the best known

TABLE I
FINDING THE MD4-39 PREIMAGES FOR HASH VALUES 0^{128} AND 1^{128}

Relaxation constraints	$\mu(\lambda)$	Solving time (s)	
		$\chi = 0^{128}$	$\chi = 1^{128}$
ρ_1	288	20	10
ρ_2	288	60	UNSAT
$\rho_{Dobbertin}$	288	20	$>$ 8 hours
ρ_{De}	256	$>$ 8 hours	7000

TABLE II
FINDING THE MD4-39 PREIMAGES FOR 500 RANDOMLY GENERATED 128-BIT HASH VALUES

Relaxation constraints	Avg. solving time (s)	Max. solving time (s)	Solved instances (in % of total number of instances)	
			with preimages (SAT)	with no preimages (UNSAT)
ρ_1	12	80	65	35
ρ_2	46	250	75	25

attack on the considered truncated variant of the MD4 hash function presented about 10 years ago in [11].

We intend to develop the approach described in this paper in the direction of studying the preimage finding problem of MD4-k, where $k \geq 40$. The preliminary results show that the corresponding problem for MD4-40 demands significantly more computational resources in comparison with MD4-39: the relaxation constrains constructed using the method described in this paper do not make it possible to solve the MD4-40 preimage finding problem on a single processor core. At the same time, this effect is not observed between the preimage attacks on MD4-38 and MD4-39. In the nearest future we plan to apply the parallel SAT solvers to the inversion problems of MD4-k, $k \geq 40$ with relaxation constraints constructed using the method presented in this paper.

VI. RELATED WORK

The first mention of the approach to the construction of hash functions, which is widely known today as the Merkle-Damgard construction, can be found in [23]. In [5] and [6] R. Merkle and I. Damgard independently described a number of important properties of hash functions based on this construction. One of the first practical implementations of Merkle-Damgard construction was the MD4 hash function [7] developed by R.Rivest. In [8] the MD4 hash function was completely compromised with respect to the collision attack. The collision search problem for the functions from MD family in the form of SAT was first proposed in [24]. However, real practical results in this direction were obtained later in [25]. The use of propositional encodings presented in [16] made it possible to find collisions for MD4 hash function (with the help of modern SAT solvers) about 1000 times faster than it was done in [25].

In a number of works the resistance of MD4 hash function to the preimage attack was studied. Today it is generally accepted that MD4 is not resistant to the preimage attack, although the best known preimage attack on the full-round version of MD4 is theoretical [26]. The first practical preimage attack on truncated variant of MD4 was implemented by H.Dobbertin: the algorithm presented in [10] allows one to find preimages of MD4-32 on a personal computer. As far as we know, in the last 10 years the best practical attack on truncated variants of MD4 was attack described in [11]. In this attack the MINISAT [12] SAT solver was used to find preimages of MD4-39 weakened by the additional constraints. In the present paper we significantly improve the results presented in [11].

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Authentication and Authorization orchestrator for microservice-based software architectures

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Abstract - Nowadays the demand for cloud and IT services is gaining more and more popularity, therefore, the various IT solutions which implement them need to face some challenges. More and more intensive user activities require the use of well-scalable and distributed solutions which (from software technology point of view) disassembles classical monolithic architectures into microarchitectures. Consequently, instead of one or a few well-determined application-level points of access, the system must provide many points of access for the users and the other parts of the application involving many authentication and authorization processes. Moreover, the number and the location of these points of access are constantly changing during the running time implying new challenges in the security and the management field. One of the solutions is to give an encrypted token (typically implemented by a JSON Web Token) to the users after their logins which will be attached to each query. In this paper we develop an authentication and authorization orchestrator for the microservices which can manage the tokens (create and delete) needed to the authentication and authorization of the users. The orchestrator service contains a client API to provide the necessary information for the microservice in Java environment without the modification of the original application.

Keywords – authentication, authorization, microservice architecture

I. INTRODUCTION

The usage and demand for different IT services in our daily lives is increasing continuously. This increase appears in not just the wider range of available services, but also in the increasing number of the users and the more intensive usage. To fulfill this ever-increasing tendency in regional, national or even international services often distributed and scalable solutions are required. From a software technological perspective, it means that the classic monolithic architectures should be decomposed and organized into microarchitectures.

With the advent of microarchitectures the so far centralized tasks are now distributed. The single or at most a few application points of access for the resources are replaced by dynamically changing ones, both in number and in place. Accessibility should now be provided for both the users and the different parts of the applications [1][2].

This change in the architecture revealed so far unknown security and operational issues. These issues should be covered from both developmental and system administration aspects [3].

Microservices are nowadays built-in containers (i.e.: Docker, [4]) in order to provide portability and easier installation. The relocation/installation and launching the containers does not need any manual activity for the administrators. An orchestrator service (i.e.:Kubernetes) is able to share, run and manage its registered containers on its own worker nodes [5]. The relocated containers are able to upgrade themselves or even their built-in microservices with the help of configuration management tools. The creation and registration of the containers can be carried out also with the help of Continous Integration/Continous Delivery (CI/CD, i.e.: Gitlab) without any human intervention. The connection between the different services in a distributed microarchitecture can be represented by graphs. Based on this graph the needed access can be easily calculated to what kind of resources should be provided [6][7].

The network that provides the communication between the microservices can be appropriately secured by already existing network and system administration tools (DMZ, VPN, Firewall, http, etc). Even larger problem is to authenticate and authorize the user in the application layer of the independent and separated microservices [8][9]. A microservice should focus only its implemented task. If we overload the microservice with the handling of authentication, authorization and logoff processes, it loses its micro feature. Moreover we do not intend to store and administer the user's data to prevent cracking and leaking personal information. Therefore we developed an Authentication and Authorization Orchestrator (AAO) which manages a complex system built from the OAuth2, OpenID, Single Sign On (SSO) and JSON web token methods for microservices. Our research was carried out within the frames of the project which aims to research and develop telemedicine monitor center that integrates different healthcare services, to implement a pilot solution validated with more than 5000 measured data and to develop telemedicine services built on improved Inclouded platforms.

The rest of the paper is organized as follows: In the next section we provide a short background and overview of works related to our research. Section 3 presents a security analysis in order to find the best solution related to the Identity management. Section 4 gives a description about

the applied tools during the implementation. In section 5 we introduce the proposed model. Finally, we summarize our conclusions and reveal the potential future research directions.

II. STATE OF THE ART

Currently, the security and most of all the authentication and authorization requirements of the microservice architecture present a burning problem which the software developers have to face with and have to solve. Consequently, different performed research and developed models have been provided.

A. Authentication

Basically, the authentication can be performed with passwords, AAA framework, certificates and tokens.

The password authentication is a method that is frequently used with smart card. Generally, it requires a username and password pair to be stored by the system. In the last decade there have been proposed several protocols but despite its two-factor authentication feature, it is still vulnerable to dictionary attacks. Thus inadequate for use in security-critical applications such as e-banking or e-health. [10]

Walsh et al. in [11] introduced an attested, centralized TLS mechanism based on two-side certificates and TLS-PSK. This method is appropriate in many scenarios when the decentralized concept is not relevant because it does not affect significantly the computational and network performance. Also, Pahl et al in [12] apply site-local certificates to secure the IoT microservices. Their solution enables all entities to verify the operation of the preceding entities in the processing chain.

The Token-based authentication model enables users to obtain a token after their password authentication and then, for a given period of time they can access all resources which are validated by the token. Ethelbert et al. in [13] use Jason Web Token (JWT) to authenticate and authorize cloud users. They extend their solution with three more components, with Policy Match Gate, Policy Control Module and Policy Validation module in order to ensure process authentication per request call.

In [9] the authors explore several solutions to implement authentication and authorization in microservice architecture including Single Sign On (SSO), JWT and API Gateway techniques. Evaluating these methods they found the JWT is the most appropriate in a distributed, microservice-based architecture.

B. Authorization

The most popular identity based access control models include Mandatory Access Control (MAC), Discretionary Access Control (DAC), Role Based Access Control and Attribute Based Access Control [14].

RBAC was introduced in1992 by Ferraiolo et al. [15] which actually covers both the MAC and DAC model. The role assigned to the user follows the least privilege concept. These models are not scalable and do not work efficiently in a dynamically changing environment. There are some modified versions of RBAC, such as distributed RBAC [16] cloud-optimized RBAC [17] and S-RBAC for Software as a Service systems [18] which are very complex and do not scale well. Moreover, in this way, their maintenance costs are high concerning space and time.

Similarly, applying the Attribute Based Access Control (ABAC) in a dynamically changing cloud-based environment, exponentially large number of attributes have to be handled every time when a user needs access to a resource [19] [20].

The Security Assertion Markup Language (SAML) is an XML-based, open-standard data format for exchanging authentication and authorization information between an identity provider and a service provider [21] [22]. It is preferable in a centralized environment. OAuth (RFC 6749, 7522) is also an authorization framework which enables (even a third-party application) accessibility to a service, either on behalf of a resource owner or by orchestrating an approval interaction between the resource owner and the service [23].

To sum up the results mentioned above, we can conclude that although there are many solutions for this challenge and all of them are well-suited in an appropriate scenario. With the exception of OAuth framework they do not support the decentralized concept. Moreover, they did not deal with the following question: How complex to crack the systems and which data could be compromised in case of cracking?

III. ANALYSIS OF THE SECURITY SOLUTIONS

Our aim is to provide a solution that prevents the microservices to handle the user credentials and authorization process. Due to the microservice architecture, the solution should be decentralized with a focus on system and user simplicity and convenience. That means that the system should not store any information about the user, in this way if an attacker gains access to the system user credentials cannot be stolen. On the other hand, it is not a requirement for the user to create digital identity and to be authenticated every time when accessing a new microservice (user experience).

We have investigated the most popular identity management models according to the following aspects: the actual solution needs centralized or decentralized implementation, scalability, complexity of cracking, implementation costs and complexity, compromised user credentials in case of cracking, and user experience (Table 1).

Concluding the results of table 1. we can claim that the two centralized solutions – login/password and AAA – are not appropriate for this healthcare system due to the high security vulnerabilities and poor user experience. The certificate based authentication is a centralized solution which is not scalable and it requires complex implementation. The token based authentication is more preferable in a microservice architecture. Amongst the two token-based authentication – SAML and JWT – the SAML consumes more resources in the process of sending and receiving the tokens, the size is bigger, the structure is more complex moreover it cannot be revoked or updated.

1. TABLE COMPARATIVE STUY OF IDENTITY AND ACCESS METHODS

Security solution	decentralized	Easily Scalable	Cost and complexity of implementation	Complexity of cracking	In case of cracking…	User experience
preferred solution	important	important	should not be so high	it should be high	it should not cause damage	good
SAML	can be	yes	high	high	user's data can be compromised	ok
AAA	no	no	low	low	user's data can be compromised	poor
User/Password	no	no	low	low	user's data can be compromised	poor
Certificate	no	no	high	high	user's data can be compromised	poor
our solution (JWT/OAuth2/OpenID/SSO)	yes	yes	medium	high	there is no compromised data	ok

IV. OAUTH2/JWT/OPENID/SSO

Thanks to the continuous development of science and technology the complete palette provided by a healthcare service cannot be determined in advance. The equipment support of telemedicine services is used more and more widespread in the field of Medical Sciences. Due to the fast evolution of Big Data technologies and the processing of measured data, every complex telemedicine service is going to progress continuously. To fulfill these challenges and requirements distributed microservice architecture based implementations can provide appropriate solutions. The independent services like user authentication and authorization should be integrated. From the user perspective authentication process must be simple and user-friendly. It is already possible to use the existing digital identities to access different services (OpenID). Also, a distributed system should be able to connect the user credentials (SSO) to background processes (OAuth).

A. OAUTH2

OAuth 2.0 (Open Authorization, RFC 6749) [24] [25] is an authorization framework which allows users to access the different services without the need to share their credentials. The user is authenticated to the authorization server via an authorization grant (e.g., username/ password) and in case of valid credentials gets an authorization code. The client getting back this code can obtain an access token and use it to access the resources of the resource server which should be able to verify the access token without the need to contact the authorization server.

B. SSO

Web-based single sign-on method, which allows a user to be authenticated only once during logging in to a particular system and then accessing all the resources and services of the system without further authentication. With the help of it the users obtain access on their own behalf to other services or applications using some access keys. The main purpose of the protocol is to exchange the access credentials required for the authorization and not the authentication itself. This distributed service can ensure the unified authentication process for the distributed microservices [26].

C. JWT

JSON Web Token (JWT) [27] is an open standard token format which consists of three part: Header, Payload, and Signature. The header typically consists of two parts: the type of the token, which is JWT, and the hashing algorithm being used, such as HMAC SHA256 or RSA. The payload stores the actual claims and the signature consist of the encoded header and payload parts. As JWTs are self-contained, all the necessary information is there, reducing the need to query the database multiple times.

D. OpenID

OpenID is an open standard authentication method which was introduced in 2005. This mechanism allows users to have only one digital identity (username and password pair) for many applications or services (for example Facebook or google).

V. PROPOSED MODEL

The aim of the project was to develop a healthcare telemedicine system which consist of a database that stores all the sensitive data about the patients and their medical conditions and values collected from sensors. Based on this data set the doctor can monitor the changes in the clinical state of the patient and make a diagnosis remotely.

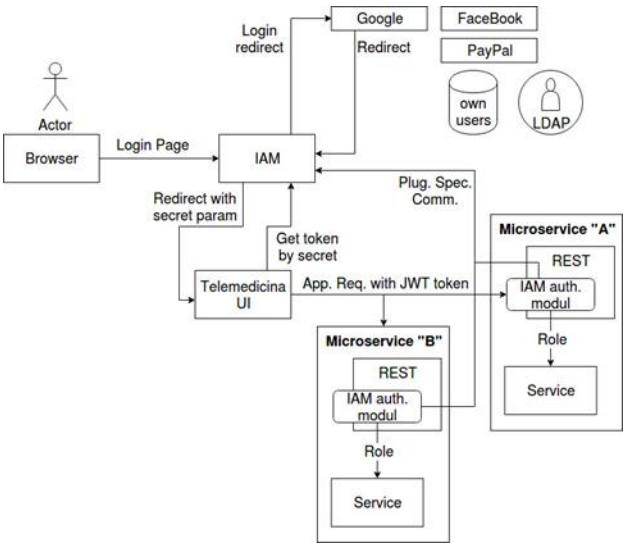

Figure 1. Authentication and Authorization Orchestrator

Being the data especially sensitive, the crucial point of the development is the authentication and the authorization process. The user identification is carried out at the common login point in a classic monolithic system. Based on the authentication the authorization takes place at the same point. Because meanwhile the service is provided all the needed data can be found at the same place, the user credentials can be stored in the memory, and every software component can access them easily.

When clustering a monolithic application two possibilities are given: the first one is to tag the user sessions at the load balancer, and every request that was tagged identically are sent to the same machine/host, the second option is to distribute the authentication and authorization data in the cluster.

Distribution of the authentication and authorization data is resource intensive thus it may worsen the performance of the clustered application. Moreover, it should be also taken into account that every data distribution is an issue of security, thus new solutions like this require handling the evolved connected security and operational problems.

With the increasing number of Internet applications, it is becoming harder to fulfill the dynamically changing user requirements based on a monolithic application. The runtime modifications of clustered applications often require service outages which could be easily avoided using different software architectures [28].

In our implementation, the resources can be accessed via REST-based protocols. The REST philosophy's main keystone lies in its stateless approach. It means that more requests initiated by the same user should be handled independently at the server's side. This request-response philosophy provides possibility to automatically scale microservices based architectures, because different requests initiated by the same user from the same user interface to the same resources can be served by different service entities. REST philosophy is not built on the previously used server's side sessions, which provided the basis for the authorization processes. The independent microservice entities are not connected into one application cluster, therefore the previously used session data could not be synchronized between the different entities. Thus, each request should contain the required authentication data for the services.

In microservice environment the dynamically changing operation is not an issue, it is a natural phenomenon according to the software architecture. In an environment like this, the cluster has a different meaning, since not the whole application stack is copied and distributed. The different components of an application are able to operate on their own, even with multiple entities, independently from other components. In a distributed environment like this, there can also be some dedicated entry point, but complex user authentication and authorization processes need not be implemented at these points, because the effective data management and functionalities are implemented in the microservices. Therefore the microservices should determine the data based on the actual incoming requests.

In order to avoid authentication and authorization by the microservice at each time a new service is requested, in the above described systems it is expedient to implement a service that realizes this function (Figure 1). The SSO service provides the unified authentication process for the distributed microservice system. After authentication, The Identity and Access Management (IAM) module redirects the user and generates a token, which should be appended to each request. IAM is capable of authenticating the users, managing their authorization, to issue and withdraw the tokens, and to determine the roles of the users represented by tokens. In our solution we have implemented JWT. The IAM auth. module in the REST part of the microservice can determined whether the user connected to the token is active or not, and what authorization entries are valid for that user. Based on the token every microservice is able to manage the users and rights connected to the requests. The tokens have an expiration-time which can be set in the configuration of IAM. If the timer expires, it can be extended. With the setting of this timer the system can be fine-tuned. From security perspective the timer should be set to relatively small value but when the load increases the timer should be set higher to prevent the frequent refresh. In our implementation we use the default value five minutes. The data is cached while the timer of the token is valid. In our implementation the token contains user information (username and email) and different system information for example timestamps (expiration timer, creating timer). In our telemedicine system the microservices can be virtual consulting room, disease type, sensor data type, visualizer etc.

We also developed a client API that is capable of providing authentication and authorization information to the microservice without the need for changing the internal logic of the microservice itself in Java microservices environment. To improve the performance we built in a cache into the API. This resulted in less load on the orchestrator microservice and decreased security overhead of the microservices.

VI. CONLUSION

In this paper we have investigated the different types of authentication and authorization methods in order to implement our solution for a healthcare application. Our system stores all healthcare information about patients/users to help the doctor to track and monitor the state of a patient or even to make a diagnosis remotely based on this database. Considering sensitive data the security solutions are especially important, most of all the authentication and authorization issues. After the study and evaluation of the existing Identity and Access Management methods we have introduced our solution which is based on a complex system of OAuth2, SSO, JWB and OpenID. To help the different components to work together, an Authentication and Authorization Orchestrator (AAO) and an API has been developed to prevent the microservices processing authentication or authorization. Conversely, the AAO can work in a well-scalable distributed environments, and we do not have to manage and store information about users while they can be sure that their data are kept secured. Moreover, since we have separated the Authentication and Authorization Module (AAM) from the system and the implementation, it can work even if the microservice architecture or the IAM module changes. In addition, thanks to the independency of the AAM on one hand the development of the whole system (and microservices) is much easier and simpler on the other hand the system is flexible and reliable.

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PAPERS

Theory of K-representations as a Tool for Designing File Managers with a Natural Language Interface

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***Abstract* - During last decade, semantic parsing of the instructions in natural language (NL) has become a significant branch of the studies aimed at creating semantics-oriented NL processing systems. A topical problem of the kind is designing file managers with a NL-interface. The principal attention in our previous papers was paid to creating new, more effective theoretical foundations of designing semantic parsers of NL-instructions. In particular, we suggested in a very concise form an original and broadly applicable algorithm of semantic parsing. This paper, firstly, illustrates a correspondence between input instructions and their semantic representations. Secondly, the main attention is given to describing mathematical foundations of executing NL-instructions by computer systems. The methodological basis for these results is the theory of K-representations (knowledge representations). Its basic formal model introduces a system consisting of ten partial operations on conceptual structures. There are solid grounds for conjecturing that, combining these operations in arbitrary order, it is possible and convenient to build step by step a semantic representation of arbitrarily complex sentence or discourse in NL. The stated theoretical results have become the basis for designing a file manager with a NL-interface NLC-2 (Natural Language Commander - Version Two).**

Keywords* - *semantic parsing; SK-language; integral formal semantics of natural language; execution of instruction; relation of correspondence to a pattern

I. INTRODUCTION

Semantic parsing of the instructions in natural language (NL) has become during last decade a significant branch of the studies aimed at designing semantics-oriented NL processing systems. This branch is interested, in particular, in the development of NL-interfaces for interaction with robots and the personages of videogames [1-4], navigation in virtual space [5, 6], and for programming by means of NL-instructions [7, 8]. Besides, one of the topical problems of the kind is the development of file managers with a NL-interface. This problem is considered by us in several previous papers, in particular, in [9-13]. The principal attention was paid to creating new, more effective theoretical foundations of designing semantic parsers of NL-instructions.

In [11, 12], an original and broadly applicable algorithm of semantic parsing SemSyntRA is presented in a very concise form. This paper, firstly, illustrates a correspondence between input NL instructions and their semantic representations (SRs). Secondly, the main attention is given to describing mathematical foundations of executing NL-instructions by computer systems. The methodological basis for these results is provided by the theory of K-representations (knowledge representations), or TKR [14-22]. It is the central constituent of Integral Formal Semantics of NL (see [23] and Chapter 2 of [19]).

The basic mathematical model of TKR introduces a system consisting of ten partial operations on conceptual structures. There are solid grounds for conjecturing that, combining these operations in arbitrary order, it is possible and convenient to build step by step a semantic representation (SR) of arbitrarily complex sentence or discourse in NL (English, Croatian, Russian, etc.).

The basic model of TKR determines a new class of formal languages - the class of SK-languages (standard knowledge languages). The SRs of NL-texts are to be the expressions of SK-languages.

The stated theoretical results have become the basis for designing a file manager with a NL-interface NLC-2 (Natural Language Commander - Version Two). This system is implemented with the help of the functional programming language Haskell.

The structure of this paper is as follows. Section 1 contains an introduction to the considered problem. Section 2 gives a very general information about TKR as a whole and about its basic mathematical model determining, in particular, the class of SK-languages. Besides, this section illustrates the correspondence between an input NL instruction and its primary SR generated by the algorithm SemSyntRA and being an expression of a certain SK-language. Section 3 explains the notion of a transformation rule used for constructing a secondary SR of an input instruction from its primary SR. The application of the transformation rules depends on special binary relation on the considered SK-language, it is called the relation of correspondence to a pattern. This relation is explained in Section 4. Section 5 shortly characterizes an applied intelligent system called NLC-2

Natural Language Commander - Version 2). The ideas described in this paper underpinned the design of this system being a file manager with a NL-interface. Section 6 contains the conclusions.

II. SK-LANGUAGES AS A CONVENIENT TOOL FOR DESCRIBING COMPLEX SEMANTIC STRUCTURES OF NATURAL LANGUAGE

One of the principal reasons for developing the algorithm SemSyntRA was the intention to considerably expand the possible complexity of input NL instructions. The algorithms of NL instructions' semantic parsing described in scientific literature by the middle of this decade are able to process only simple instructions, including one verb with dependent words. But the instructions emerging in applications may be much more complex: include several actions joined by the connective AND or OR, indicate the order of actions, time distance between actions, mention compound designations of objects' groups as the operands of actions, include the modal words "necessary", "should", etc.

The analysis of the scientific literature shows that the main approaches to this problem used in practice are Abstract Meaning Representation (AMR) [3] and lambda-calculus meaning representation (LCMR) [1].

The semantic formalism AMR was introduced in 2013 in the ACL publication [24] by a group consisting of ten researchers from UK and USA. The paper [25] shows that much broader prospects for creating semantic languages-intermediaries in comparison with AMR are opened by the theory of K-representations, developed by V. A. Fomichov [14-22]. The advantages of TKR in comparison with AMR are, in particular, the possibilities to construct semantic representations of compound infinitive constructions (expressing goals, commitments, etc), of compound descriptions of notions and sets, and of complex discourses and knowledge pieces, in particular, of discourses with the references to the meaning of sentences or larger parts of discourse.

The approaches AMR and LCMR are rather convenient for representing structured meanings (SMs) of simple instructions: with one verb, containing no connective OR. However, the analysis shows that the expressive power of AMR and LCMR is insufficient for effectively dealing with complex instructions characterized above. The appropriate expressive mechanisms are provided only by TKR.

The part 1 of TKR is a mathematical model (Model 1) of a system of primary units of conceptual level used by an applied intelligent system. This model determines, in particular, a new class of complex formal objects called *conceptual bases.* To construct an arbitrary conceptual basis (c.b.) *B* is equivalent to defining a certain finite sequence of formal objects *Tuple(B).* The interpretation of its distinguished components *St, X, V, F, tp* is as follows [19]. *St* is a finite set of symbols called sorts and interpreted as designations of most general notions used in the considered application domains: *physical object, intelligent system, organization, distance value, price value*, etc. The countable set *V* contains the variables. The countable set *X* includes the subset *St* of sorts and contains the symbols interpreted as the designations of primary informational (or conceptual) units. The set *X* is called *the primary informational universe of the c.b. B*. The finite subset *F* of *X* contains the designations of functions.

The component *tp* of the sequence *Tuple(B)* is a function from the union of *X* and *V* into a countable set of strings *Types (B)*, it includes *St*. The elements of this set are called *types* and are interpreted as structured characteristics (labels) of the entities denoted by the elements of *X*. The mapping *tp* gives us a much more fine-grained structuring of application domains than first order logic.

Example. A c.b. *B* may satisfy the following conditions: (a) *St* includes the elements (sorts) *dyn.phys.ob* (dynamic physical object), *ints* (intelligent system), *org* (organization), *inf.ob* (informational object); (a) *X* includes the elements *M-Bulgakov, Master-and-Margaret, person, tourist-group, Suppliers, Authorship,* and

$tp(person) = \uparrow ints * dyn.phys.ob$, $tp(M\text{-}Bulgakov) = ints * dyn.phys.ob$, $tp(Master\text{-}and\text{-}Margaret) = inf.ob$, $tp(Authorship) = \{(ints, inf.ob)\}$,

$tp(tourist\text{-}group) = \uparrow \{ints * dyn.phys.ob\}$, $tp(Suppliers) = \{(org, \{org\})\}$.

Here the symbol ↑indicates a type of a notion; *Suppliers* is the name of the function associating an enterprise with the set of all its suppliers.

A partial order $\vdash$ is defined on the set of types *Types (B),* it is called the *concretization relation.* For instance, the following relationships may take place:

$phys.ob \vdash dyn.phys.ob$, $phys.ob \vdash ints * dyn.phys.ob$, $ints \vdash ints * dyn.phys.ob$, $\{phys.ob\} \vdash \{ints * dyn.phys.ob\}$.

The part 2 of TKR determines a mathematical model (Model 2) of a system consisting of ten partial operations on conceptual structures. The Model 2 defines, in particular, a new class of formal languages called SK-languages (standard knowledge languages). There are weighty reasons to conjecture that SK-languages are a convenient formal tool for building SRs of arbitrarily complex NL-texts (sentences and discourses) pertaining to mass spheres of professional activity (engineering, medicine, business, sport, etc.). The term "a K-representation" (KR) is used for denoting SRs of NL-texts being the expressions of SK-languages.

The expressions of SK-languages are built from primary semantic units and several service symbols by means of inductive application of some original rules P[0], P[1], …, P[10]. A set of primary semantic units and several distinguished subclasses of this set are determined by a conceptual basis (c.b.) [19]. The language corresponding to an arbitrary c.b. *B* is designated by *Ls(B).*

The mapping *tp* from the union of the primary informational universe *X(B)* and the set of variables *V(B)* into the set *Types(B)* is expanded in [19] to the mapping *tpl* from the SK-language *Ls(B)* into the set *Types(B).* For instance, the value of the mapping *tpl* for the argument *Greater(Distance(Moscow, London), Distance (Moscow, Paris))* could be the sort *prop* (meaning of proposition), it is interpreted as the type of SRs of assertions (propositions).

The rule P[0] describes an initial set of formulas from *Ls(B);* in other terms, they are called K-strings. E.g., the

unit *file1* is a K-string. The rules P[1] – P[10] jointly define a system consisting of ten partial operations on conceptual structures [19].

The rule P[1] allows us to join intensional quantifiers and designations (simple or compound) of notions, in particular, to construct the formulas *certain file1,*

*certain file1 * (Extension1, "doc"),*

*all file1 * (Extension1, "doc").*

The rule P[2] is used for constructing the expressions of the form $f(t_{1\ ,...,}\ t_n)$, and P[3] enables us to build the expressions of the form ($c \equiv d$). Example: *(document ≡ file1 * (Extension1, "doc"))*.

One uses the rule P[4] for building the expressions of the form $rel(t_{1\ ,...,}\ t_n)$, where *rel* is the name of a relation with *n* attributes (example: *Earlier (Creation-date(certain file1), #yesterday")*). The rule P[5] provides the possibility to mark a formula or its part by means of a variable. Example: *all file1 * (Extension, "doc") : S1*.

The rule P[6] allows us to join the negation connective ¬ to a formula (example: ¬*file1*). The rule P[7] governs the use of the logical connectives ∧ (and) and ∨ (or). Example: *file1 * (Extension1, ("doc" ∨ "docx"))*.

Using the rule P[8] at the last step of an inference, it is possible to construct compound designations of notions. Example: *file1 * (Extension1, ("doc" ∨ "docx"))(Location, certain desktop).*

The rule P[9] allows us to use the universal quantifier and existential quantifier (∀ и ∃) in formulas. The rule P[10] enables us to construct the SRs of finite sequences as the strings of the form $< c_{1\ ,...,}\ c_n >$, where $c_{1\ ,...,}\ c_n$ are the elements of a sequence.

Example 1. The algorithm SemSyntRA associates the instruction "Archive documents in folder "Project" and send to somebody@example.org" with the primary K-representation (KR) *Semrepr1* of the form

*(IsAction (#now#, archiving1 * (Object1, certain set * (Qualitative-composition, document1 * (Location, certain folder 1 * (Name1, "Project") : S1))(Result, x1), e1 ∧ IsAction (#now#, sending1 * (Object1, x1)(Email-address, "*somebody@example.org"), e2) ∧ *Immediately-after(e2, e1))*.

III. THE PRINCIPAL IDEAS OF EXECUTING K-REPRESENTATIONS OF INSTRUCTIONS

In order to execute an instruction, more exactly, a KR of an instruction, it is necessary to do two steps: (a) to form a KR including only the notions being "known" to the goal applied system; (b) to translate the obtained KR to the language of the goal system.

Let's consider the user instruction "Move the video with the name "Lecture 2017-12-15" to the reserved disc". For escaping many details, let's restrict ourselves by considering the processing of the fragment the video with the name "Lecture 2017-12-15", associated with the KR of the form *certain video1 * (Called, "Lecture 2017-12-15")*.

Suppose that we have the transformation rule

*video1 * (Called, filename) → file1*(Called, filevame)(Extension1, ("avi" ∨ "mkv" ∨ "mp4"))*,

where *filename* is a certain string such that the type *tpl("Lecture 2017-12-15")* is a concretization of the type *tpl(filename).*

Then, applying this rule to the KR *certain video1 * (Called, "Lecture 2017-12-15"),* we obtain the secondary KR of the form

certain file1(Called, filevame)(Extension1, ("avi" ∨ "mkv" ∨ "mp4"))*.

For applying this transformation rule, it is necessary to get to know that the K-string *certain video1 * (Called, "Lecture 2017-12-15")* or its certain substring corresponds to the left part of the considered transformation rule.

With this aim, a special binary relation is introduced. It is called *the relation of correspondence to a pattern* and receives the name (designation) *Match*. For the considered example, the pair (*video1 * (Called, "Lecture 2017-12-15"), video1*(Called, filevame))* belongs to *Match*.

Next section is devoted to considering the grounds for including the pairs of K-strings into a binary relation *Match*.

Similarly, it is assumed to fulfill the transformation of KR into the scripts of the goal system. The only difference will be that the right parts of the transformation rules will contain not the K-strings but the scripts of the goal system.

IV. THE GROUNDS FOR INCLUDING THE K-STRINGS INTO THE RELATION OF CORRESPONDENCE TO A PATTERN

In order to fulfill a transformation, let's formulate a rule of checking a correspondence between the left part of the transformation rule and the processed K-string. With this aim, we'll define the relation of correspondence to a pattern on the set of K-strings. The relation is defined with the help of several natural assumptions called below the grounds.

Firstly, a correspondence of an element of the primary informational universe X(B) to the pattern z may be defined by the coincidence of the meanings (synonymy). This synonymy may be determined by a certain reflexive symmetric relation. Let's introduce

Definition 1. Let *B* be an arbitrary conceptual basis (c.b.). Then the *synonymy relation coordinated with the c.b. B* is an arbitrary reflexive symmetric relation *Syn* on the primary informational universe *X(B).*

Let's determine the relation of correspondence to a pattern *Match* on the SK-language *Ls(B).* The fact that the pair *(y, z)* belongs to the relation Match will be denoted by the record $y \succ z$. We do know that the relation *Match* depends on the synonymy relation *Syn* and on the set of rules enabling us to expand *Syn* on the set *Ls(B).* That is why it would be correct to say about the relation of correspondence to a pattern with the precision to within a synonymy relation *Syn.*

Taking this into account, we formulate

Ground 1. Let *B* be an arbitrary c.b, *y* and z be the arbitrary elements of the primary informational universe *X(B).* Then the fact *(y, z)∈ Syn* implies the fact *(y, z)∈ Match*.

For instance, the pair (*folder1, catalogue1*) may belong to the synonymy relation, because the informational units *folder1* and *catalogue1* correspond to

the words "folder" and "catalogue", and these words are synonyms in the field of manipulating with files. Hence the unit *folder1* corresponds to the pattern *catalogue1*, i.e., (*folder1, catalogue1*) $\in$ *Match*, it is the same as *folder1* $\succ$ *catalogue1*.

In case the pattern is a variable, the correspondence of the K-string *y* to the pattern *z* is determined by the types of the pattern *z* and *y*. The type of the pattern *z* is to coincide or to be more general than the type of *y*. E.g., if the element of a primary informational universe *disc1* has the type $\uparrow$*inf.object * dyn.phys.object*, and a variable *var* has the type $\uparrow$*inf.object,* then the element *disc1* corresponds to the pattern *var*. We obtain in this way

Ground 2. Let *B* be an arbitrary c.b, *y* belong to *Ls(B),* and *z* be an arbitrary variable from *V(B).*Then the pair *(y, z)*$\in$ *Match* then and only then when $tpl(z) \vdash tpl(y)$, where *tpl* is a mapping from the SK-language *Ls(B)* into the set of types corresponding to *B Types(B)*.

Since a pattern may be constructed with the help of some rules P[1] - P[10], it is reasonable to see how the relation of correspondence to a pattern will be defined in each of these cases.

Let's start from considering the usage of intensional quantifiers in the K-strings (the rule P[1]). For instance, the K-string *certain folder1 * (Called, "Video")* will correspond to the pattern *certain catalogue1*, but will not correspond to the pattern *catalogue1*. Besides, a more simple K-string *certain folder1* will correspond to the pattern *certain catalogue1.*Thus, we have

Ground 3. Let *B* be an arbitrary c.b, *Syn* be a reflexive symmetric relation on X(B), *y* be a K-string of the form $intq_1c_1$, *z* be a K-string of the form $intq_2c_2$, and $(intq_1,intq_2) \in Syn$, $(c_1,c_2) \in Match$. Then *(y ,z)* $\in$ *Match*.

The K-strings with functional and relational symbols (i.e., with the names of functions and *n*-ary relations, where $n \geq 1$), built respectively according to the rules P[2] and P[4], will correspond to the patterns with similar structure.

For instance, the K-string *Size1(certain file1 * (Called, "a.txt"))* will correspond to the pattern *Size1(certain file1).* In more general cases, the functional symbols of the K-string and the pattern should be synonyms, and the arguments of a function (of a predicate) should correspond to the arguments of the pattern as the argument *certain file1 * (Called, "a.txt")* corresponds to the pattern *certain file1*.

Besides, if a variable *n* has the type *number*, the K-string *Size1(certain file1 * (Called, "a.txt"))* has the type *integer*, and the type of the sort *number* is a more general type than the sort *integer*, then the K-string *Size1(certain file1 * (Called, "a.txt")* corresponds to the pattern *n*.

We'll formulate the similar requirements to the K-strings built with the use of relational symbols and also to the K-strings of the form $(a \equiv b)$. The above said enables us to introduce three additional grounds.

Ground 4. Let *B* be an arbitrary c.b, *Syn* be a reflexive symmetric relation on *X(B*), *y* be a K-string of the form $f(a_1,\ldots,a_n)$, *z* be a K-string of the form $g(b_1,\ldots,b_n)$, where *f* and *g* be functional symbols from *F(B)*, and $(f,g) \in Syn$. Let for every *i* from 1 to *n*, the pair (a_i, b_i) belongs to *Match*. Then *(y, z)*$\in$ *Match*.

Ground 5. Let *B* be an arbitrary c.b., *y* be a K-string of the form $(c \equiv d)$, and *z* be a K-string of the form $(a \equiv b)$. Let the pairs *(c,a)* and *(d,b)* belong to *Match*. Then *(y,z)* $\in$ *Match*.

Ground 6. Let *B* be an arbitrary c.b., *Syn* be a reflexive symmetric relation on *X(B)*, *y* be a K-string of the form $r(a_1,\ldots,a_n)$, and *z* be a K-string of the form $p(b_1,\ldots,b_n)$, where *r* and *p* are relational symbols from $X(B) \backslash F(B)$. Let for every *i* from 1 to *n*, the pair (a_i, b_i) belongs to *Match*. Then *(y, z)*$\in$ *Match*.

It is obvious that the application of the rule P[5] to a K-string doesn't cause any changes in the correspondence to a pattern. Taking this into account, we formulate

Ground 7. Let *B* be an arbitrary c.b., *y* and *z* are K-strings from the SK-language *Ls(B)*, and *var* be a variable from *V(B)* such that it is possible to form the K-string *y : var* in accordance with the rule P[5]. Then it follows from (*y, z)*$\in$ *Match* that the pair *(y : var, z)* belongs to *Match*.

Consider in a simple example the case of K-strings with the left segment $\neg$ (the connective "negation"). The K-string *certain file1 * (Called, "a.txt")* corresponds to the pattern *certain file1*. It would be logical to assume that the negation of the considered unit corresponds to the negation of the pattern. That is, the K-string $\neg$ *certain file1 * (Called, "a.txt")* corresponds to the pattern $\neg$ *certain file1*.Thus, we can define

Ground 8. Let *B* be an arbitrary c.b., *y* and *z* be the K-strings from *Ls(B).* Then the fact *(y,z)*$\in$ *Match* implies the fact $(\neg y, \neg z) \in Match$.

The case of binary logical connectives $\wedge$ and $\vee$ (conjunction and disjunction) is more complex. Let's consider firstly the disjunction. i.e. the logical connective OR.

Ground 9. Let *B* be an arbitrary c.b., *y* be a K-string of the form $(y_1 \vee \ldots \vee y_n)$, and $z \in Ls(B)$. Let there be such *i* from 1 to *n* that $(y_i, z) \in Match$. Then the pair *(y,z)* belongs to the relation *Match*.

To the contrary, $y \succ (z_1 \vee \ldots \vee z_n)$ in case *y* corresponds to every substring z_i.

Ground 10. Let *B* be an arbitrary c.b., $y \in Ls(B,$ and *z* be a K-string of the form $(z_1 \vee \ldots \vee z_n)$. Let there be such *i* from 1 to *n* that $(y, z_i) \in Match$. Then *(y, z)*$\in$ *Match*.

The grounds 9 and 10 allow us also to define a correspondence to a pattern for a K-string *y* of the form $(y_1 \vee \ldots \vee y_n)$ and a pattern *z* of the form $(z_1 \vee \ldots \vee z_m)$. It is not difficult to see that $y \succ z$ in case there is such pair *(i, j)* that $y_i \succ z_j$.

Similarly to the grounds 9 and 10, it is possible to define that a K-string of the form $(y_1 \wedge \ldots \wedge y_n)$ corresponds to the pattern *z* in the case at least one of the substrings y_i. corresponds to *z*. To the contrary, a K-string y corresponds to the pattern *z* of the form $(z_1 \wedge \ldots \wedge z_n)$, if y corresponds to all substrings z_i for *i* from 1 to *n*. We use also several additional grounds, they are formulated in [13].

Example. Let's illustrate the ideas stated above in a formal way. Assume that the synonymy relation includes the pairs *(file1, document1), (folder1, catalogue1), (folder1, directory1), (disc1, carrier1), (disc1, USB)* and also the inverse (symmetric) pairs. Then the following relationships will take place:
catalogue1 $\succ$ *folder1*;

disc1≻z, if *z∈ V(B)*, *tpl(certain folder1)=inf.object * dyn.phys.object*, and *tpl(z)= inf.object* , because *inf.object ⊢ inf.object * dyn.phys.object*;
certain catalogue1≻ certain folder1;
Size1(certain catalogue1)≻ Size1(certain folder1);
*Size1(certain catalogue1 * (Called, "Docx")) ≻ Size1(certain catalogue1)*;
(certain file1 ∧ certain catalogue1)≻ certain file1;
certain catalogue1≻(certain file1 ∨ certain catalogue1).

V. Application of the Stated Formal Approach

The ideas stated above together with the model of linguistic database, the notion of a graph-like semantic-syntactic structure, and the algorithm of semantic parsing SemSyntRA [11-12] underpinned the design of file management system NLC-2 (Natural Language Commander – Version 2). This program is the next generation of NLC-1, which was developed for the studies and experiments in the field of NL-interfaces to action-based applications [9, 10]. NLC-2 processes natural language instructions in accordance with the following scheme:
User instruction ==> Primary K-representation ==> Secondary K-representation ==> BASH Script

Example. Let's look how NLC-2 processed the user instruction from the example of Section 2: "Archive documents in folder "Project" and send to "somebody@example.org"". This instruction is transformed by the algorithm SemSyntRA described in [11] into the primary K-representation *Semrepr1* described in Section 2.

Now if the knowledge base of NLC-2 contains the transformation rule *document1 → file1 * (Extention1, ("doc" ∨ "docx" ∨ "odt"))* then the system NLC-2 transforms the constructed primary K-representation of the user instruction into its secondary KR

*(IsAction (#now#, archiving1 * (Object1, certain set * (Qualitative-composition, certain file1 * (Extention1, ("doc" ∨ "docx" ∨ "odt"))(Location, certain folder 1 * (Name1, "Project") : S1))(Result, x1), e1 ∧ IsAction (#now#, sending1 * (Object1, x1)(Email-address, "somebody@example.org"), e2) ∧ Immediately-after(e2, e1)).*

Then the result shell script for Bourne-Again Shell (BASH) is as follows:

```
zip /tmp/z000129.zip "Project/*.doc"
"Project/*.docx" "Project/*.odt"; sendfile
somebody@example.com /tmp/z000129.zip
```

The final step is the execution of this script.

NLC-2 software complex contains two applications: NLC-TI – command line tool with text interface and WebNLC – tool for settings tuning and experiments with Web-interface. Both of them use the same TKRlib library. NLC-TI uses it directly. WebNLC uses TKRlib through the NLC-RESTful – a set of services for Web-applications and integration with another software.

VI. Conclusion

This paper expands new mathematical foundations of designing semantic parsers of NL instructions. The theory of K-representations underpins the stated formal approach. The principal advantages of this approach are that it is application domain independent and can be effectively used for dealing with arbitrarily complex NL instructions.

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Novel BI data architectures

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Most modern companies utilize business intelligence (BI) platforms and tools to acquire new insights into their customers and operations and consequently make better business decisions. The traditional approach to BI consists of a data warehouse containing historical data records, an OLAP engine for faster and more complex data analysis, and various reporting and visualization tools used to present the results. With the advent of big data and cloud technologies, the BI approaches have started to diverge to accommodate various new usage scenarios. Examples for such scenarios include small-scale analytics, which can be performed offline on personal computers, and large-scale, often near real-time, big data analytics. This paper gives an overview of the novel BI approaches and associated BI solutions, proposes architectural dimensions used to classify these systems, and presents a feature comparison with respect to the proposed dimensions.

Keywords: BI architectures, Big Data, Real time BI, Streams

I. INTRODUCTION

Data warehouses (DWs) consolidate data from various sources during longer periods, and consequently tend to be orders of magnitude larger than operational databases (DBs). In the world of big data, the massive data sizes and huge creation velocities condition a shift in data warehousing techniques. While traditional data warehousing uses relational DBMS with periodical batch data loading and OLAP, big data analytics typically relies on alternative warehouse architectures and often requires minimal latency between data creation and data analysis. In such new circumstances, novel architectures are designed, and they include concepts such as data streams, in-memory engines, big data OLAP and out-of-the-box cloud BI solutions. The cloud BI approach enables smaller companies to perform analytics without having to acquire expensive equipment, but at the same time opens many questions regarding information ownership and data security. Query workloads have changed as well, adding the requirements for data mining and complex queries next to the traditional OLAP cube analysis. In this paper, we explore novel DW and BI tool architectures, as well as the various use case and architectural shifts undertaken by their vendors. We propose several architectural dimensions for the purpose of reasoning and classification. In the closing chapter, we bring a comparison of the surveyed software with respect to the proposed architectural dimensions.

II. ARCHITECTURES AND ARCHITECTURAL DIMENSIONS

A. Traditional DW architecture

The traditional approach to data warehousing includes a relational subject-oriented DB containing historical data in a star or snowflake schema and often a corresponding OLAP server (Figure 1). Operational data is transformed, and batch loaded into the warehouse using the ETL process. The ETL process pipeline detects changes inside the sources and adds new records to the DW to reflect them. Depending on the usage scenario, the batch loading can be performed frequently, e.g. daily, or infrequently, e.g. once a month. This approach lacks real-time capabilities, since ETL and OLAP cube pre-aggregation are resource intensive operations, which, without a specialized real-time architecture, must be performed in batch during hours of low system load. Extending DWs with real time partitions addresses these issues by splitting the warehouse into a large immutable storage containing most of the data, and a small real-time storage, called the real-time partition [1]. The immutable storage is optimized for reading, and often column-oriented, while the real-time storage is optimized for writing, and often row-oriented. Real-time partition data is periodically batch-loaded into the immutable store and emptied. These real-time modifications to the traditional architecture are not so common and are not additionally indicated in the Figure 1. They should be distinguished from real-time stream analytics described later that are vastly bigger in volume.

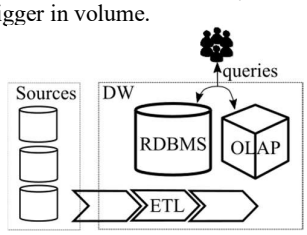

Figure 1. Traditional DW architecture

B. Big-Data/NoSQL architectures

Since traditional single-server RDBMS cannot handle big data volumes, in recent years traditional DWs are augmented and integrated with adjoining big data/NoSQL systems. There is a vagueness to the term big data system, as there is a myriad of technologies available today that claim the name, but most commonly, it involves a distributed (scalable) system like Hadoop. We call this the Big Data DW architecture (Figure 2): a traditional DW, big data system and integration layer supporting a more or less unified view of the data. Data lake, another vague concept that appeared recently also fits into this category.

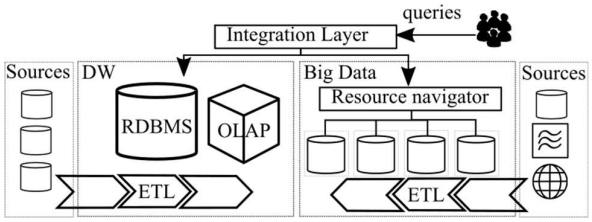

Figure 2. Big Data DW architecture

C. Serverless architectures

Personal computers are becoming more powerful and have increasing amounts of memory, which opens them up for in-

memory server roles for small and medium workloads. In this serverless architecture scenario (Figure 3), a user imports data from various sources to his or her computer, which features an in-memory query engine and analyzes the data, even offline if needed.

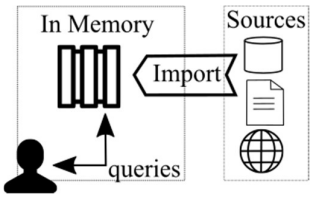

Figure 3. Serverless DW architecture

For instance, Tableau [2] can handle several hundred million of rows in this manner on a typical laptop. This approach potentially violates the single-version-of-truth premise in DWs but is a viable approach from the architectural point of view.

D. Stream architectures

Data streams are a relatively novel addition to data analytics. They are a series of individual data entries which come asynchronously in real time, and as such, are an integral feature of big data processing. As traditional data warehousing implies resource-intensive batch loading of data, the usage of data streams requires an updated architecture. Two common data processing architectures that support stream processing are commonly called the *lambda* and the *kappa* architecture.

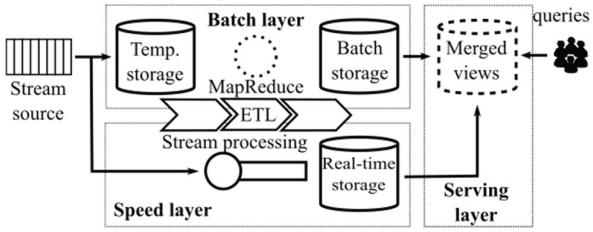

Figure 4. The lambda architecture

Lambda architecture [3] (Figure 4) splits the big DW into three layers. The *batch layer* contains immutable data optimized for fast reading. This constitutes most of the data, since batch loading is performed periodically, e.g. every few hours. Stream processing is performed through the *speed layer*, which ingests and processes the stream of data updates coming from the source and writes the results into a write-optimized temporary storage. Finally, the *serving layer*, which is tightly bound to the batch layer and maintains its indexes, receives queries, propagates them to the batch and stream layers, and integrates the results. This architecture treats the speed layer data as unreliable and removes it once its batch loading has finished. A significant disadvantage of this architecture is the need of maintaining two separate codebases, one for the batch and the other for the speed layer [4]. Kappa architecture [4] (Figure 5) uses the recent advances in stream processing to tackle the duplicate codebase problem in log analysis. It removes the batch layer and uses the data stream processing components' storage, which can be viewed upon as an immutable log, as the central data storage. In Kappa architectures, stream data are persisted for a longer period so that they can be reprocessed again. E.g. if the application logic (and code) changes, the streams can be rewound and reprocessed, and results again written into the serving DB system. The two architectures are not interchangeable and each of them has its own use cases. Some of the disadvantages of the kappa architecture are a lack of batch layer specific optimizations, and the requirement for a single data scheme in the system [5].

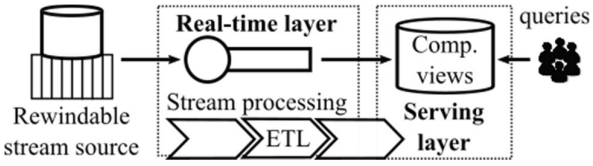

Figure 5. – The kappa architecture

E. DW Appliances

We give little attention to the DW appliances, as they are black-box solutions available to a limited number of users. DW appliances architecture consists of a single node (appliance) with a number of parallel customized storage and processing hardware components. However, if we consider the appliance as undividable unit, they fit in the traditional architecture.

F. Architectural dimensions

Through this survey, we found that all existing products fit into one of the coarsely defined architectures in this section. However, to be able to reason about and classify surveyed systems, we have identified several architectural *dimensions* that further distinguish those systems. The term "architectural" should be taken in a broad sense, as some of those dimensions are not architectural per se (e.g. "real-time") but rather have significant influence on the architecture or are a consequence of the architecture. We consider the following dimensions:

- **QPD**: Query Processing Distribution. Most DW systems are distributed in one way or another. For instance, even traditional DWs can process the ETL phase in a distributed manner, deploy cubes on multiple servers, use clustered RDBMS, etc. but what truly distinguishes DW systems is how query results are computed. If more than one node processes a query and the resulting data is gathered to form the final result – then we consider the system QP distributed. In non-distributed category, we distinguish the traditional single-server-processing approach and the serverless approach, where queries are processed on the client.
- **VI**: Volume Ingestion Capabilities. This feature speaks of processing capabilities with respect to data sources. A traditional DW typically extracts data from relational DBs, but, with proper adapters, it can accept data from any kind of source, even streams. The differentiator here is the volume of data. After a certain size, the traditional DW cannot handle the sheer data volume, and that is where big data systems step in with distributed file system persistence. Third option in this category are streams that might not be even permanently persisted.
- **MD**: In-Memory or Disk-based. DWs are a good use case for in-memory DB systems as durability is not really an issue here – data analytics is a read-only process. On the other hand, potentially big data volume presents a problem, but one that could be alleviated through horizontal distribution. Disk-based approach is, of course, the traditional and proven one.
- **Latency**. This dimension considers the latency between data ingestion and its availability for analysis. This translates to real-time or batch architectures.
- **QL**: Query Languages. QLs are closely tied to the data model and the overall architecture. Options in this dimension vary from limited proprietary functions and APIs, general

purpose programming abstractions (map-reduce) to SQL and OLAP as the most powerful options.

- **Scope**: There are many notable BI tools that are limited in scope to a certain task, e.g. a query processing engine that integrates other systems. Another example is "just" an OLAP server. On the other side of the spectrum are comprehensive platforms that include storage and query processing and corresponding tools.
- **Placement**: Lastly, placement dimension distinguishes deployment capabilities to three options: cloud, on-premise, hybrid and offline (serverless).

In the remainder of the document we bring an overview of modern DB systems and related technologies used in the DW context and provide a feature matrix of those systems with respect to the proposed dimensions.

III. PRODUCTS OVERVIEW

A. Stream Ingestion Platforms

1) Apache Kafka

Apache Kafka is a distributed streaming platform based on message processing, where data streams are represented as messages organized in custom topics [6]. Topics are further grouped into partitions. Each message, or record, contains a key, a value and a timestamp. The topics are stored in real time and retained for a specified period to guarantee message delivery. Each of the consumers maintains a topic offset, so that recent messages can be requested again in case of a system failure. Offsets can be tweaked to rewind the stream or read messages in a custom order. Kafka supports five APIs for message processing. Stream sources use the *Producer API* to feed data into the data streams by creating and dispatching messages within the applicable topics. Consumers use the *Consumer API* to subscribe to topics and retrieve the incoming messages in a fail-safe manner. The *Streaming API* enables the integration of intermediate stream processing components, which can process the streams in real time. The *Connector API* can be used to integrate external systems into the streaming platform. An example of such integration is adding listeners to a compatible DB system to produce a stream of data update events. Finally, the *AdminClient API* is used to inspect and manage the various Kafka objects. Each process can be configured to process a different set of partitions. The system guarantees that the ordering of produced messages will be maintained until delivery. Topics can be replicated for fault tolerance.

2) Apache Flume

Apache Flume is a distributed, reliable and available service for efficiently collecting, aggregating, and moving large amounts of log data from many different sources to a centralized data store [7]. Although it was developed with the gathering of log data in mind, Flume can be used for various stream processing purposes. The basic unit of a Flume data stream is a Flume event, which consists of a binary payload and several string attributes. The system is composed of agents, JVM processes hosting components used for stream propagation. There are three types of components, sources, channels and sinks. Sources receive data from external data sources and are specific to those sources. Sources store the received events to one or more channels. Channel types are dependent on the underlying storage medium. The reliability of the system is channel type dependent, with memory channels being much faster than file channels, but at the same time posing greater risks for data losses. Sinks read events from the channels, and propagate them to compatible external systems, such as HDFS files or adjacent Flume agents. Complex data flow configurations that include fanning in and out are supported as well. While Kafka offers superior data availability guarantees to Flume, it also requires a large-scale customized deployment [8]. Flume supports integration with various sources out-of-the-box.

3) Amazon Kinesis

Amazon Kinesis, a product within the Amazon Web Services, is a cloud based streaming platform. Each data stream is composed of base throughput units called shards [9]. Kinesis and Kafka are similar products and share many of the inner workings [8]. While the latter is fast and free, it requires the organization to build an enterprise-class solution. Kinesis provides an out-of-the-box solution with comparable features and scalability inside a package priced according to the required resource usage.

B. Stream Processing Engines

1) Apache Spark – Spark Streaming

Spark is a framework that presents a data abstraction for big data analytics, called resilient distributed dataset (RDD) [10]. RDDs support operations called transformations, which are applied to the entire dataset and result in new RDDs. They also possess a persistence model, which can persist datasets in memory, disks, or both, and a light-weight fault-tolerance mechanism which makes it possible to recreate RDDs from their dependent RDDs by using transformation logs (i.e. *lineage*) [11]. Spark Streaming is a micro-batch stream processing engine that runs on top of the Spark framework. The incoming stream records are grouped into small continuous batches over which operations are performed. A data stream is abstracted into a Discrete Stream (*DStream*) structure that internally creates and uses a series of continuous RDDs [12]. Spark Streaming supports RDD transformations as well as stream-specific operations for stream processing, resulting in new *DStreams*. Streams can be filtered, mapped, aggregated, repartitioned for better parallelism, combined with other streams, etc. Another supported feature are the window operations, which allow users to perform operations over a sliding window of data [12]. Once the desired transformations have been performed, the resulting stream can be propagated to external systems, such as HDFS or DB systems, using the *DStream* output operations. As noted in [10], the batching introduces a latency of several seconds, depending on the chosen batch time interval. This latency must be taken into account when designing systems relying on Spark Streaming. Spark Streaming supports only "exactly once" data processing mode and shares the same code base with Spark batch processing components, enabling code reusability [13].

2) Apache Storm

Storm is an open source distributed stream processing engine. Inside Storm, streams are represented as unbounded sequences of data tuples with dynamic fields. They are processed using continuously running jobs called topologies, which are graphs of spouts and bolts connected with stream groupings [14]. Spouts read external data sources and emit them into the topology, while bolts perform operations over the incoming data and emit the results. Bolt operations encompass filtering, aggregation, joins, DB access, etc. After the stream operations have completed, bolts push the data to external stores and services [8]. The author in [13] gives a feature comparison of Spark Streaming and Storm. Storm operates with lower latencies than Spark, and in addition to

"exactly once" data processing mode, it also supports "at least once" and "at most once" modes, but does not offer code reusability nor does it support batch processing [15].

3) Apache Flink

Apache Flink is an open-source distributed stream processing framework [16]. It guarantees the "exactly once" processing mode and high data availability, while it also allows "at least once" processing mode. The Flink streaming dataflow consists of a directed acyclic graph which starts with data sources, contains transformations, and ends with data sinks. Sources can be batch connectors, which read data from file systems, e.g. HDFS, or DB systems, e.g. MongoDb, and streaming connectors for data streams. Transformations can include simple operations, aggregations, iterations and window operations. Sinks forward the data streams to external systems. The data flow and system state reside inside the main memory, whose performance was improved by replacing the standard JVM garbage collector with a custom memory manager. Fault tolerance is achieved through continuous creation of lightweight data flow and state snapshots, but a complete recovery requires the stream ingestion platform to support rewinding. Unlike Spark, which is based on micro-batches and employs batch processing for stream processing, Flink is based on true data streams, employing item-to-item processing, and treats batch processing as a subset of stream processing [17]. The authors in [15] concluded that Flink achieves much lower latencies and better performance, and has better customer support.

C. Big Data Query Tools and OLAP engines

1) Apache Hive

Apache Hive [18] is a query engine specialized for performing SQL batch operations over data stored in HDFS. It supports a subset of SQL called HiveQL. SQL queries are internally executed using MapReduce jobs. HiveQL does not support editing existing tables, but it can create new tables for storing query results. Hive can read various file formats, as well as use custom (de)serialization. Trough HiveQL, data sources are accessed as if they were relational tables and their metadata is stored inside a specialized data repository called the Hive Metastore or HCatalog (residing in relational DB). Clients can connect to Hive using ODBC, JDBC or Thrift API. As MapReduce jobs require large amounts of resources and coordination, and write and read all intermediate results on the disk, Hive cannot be used in near-real-time BI. Nevertheless, Hive is still used in large organizations such as Yahoo and Facebook [19] to run complex queries or to build aggregations over the Hadoop data for usage in external DWs.

2) Apache Impala

Impala [20] is a SQL query engine specialized for performing analytical queries over data stored in HDFS. It supports the same SQL subset that Hive supports and uses metadata from external catalogs, such as the Hive Metastore. Like Hive, it supports client connections through ODBC and JDBC API. Unlike Hive, it circumvents MapReduce jobs and uses its own distributed query engine, described in [21], for query execution. This removes the heavy MapReduce infrastructure and excessive disk access, and consequently reduces the query latency by an order of magnitude. Impala services are distributed over the Hadoop cluster to make use of data locality and minimize the volume of required network communication.

3) Apache Drill

Apache Drill [22] is a SQL query engine that supports various structured and semi-structured data sources, including local files, HDFS files and NoSQL DB engines. It supports the ANSI SQL:2003 standard and includes extensions for JSON data manipulation [23]. Drill nodes, called *Drillbits*, are distributed over the Hadoop cluster to make use of data locality and avoid unnecessary network communication. Queries are received through Zookeeper and sent to the first available *Drillbit*, which then acts as the node in charge and distributes them to other *Drillbits*. At this point, queries can be pushed into the underlying storage engines using the Drill storage plugins and are converted to their native query languages in the process. Finally, all nodes send query results back to the node in charge, which then performs the final processing and returns the results to the user. Metadata regarding the external data sources is dynamically built during query execution and cached in the *Drillbits'* distributed cache. Client connections are supported through JDBC, ODBC and REST API.

4) Kyvos Insights

Kyvos Insights [24] is a Big Data OLAP engine built on top of the Hadoop infrastructure. The OLAP cube is stored in a proprietary format [25] within HDFS and supports incremental building [26]. The engine supports MDX queries as well as SQL and is compatible with all major BI tools. As the aggregates can be stored in the same Hadoop cluster that contains the original data, the engine enables drilling down to the granularity of individual fact records [19]. The system's distributed architecture consists of query engines and OLAP engines. Kyvos ETL module enables specification of the data transformation process through a visual designer and can include a plethora of semi-structured and external data sources. A benchmark performed by the Barclays Investment Bank [27] has shown that Kyvos Insights, due to the pre-aggregation and incremental cube building, performed analytical queries with much lower latencies than Impala or Spark when confronted with large numbers of concurrent users.

5) AtScale

AtScale Intelligence Platform [28] is a big data OLAP engine that aims to avoid ETL and builds a virtual cube (vROLAP) directly above the original data storage. However, the users still must describe a mapping of the target data to a relational star schema using the system's designer component. The AtScale cube is virtual because it does not contain data. Instead, it describes how to process and optimize the data at query runtime [29]. Aggregate tables are built and maintained dynamically when demanded by queries, but if required, can also be manually overridden and created in advance. They are stored using the underlying storage engine, e.g. HDFS. The system is installed on a single node in the cluster, called the gateway node, and makes use of the already present distributed infrastructure to push queries towards the data. AtScale supports the integration of various big data sources, such as Hadoop, Google BigQuery, Microsoft HDI, and Amazon Redshift, containing both structured and unstructured data, as well as the major BI tools, like Tableau, Qlik View, etc. It exposes OLE DB, ODBC, and JDBC endpoints, and can be queried using SQL and MDX.

6) Apache Kylin

This system [30] is an open source distributed OLAP engine for Hadoop. It incorporates a wizard for building MOLAP cubes using Hive tables. The wizard also supports incremental cube building. Cubes are built using a series of MapReduce jobs and the resulting cube segments are stored in

HBase according to the specified partitioning configuration [31]. Kylin also supports an experimental streaming cubing feature for building cubes over streaming data sources, such as Kafka, which can periodically (e.g. every 5 minutes) perform micro-batch incremental cube builds [32]. The system consists of distributed stateless Kylin instances connected to an HBase table called the Metadata Store. The metadata store contains table schemas, job status, cube status, etc. Instances can be configured to run in job mode, for running jobs, query mode, for running queries, and both. To achieve load balancing, users must manually deploy a load balancer in front of the system. Kylin supports ANSI SQL queries and exposes ODBC, JDBC and RESTful API endpoints. It is compatible with most major BI tools, such as Tableau, PowerBI and MicroStrategy. The RESTful API enables straightforward integration with web applications and mobile apps.

7) Splunk

This data integration platform [33] allows users to index and analyze data from various sources. Real-time analysis can be used to trigger actions, e.g. for security breach detection. The distributed system consists of three types of nodes, forwarders, indexers and search heads. Forwarders collect data from sources or other forwarders and forward it to other Splunk nodes. Because of their low resource footprint, they can reside directly on the machines containing the source data. Indexers perform indexing queries over the data and store the indexes, which is the most resource consuming activity in the system. An indexer cluster consist of a master indexer node, which manages the cluster, peer indexer nodes, which index, replicate and search the data, and search heads, which coordinate searches. Indexers store the raw data in a compressed format and create proprietary index files. If low-latency is required, the users can configure summary indexing, which creates summary indexes above the original indexes. Splunk offers high platform extendibility, and users can write their own plugins. A component called Splunk Stream [34] enables data stream ingestion and processing. Splunk can be installed on-premise or on the cloud and consists of indexer clusters and search head clusters. Queries can be made using the system's REST API.

D. Analytical DB Engines and BI tools

1) Druid

Druid [35] is a columnar distributed shared-nothing DB engine specialized for log data analysis. It was developed to support the Metamarkets product, which, when confronted with thousands of concurrent users, required sub-second query latencies to show interactive visualizations. The authors at the time concluded that no existing NoSQL or relational DBMS was up to the task. The system consists of real-time, historical, broker and coordinator nodes. Real-time nodes consume a stream, e.g. from Kafka, and incrementally build a row-oriented in-memory buffer. The buffer is periodically persisted to the disk, where the data is column-oriented. The data from the disk is then periodically collected into segments and stored to the *deep storage*, such as HDFS. Historical nodes load and serve the segments contained within the *deep storage* and can be grouped into tiers with different performance requirements. Coordinator nodes manage the distribution of data segments in the cluster for which they use a MySQL DB, containing the configuration and metadata, and Zookeeper. Broker nodes receive queries, forward them to real-time and historical nodes, and collect the results. They also maintain a LRU query result cache for historical nodes. Druid data can be accessed through a JSON query API, which supports filtering and aggregations. Joins are not supported, but star joins can be simulated using lookups. SQL is supported through a built-in layer called Druid SQL which translates SQL queries into the JSON-based queries.

2) Exasol

Exasol is a hybrid In-Memory distributed analytical DBMS [36]. Its physical data storage stores the data on the disk but tries to mimic a pure In-Memory DB by assuring that the data will be inside the main memory when needed [37]. This is achieved using innovative pre-fetching algorithms on all memory levels. The data is replicated without user intervention, while partitioning can be defined with *DISTRIBUTE BY* clause. The system automatically builds and maintains distributed indexes and statistics, and requires minimal technical user intervention. SQL can be extended with user defined functions supporting the Map-Reduce model. To minimize the network traffic and latency of distributed joins, smaller tables are replicated on all nodes. Another feature is the Skyline operator which finds a set of all optimal answers for decision problems depending on various criteria. Older data is stored column-wise to improve query performance and compression, while newer data is stored row-wise for fast inserts and updates. External data sources, such as Hadoop, can be mapped using virtual schemas and used in queries, or bulk loaded. Clients can connect to Exasol using ODBC, JDBC, MDX, ADO.NET, or data mining packages for programming languages such as R, Python, Lua and Java.

3) Amazon Redshift

Amazon Web Services (AWS) feature a petabyte-scale cloud DW called Amazon Redshift [38]. Redshift is a distributed column-oriented data store, based on the relational row-based PostgreSQL DBMS. A Redshift cluster consists of several compute nodes, which reside in the internal network and contain the data, and a leader node, which receives queries and manages their execution in the cluster [39]. The system also contains a component called Redshift Spectrum, which

	QPD	VI	MD	LLat	QLat	QL	Scope	Placement	License
Hive	D	B	D	N/A	h/m	SQL	QPE	Hadoop	Apache v2.0
Impala	D	B	D	N/A	m/s	SQL	QPE	Hadoop	Apache v2.0
Drill	D	B	D	N/A	m/s	SQL	QPE	Hadoop	Apache v2.0
Kyvos	D	B	D	Batch	s/ms	MDX, SQL	OLAP	OP, C, Hadoop	Proprietary
AtScale	N	B, S	D	Batch, RT	s/ms	MDX, SQL	OLAP	Hadoop	Proprietary
Kylin	D	B, S	D	Batch	s/ms	SQL	OLAP	Hadoop	Apache v2.0
Splunk	D	B, S	D	Batch, RT	m/s	SPL	SE/QPE	OP, C	Proprietary
Druid	D	B, S	D	Batch, RT	< s	JSON, SQL	DBMS	OP	Apache v2.0
Exasol	D	B	H	Batch, RT	< s	SQL, MDX	DBMS	OP, C, H	Proprietary
Redhift	D	B, S	D	Batch, RT	m/s	SQL	DBMS	C	Proprietary
Tableau	S	B, S	IM	Batch	< s	N/A	BI tool	OP, C	Proprietary

Table 1 - Overview of the surveyed systems; QPD: D = Distributed, S = Serverless, N = Single server; VI: B = Big data sources, S = Streams; MD: IM = In-Memory, D = Disk-based, H = Hybrid; LLat = Load latency, RT = Real-time; QLat = Query latency; Scope: QPE = Query processing engine, SE = Search engine; Placement: OP = On premise, C = Cloud, H = Hybrid, Hadoop – depends on the underlying Hadoop deployment

enables running SQL queries on semi-structured data from the S3 distributed file system. Data streams can be ingested and loaded using the Kinesis Firehose. Redshift is well integrated with AWS ETL tools and client applications, as well as the major third-party BI tools, and exposes ODBC and JDBC endpoints that support a subset of SQL.

4) Tableau

Tableau is one of the major BI platforms on the market, which offers advanced visualization capabilities and provides connectors for numerous types of data sources out-of-the-box [40]. Since version 6, the Tableau server uses a hybrid In-Memory column-oriented storage system to provide fast query answers required for interactive visualizations [2]. Because of high compression rates offered by column stores, Tableau can store billions of rows of data locally, and hold a significant portion of them inside the main memory. The engine still offers direct connections to high-performance and real-time data stores. This redundant architecture can be used to perform offline data analysis on the client machine, an approach like the much older Microsoft's offline cube files, described in [41].

IV. Conclusion

There are more options available today than ever before in structuring the BI architecture and choosing the corresponding software. While this opens numerous opportunities, it also presents a demanding task of navigating through the vast supply of BI or BI-related systems, which can be a time-consuming and complex endeavor. In this paper, we propose architectural dimensions used to classify and reason about these systems and give an overview of the most notable systems. A comparison of the surveyed systems according to the proposed dimensions is presented in Table 1. Considering the BI project requirements, Table 1 gives a good starting point for the design and choice of technology of the future BI system.

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NoSQL document store translation to data vault based EDW

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***Abstract* - With evolution of technology and Web 2.0 tools NoSQL stores appeared as a common solution to data storage and management demands in modern databases and applications. Relational databases were not designed to cope with agility challenges, scale, commodity storage and processing power demanded by modern applications. Many industries today are choosing NoSQL database technology over relational databases (or at least combining them) in order to gain needed flexibility and scalability. Due to the limitations of relational databases, most researchers are oriented toward relational database transformations and data migration to different types of NoSQL stores. Our research goes in the opposite direction – we aim to develop a metamodel for translating a NoSQL document store (MongoDB) into a data vault based enterprise data warehouse. The reason we do so is to integrate different data sources into a data vault central repository and develop a new data warehouse system catalog that will track changes in both relational and NoSQL schemas. The integration of relational database and NoSQL store would help extract wider knowledge through BI tools, enable data traceability, trend discovery and will accommodate auditing process. The main contributions of this paper are translation rules that accommodate the translation between NoSQL MongoDB document store and data vault based enterprise data warehouse.**

Keywords – NoSQL; data vault; data warehouse; relational database; metamodel; translation rules; system catalog

I. INTRODUCTION

Relational databases have been in use for decades as a first choice for data storage. They are based on the relational model, defined by its schema. In practice, this rigid schema is not convenient for storing different application data [1]–[3]. Followed by the phenomena of Big Data, new requirements have emerged over the database design and relational stores cannot cope with it.

NoSQL stores provide a different mechanism for storing and retrieving data. They adapt well in changing environments, with their flexible schema and scale-out properties. NoSQL covers a large variety of different systems that can be classified into four basic types: key-value, column-oriented, document and graph-oriented systems. Each of them follows its specific data model in order to organize, store and query data. The problem with the variety of models is a large number of specific systems for different models and within the same model. In this paper the focus is on a document store model, more specifically a MongoDB document model.

Because of the properties previously mentioned, NoSQL stores became valuable not only in database environments, but in data warehousing as well. Business organizations see potential of extracting information from all corporate data, not only transaction (relational) data stored in (and around) their information systems.

Data warehouses cope with another problem, integrating all those data coming from relational databases and NoSQL stores so that new corporate values could be extracted. This is the main focus of our research and a small part of it is addressed in this paper. We aim to develop a data warehouse system with the ability to query relational and NoSQL data as well as to integrate, store and preserve history of all the corporate data and their changes into a single system of records [2]–[4]. We use a data vault model to design our data warehouse, and some common features of the model will be explained bellow. The main contributions of this paper are translation rules that accommodate the translation between NoSQL MongoDB document store and data vault based enterprise data warehouse. This translation rules will be used to build the metamodel and will provide a base for the integration process.

The rest of this paper is structured as follows: Section 2 briefly presents related work in migration and integration of NoSQL stores; Section 3 shortly describes the two main models used in defining our translation rules: NoSQL MongoDB document model and Data Vault data warehouse model; Section 4 presents the translation rules between source model, MongoDB document model, and destination model, Data Vault data warehouse model; finally, Section 5 includes conclusions and some guidelines for our future research.

II. RELATED WORK

There are two major approaches found in related research: migration approach between NoSQL and relational database management system (RDBMS) that mostly goes in the direction RDBMS to NoSQL and the metamodel approach. Besides those two, there is some research of data migration between NoSQL stores, but it is out of the scope of this work.

Most of the research is oriented on migration between RDBMS and some type of NoSQL stores [5]–[13]. The

process usually starts with determining specific blocks of RDBMS and then mapping them with their destination entities.

In [8] authors present a comparison between two migration processes, one based on the traditional heuristic approach and the second one using guidelines created by the authors.

In [5] authors present the NoSQLayer, a framework that supports migration from RDBMS (MySQL) to NoSQL (MongoDB). The framework consists of two parts: data migration module for metadata extraction and migration of data in the NoSQL store, and data mapping module that provides an abstraction layer between the application and the RDBMS.

Authors in [7] propose an automatic SQL to NoSQL schema transformation mechanism carried between the MySQL database and NoSQL HBase store. The authors read MySQL metadata and use Primary and Foreign Keys to concatenate the associated columns with the keys in HBase column model.

Work done in [6] presented a preliminary approach that aims to translate Web data between heterogeneous formats. This translation uses XML representation of data and is derived by the combination of predefined functions that perform XML transformations.

Apache developed Sqoop [10], a tool for transference of bulk data between a RDBMS and Apache Hadoop. The tool is designed to transfer data in both directions, from RDBMS to Hadoop and vice versa.

In [9] authors propose relational database to document NoSQL (MongoDB) schema conversion model. Author propose a general migration program and related algorithms based on the used nested method. Nested mappings are also used by authors in [13], where they presented a heuristic approach for transforming a relational database into a NoSQL HBase store.

A new methodology for migrating RDBMS data to NoSQL store is presented in [11]. The methodology follows two main steps: the logical structure of source database (RDBMS) is loaded and then the mapping process is defined between relational model and MongoDB.

Stanescu et al. [12] have shown an algorithm for automatic mapping between relational database and MongoDB NoSQL store. The algorithm uses relational database metadata in the mapping process.

Another approach in research is the metamodel strategy used in [14]–[18].

A series of articles presented a methodology to NoSQL database design called NoAM (NoSQL abstract model) [14]–[17]. NoAM is an intermediate, system-independent, abstract data model for NoSQL stores that exploits common elements available in different NoSQL systems and introduces abstractions that balance these differences. The NoAM approach is seeing the application data as aggregates [19], [20]. Aggregates are a group of related objects with complex structure and value, representing a unit of data access. Authors from [21] presented and interesting approach in data modeling aggregate data. They developed a support data modeling style using three new operators (ROOT, REFI and EMBED) with the Idef1X modeling language and for aggregate-oriented NoSQL stores (Key-Value, Document and Column NoSQL stores).

Author in [18] presented an original approach that permits data migration between NoSQL stores, each one with its own data model. The migration framework is composed of an intermediate data representation, JSON format, that is sliced and represented in a metamodel.

In Table I is given a complete overview of databases used in different approaches of database migration stated in related work. The table includes a research summary in migration between relational database and NoSQL stores and a different approach using a metamodel. The metamodel approach is not so represented in the research; it is mostly used in migration between different NoSQL stores.

Besides the two mentioned approaches in migration between relational database and NoSQL stores, some application might need to use different databases simultaneously. This is often referred as polyglot

TABLE I. THE SUMMARY OF RELATED WORK

Authors	Relational database	Key-value store	Column store	Document store	Other
Migration from relational database to NoSQL store					
[8]	●			●	
[5]	●			●	
[7]	●		●		
[6]	●		●		
[9]	●			●	
[13]	●		●		
[11]	●			●	
[12]	●			●	
Metamodel approach					
[14]–[17]		●	●	●	●
[18]		●	●	●	●

persistence [22], [23] and major database providers, like Oracle [24] and Microsoft [25], which are adapting to those needs by developing management systems that provide integration and access to all the data – through data stored in relational databases up to different types of NoSQL stores.

III. DATA MODELS

A. Mongo DB document model

MongoDB is one of the most popular open-source document databases that provides the most common characteristics of NoSQL stores: high performance, availability, and automatic scaling. Since there might be present some differences between document NoSQL stores, we will focus on MongoDB data model and define translation rules for this specific database.

Thorough the paper, the MongoDB document data model is an integrated conceptual and logical model. Since this is a new age database concept, there is no clear division between conceptual and logical level, as it was in relational databases.

MongoDB document model has the following entities: database, collection, document and field. A table from relational database terminology is a collection and a record in MongoDB is a document, which represents a data structure composed of field and value pairs (similar to key-value pairs in key-value NoSQL databases). The values of fields may include other documents, arrays, and arrays of documents.

The main advantage of using documents as objects is their correspondence to native data types in many different programming languages, reduction of joins due to the embedded documents and arrays as well as the dynamic schema.

Nowadays data is often represented as JSON [26] documents instead of tables, because of the complex structure of data. JSON is an acronym to JavScript Object notation and it is a standard format for data expression. Each JSON document is an object enclosed by curly braces { } and each name or key is separated by a colon ":" and the sequential or subsequent values are separated by a comma "," [18]. MongoDB stores BSON (Binary JSON) documents (data records) to represent data. BSON extends JSON and additionally includes data types as *long*, *int* and *floating point*.

B. Data Vault

The Data Vault is a hybrid data modeling methodology providing historical data representation from multiple sources designed to be resilient to environmental changes. It was developed by Dan Linstedt in 1990 and released in 2000 as a public domain modeling methodology. The Data Vault design is scalable, consistent, and adaptable to changes and to the needs of the enterprise [27].

The Data Vault 2.0 is an improvement of the previous Data Vault 1.0, and its three-layer DW architecture provides an integration of NoSQL store systems through staging area.

The main entities used in the Data Vault model are: hubs, links and satellites [27].

- Hubs contain business keys that refer to business objects, there are hubs for each type of business key.
- Links establishing relationships between business keys (typically hubs), and they always represent an M:M relationship. Links are often used to deal with changes in data granularity.
- Satellites provide descriptive attributes that can change over time.
- Reference tables are also a type of entity. They contain data that is commonly used to give context and describe other business keys, such as standard codes and descriptions or classification of information [27].

Hubs and Links form the structure of the data model while Satellites contain temporal and descriptive attributes including metadata, linking them to their parent Hub or Link tables. Satellites metadata contains a date the record became valid and a date when expired, which provides great historical capabilities.

While modeling MongoDB data model we must think about the application needs, performance needs and data retrieval pattern. The focus is on application usage of data, not the user usage as in the case with relational databases. Since the nature of NoSQL stores and MongoDB store itself is to store denormalized data in order to gain high performance results, reference tables will not be considered in our integration process and it will be put aside for future work.

The Data Vault is both a data modeling technique and methodology which accommodates historical data, auditing, and tracking of data.

Data vault model and MongoDB document model have some common features; they are both very scalable (horizontally and vertically) and adaptive to changes in fast-changing environments. With their flexible schema, they accommodate user needs on one side (MongoDB) and business needs on the other side (Data Vault) as well as the evolution of data on both sides.

IV. TRANSLATION RULES

In this paper we present the initial set of translation rules. The translation rules explained and defined in the following section will be used in the integration process in order to develop a new data vault based enterprise data warehouse system catalogue that tracks changes in relational and NoSQL data sources. Figure 1 shows a part of the metadata data vault model with two main parts (nodes), partly available in [28], [3], [29]: data sources (DS_Node) and data vault based enterprise data warehouse (DV_Node).

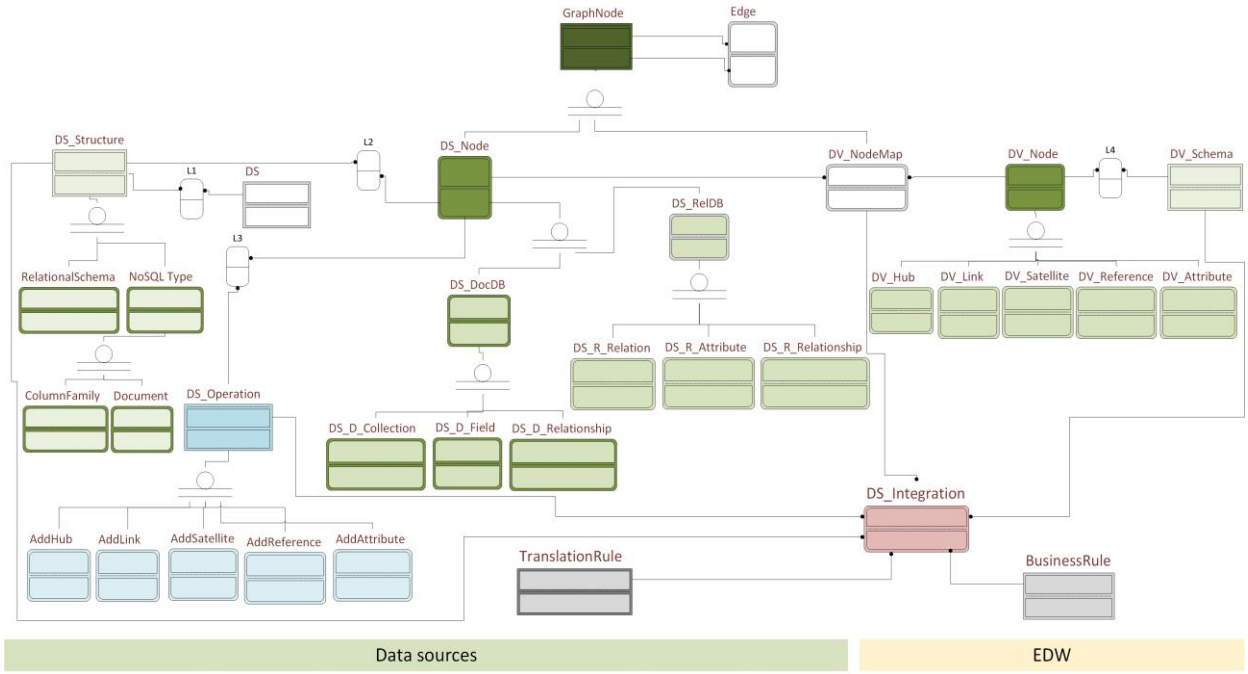

Figure 1. A part of the metadata data vault model with 2 main parts (nodes): data sources (DS_Node) and data vault based enterprise data warehouse (DV_Node) [28]

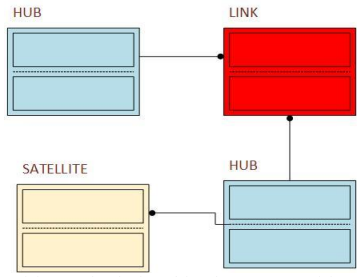

Figure 2. Entities and relationships between entities in the Data Vault model

Translation Rule 0: ***MongoDB collection is translated into a set of hubs, links and satellites.***

A MongoDB document database consists of collections of documents, which can be compared to tables in relational database terminology. Thus, collections are the starting point and they need to be translated into a set of Data Vault concepts as hubs, links and satellites (Figure 2).

Let's consider now the main object of MongoDB document model, a document presented as JSON object. A document is composed of field and value pairs. The following JSON object example shows a simple document containing only a few field-value pairs, as shown in Figure 3:

```
student document
{
        _id: 5263259625,
        name: "Ana",
        surname: "Anic"
}
```

Figure 3. A student document example

Translation Rule 1 (TR1): ***each document id is translated into a hubID (business key), while the HashKey of the hub is calculated and added to the hub.***

Each document has its unique _id field, generated automatically or created by the user. It is like a primary key in relational database terminology. This _id uniquely defines each document so it is translated into a hub in the DV model (Figure 4). The rest of the document data, field and value pairs (name and surname fields in our example), are considered as descriptive data and translated into a satellite entity (Figure 5). Document field can be compared to columns in relational model and values are actual data in the intersection of row and column.

Translation Rule 2 (TR2): ***the non-id fields of the document are translated as attributes of the satellite entity where the value of the satellite attribute is the value part of the document.***

Beside descriptive data, satellites use the *LoadDate*, *RecordSource* and *LoadEndDate* metadata attributes. *LoadDate* attribute is the time the record was introduced in the data warehouse for the first time. *LoadEndDate* indicates when the satellite becomes invalid and it is the only attribute updated in the satellite. *RecordSource* is the key attribute used in auditing and indicates the master data source. The *HashDiff* attribute is an optional attribute and

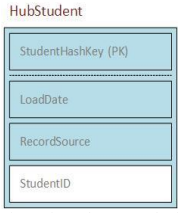

Figure 4. A hub entity after the translation (TR1) from the student document

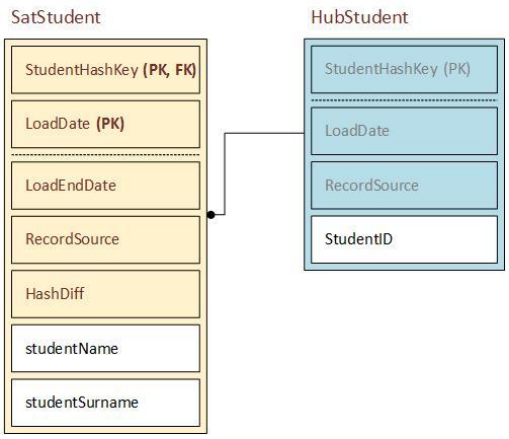

Figure 5. The data vault model after the TR2 applied on the non-id fields of the student document

is used for speeding up lookups on the satellite by comparing the row differences [27].

Considering the collection of documents, there might be present connections between documents. The relationships between documents can be represented in two ways: through *references* or *embedded documents* [30].

References store the relationships between data by including links or references from one document to another [30]. They are known as normalized data models that represent M:M relationships and are more flexible than embedding.

We can extend our previous student document so that it is referenced by the contact document, as shown in Figure 6:

student document	contact document

{
_id: 5263259625,
name: "Ana",
surname: "Anic"
}
	{
	_id: 222333,
	student_id: 5263259625,
	phone: "9913659632",
	email: "aanic@mail.com"
	}

Figure 6. Student document referenced by the contact document

Translation Rule 3 (TR3): ***a document reference to another document is translated into a Data Vault link entity connecting the current hub (document) and the parent hub (referenced document).***

With the presence of the referenced document (_id value), the current hub - *HubContact*, is connected through link entity with the parent hub - *HubStudent* (Figure 7).

Another way of connecting documents is through embedding documents where the related data is embedded into a single structure or document [30]. In this way, the application has access to one piece of information in the same database record with only a few queries. This type of relationship is common in denormalized models and they represent 1:M, M:1 and 1:1 relationships.

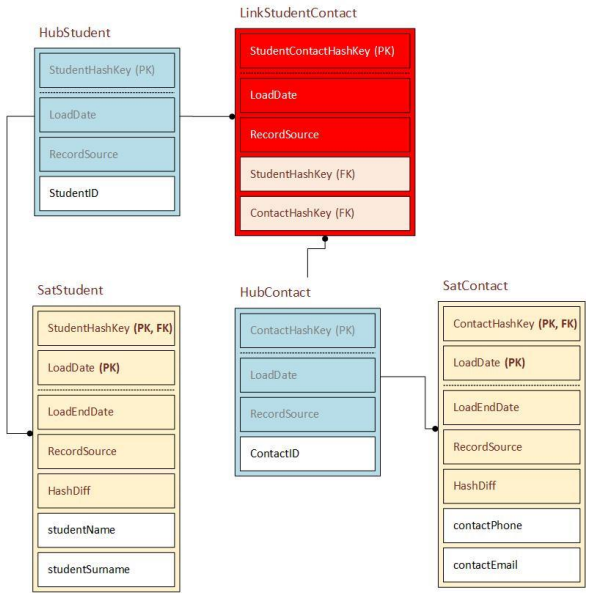

Figure 7. The Link entities translated from referenced document connections in the contact document

Modifying the previous example to use embedded relationship, we get the document presented in Figure 8:

```
student document
{
        _id: 5263259625,
        name: "Ana",
        surname: "Anic"
        contact: {
                phone: "9913659632",
                email: "aanic@mail.com"
        }
}
```

Figure 8. Student document extended with embedded relationship (*contact*)

Translation Rule 4 (TR4)*: an embedded document is translated into a DV satellite entity connected to the current hub (parent document). In that case TR1 – TR3 are applied accordingly.*

The nature of DV link entities is to represent M:M relationships, and since the embedded document relationship is used for retrieving the set of data in a single database operation and contains only non-key fields, TR2 is applied - they become part of the satellite entity as descriptive data of a single hub (document).

In case of an array structure in document object, the array element must be translated according to previously defined translation rules and depending on the used relationship.

V. CONCLUSION

In previous chapters of this paper we have given an overview of related work in mapping and metamodel approach of migration and integration of NoSQL stores. The related work is mostly oriented in translating different

NoSQL stores into a relational model while the metamodel approach is not so frequent but it is a direction we aim to focus in our future work.

Furthermore, we have shortly described the model used in formation of our translation rules, NoSQL MongoDB document store model and Data Vault data warehouse model with its relevant entities.

We presented an initial set of transformation rules that will be used in the integration process in order to develop a new data vault based enterprise data warehouse system catalogue that tracks changes in relational and NoSQL data sources. The initial set of transformation rules is developed for NoSQL MongoDB store and data vault model and it includes five rules in total. On the source model side, a document is observed as a JSON objects and its elements (_id, field-value pairs and two different types of relationships) are translated into data vault entities (hub, link, satellite). The simple example is used in order to visualize the proposed rules.

The limitation of this research is that includes only one model (MongoDB document store) with its particular JSON object. In our future research we intend to expand our rules on NoSQL columnar store type. This initial set of transformation rules will be broaden when more complex test case scenarios are defined. As a next step, we intend to formalize this initial set of rules in order to develop a system metamodel which will serve as a base for our integration process and the associated system catalog.

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Self-Organizing Maps for Fraud Profiling in Leasing

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***Abstract* - Fraud is intended and planned activity aimed at achieving material or immaterial gains against interests of an organization or a person. It often occurs in financial industries, such as banking, insurance, and leasing. The goal of this paper is to present a novel approach to profiling fraudulent behavior in leasing companies, using self-organizing maps. Dataset of one leasing company that consists of both fraudulent and non-fraudulent transactions has been analyzed. Cluster analysis has been applied using the self-organizing maps algorithm, with the support of Viscovery SOMine software. Five clusters were identified, that have a different structure according to an industry of the client, previous experience with a client, type of a leasing object, and status of a leasing object (new or used). The clusters were compared using chi-square test according to proportion of fraudulent and non-fraudulent transactions, resulting in profiles of clients and leasing objects that are more prone to fraudulent behavior.**

Keywords – fraud; leasing; self-organizing maps

I. INTRODUCTION

The focus of this paper is frauds and defaults in leasing industry committed by clients. According to the Basel Committee [1] frauds are "losses due to acts of a type intended to a defraud, a misappropriate property or a circumvent regulation, a law or a company policy which involves at least one internal or third party", where former denotes internal and later denotes external fraud. External fraud can be committed by a customer or a supplier. Internal fraud can be committed by an employee in a front office, an employee in accounting, back office and so on. In reality, fraud is occasionally a mixture of both types.

Leasing industry is suspected of a high risk of fraudulent behavior. Understanding of circumstances, conditions and repercussions of fraud in leasing industry is therefore of high importance. Frauds committed by a third party often happen due to financial problems and opportunities due to omissions in procedures.

Two fraud scenarios that describe a client act are (i) intentional fraud and, (ii) refusal to return a leasing object. Leasing companies are not able to contact a client or trace an asset if fraud is intentional. When a client refuses to return a leasing object, a leasing company can contact the client and knows the location of the leasing object. However, due to a client refusal based upon different explanations, regaining or repurchase of a leasing object is not possible without a struggle. For this purpose, we will define term fraud as every act of a client that results in decreased possibility to regain a leasing object or a payment during collection.

When it comes to fraud management, leasing companies need to be aware that business environment is highly dynamic. Fraudsters change their strategies to be ahead of leasing companies and regulators, so leasing companies need to take actions to prevent frauds by investing in data analytics and artificial intelligence for fraud detection as much as possible.

Data analytics solutions and built-in fraud detection algorithms can handle large amount of data and discover patterns which also can be visualized in an easily understandable format. A useful method is clients' segmentation and profiling based on their demographic characteristics, behavior patterns, a risk profile, and so on. For this purpose data generated from various sources, including corporate data such as clients' database can be used. This way a leasing company can analyze transactions, recognize and predict a fraud/default happening, and develop an appropriate response system for fraud specific patterns noticed.

Fraud and default detection and prediction systems are based on different data mining methods. Some of the standard data mining methods used for financial fraud detection are neural networks and clustering methods such as self-organizing maps.

Here are some examples of applications of neural networks for researching frauds in insurance and finance. Gómez et al. [2] and Dorronsoro et al. [3] used neural networks for fraud scoring in card payments and operations. Zakaryazad and Duman [4] used neural networks for fraud detection on real-life data sets about bank's direct marketing. Viaene et al. [5] explored "capabilities of neural network classifiers for personal injury protection in automobile insurance claims fraud detection". Fuzzy neural networks were used to assess risk of fraudulent financial reporting [6]. Van Vlasselaer et al. [7] presented "APATE, the approach to detect fraudulent credit card transactions conducted in online stores". APATE combines data on transactions and customer spending and exploits the network of merchants and credit card holders.

Self-organizing maps are unsupervised neural network approach to clustering [8] and are widely used for research of different aspects of banking, such as marketing and finance. Several authors discussed applications of self-organizing maps. Pejić Bach et al. [9] used self-organizing

maps for market segmentation of business clients of Croatian banks. Three clusters were identified and used to suggest appropriate marketing activities. Holmbom et al. [10] used self-organizing maps for customer portfolio analysis. Merkevicius et al. [11] investigated how self-organizing maps can be used for forecasting of credit classes. They generated the model of credit units by similar characteristics of the process to determine credit classes. Lee et al. [12] compared the back-propagation network and self-organizing maps regarding the accuracy of bankruptcy prediction.

Self-organizing maps have been applied to financial fraud detection as well. Quah and Sriganesh [13] focused on real-time fraud detection and presented a new approach based on self-organizing maps for better understanding of fraudulent spending patterns. Zaslavsky and Strizhak [14] used self-organizing maps to derive the model of typical cardholder's behavior and to find suspicious transactions based on the analysis of deviations in transactions. Brockett et al. [15] used self-organizing maps to classify automobile bodily injury claims by fraud suspicion. Olszewski [16] used self-organizing maps for visualization of user profiles and comparison of credit card frauds, telecommunications frauds, and network intrusion.

To our best knowledge, there is no previous research that would test the usage of self-organizing maps in leasing industry. Based on this research gap, we form the following goals of the paper: (i) to determine and describe client clusters of Croatian leasing industry by using self-organizing maps based on demographic, behavioral and operational attributes, and (ii) to identify attributes that are crucial for an explanation of committed frauds and defaults. These attributes can be used for further detection and prediction of frauds and defaults. The scientific contribution of our paper is that the self-organizing maps algorithm are applied for profiling fraudulent behaviour and tested on the dataset of Croatian leasing company.

The paper consists of five sections. After the Introduction, there is Methodology section in which self-organizing maps, sample description as well as statistical analysis are presented. The third section provides Results, including results of cluster identification and cluster analysis according to fraud and default. The fourth section of the paper discusses results, while the last section is Conclusion. *This work has been fully supported by the Croatian Science Foundation under the project "Process and Business Intelligence for Business Performance" - PROSPER (IP-2014-09-3729).*

II. METHODOLOGY

A. Self-organizing maps (SOMs)

The concept of neural networks presents basic idea behind self-organizing maps (SOMs). The architecture of the SOM is a "feed-forward neural network with a single layer of neurons arranged into a rectangular array" [17]. The main characteristic of artificial neural networks, including SOMs, "is the property of learning from data entered in the network input layer" [9]. SOMs are representatives of unsupervised learning, which means that they are trained with "no prior knowledge available, and no assumptions made about the class membership of the data" [18]. Kohonen [19] defined the relationship between the input signal and the synaptic adaptation of neurons. This relationship is called the learning rule or Kohonen algorithm.

Kohonen algorithm is defined as follows. "When an input pattern is presented to SOM, each neuron calculates how similar the input is to its weights. A neuron whose weights are most similar (minimal distance in input space) is declared the winner of the competition for the input pattern, and weights of the winning neuron are strengthened to reflect the outcome" [17]. "The winning neuron receives the most learning at any stage with neighbors receiving less, the further away they are from the winning neuron" [20]. After learning process is completed, neighboring nodes have values similar to original data space. This process can mathematically be seen as non-linear, non-parametrized regression. Entirely few refinements have been made to Kohonen algorithm.

Clustering allows homogenous groups to be found. In a SOM all the data is ordered according to similarity. Intuitive representation makes it possible to determine homogenous regions manually. In Viscovery SOMine software, clusters can be built by using several clustering algorithms including classical Ward algorithm, SOM-Ward algorithm and SOM Single Linkage algorithm. At the initial clustering step of Ward algorithm, every cluster contains a single point. Such cluster is called singleton. Each of the next clustering steps finds and joins a pair of clusters that have a minimal distance called Distance Niveau [9, 21].

Viscovery became the market leader in SOMs by employing an optimized version of Kohonen algorithm. The SOM algorithm is highly efficient in handling large amounts of data [22]. SOMs are visually presented so users can intuitively analyze dependencies in data. Therefore, for the purpose of this research, SOM-Ward algorithm implemented in Viscovery SOMine software was used.

Training parameters of SOM-Ward algorithm are tension and training schedule. Tension is related to the map adaptation to data space. When tension is small, the map adapts better to data space. Typical values are between 0.3 and 2.0. Training schedule can be set to *Normal*, *Fast* and *Longer*. *Normal* training schedule is used to get standard accuracy, *Fast* is used to get a quick review of the data, and *Longer* is used to get the higher accuracy. Disadvantage of Viscovery SOMine is that the number of clusters needs to be set before running the algorithm. Moreover, characteristics of data are commonly not known in advance. Therefore, determining the number of clusters is a crucial point of clustering. This problem was solved by running the SOM algorithm with varying numbers of clusters and selecting the most appropriate clustering result

using domain knowledge, by consulting the expert in the field [23].

B. Sample description

Dataset used in this research is the client base of one Croatian leasing company containing the 13.057 SMEs and sole proprietorships clients with expired contracts, with the limited number of demographic, behavioral and operational attributes. Table 1 presents attributes used in this research. Demographic attribute of clients is Client Sector. Behavioral attributes of clients are Client New/Old and Fraud/Default. Operational attributes are Leasing Object and Leasing Object New/Used. Modalities of attribute Fraud/Default are based on aliases, which are the result of data pre-processing. Attribute Leasing Object – Detailed was not used for clustering.

TABLE 1. DATASET ATTRIBUTES

Attribute name	*Modalities of attributes*
Attributes used for clustering	
Client Sector	8 modalities: trade, other services, construction, agriculture, tourism, public, financial, chemical
Client New/Old	2 modalities: new, old
Leasing Object	12 modalities: car, light commercial vehicle, truck_tugboat, machine, equipment, trailer_semitrailer, motor, agri_forest, forklift, vessel, public, other
Leasing Object New/Used	2 modalities: new, used
Fraud attribute	
Fraud/Default	2 modalities: 1 (1 alias: termination fraud_default; 0 (5 aliases: financial, pre-term repurchase, normal, pre-term termination, harm)
Attribute used for additional analysis of fraud/default	
Leasing Object - Detailed	brands' names of leasing object (if available) or other detailed description of leasing objects

Source: Authors

C. Statistical analysis

Cluster analysis was performed by using the SOM Ward algorithm implemented in Viscovery SOMine software. First, map size, training parameters as well as the clustering method were defined. Number of nodes determines granularity of the map where more nodes result in a more detailed map but require more time for training. For the described dataset, parameter values were set as follows: training schedule was set to Normal and tension was set to 0.5. A map with 14000 nodes and the automatic ratio was trained. The number of 5 clusters was determined and specified. SOM-Ward clustering method was requested. Next steps were to explore the map and to identify clusters which are presented in the Results section.

Chi-square tests results were used to discover: (i) significant associations between clusters and following attributes: 1. Client New/Old, 2. Client Sector, 3. Leasing Object, 4. Leasing Object New/Used; and (ii) significant associations between modalities of chosen attributes and occurrence of fraud/default within clusters.

III. RESULTS

A. Cluster identification

Five clusters were identified based on the map size, training parameters and the clustering method set as described in II.C., 1st paragraph. Figure 1 visually represents SOM-Ward Leasing client clusters after training with their names given according to the most often leasing objects and client sectors: C1: New cars / Trade (72.18% of clients), C2: Used trucks or tugboat / Other services (14% of clients), C3: New machinery / Construction (7.28%), C4: New motors / Trade (4.68% of clients), and C5: New machinery and tractors / Agriculture (1.86% of clients). For each of clusters, average values of numerical variables and modal values of categorical variables are presented (Table II).

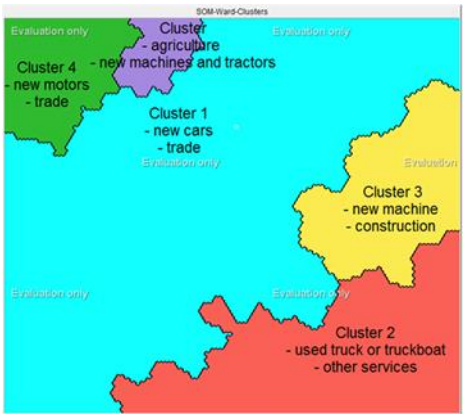

Figure 1. SOM-Ward Leasing client clusters (Source: Authors, using leasing dataset and Viscovery SOMine software)

TABLE II. AVERAGE VALUES OF NUMERIC VARIABLES AND MODAL VALUES OF CATEGORICAL VARIABLES ACCORDING TO CLUSTERS

Cluster	*C1*	*C2*	*C3*	*C4*	*C5*
Client - New	48.5%	44.3%	42.5%	38.6%	67.9%
Client - Old	51.5%	55.7%	57.5%	61.4%	32.1%
Client Sector	trade; other services	trade; other services	construction; other services	trade; other services	agriculture
Leasing Object	car, light commercial vehicle	truck_tugboat, trailer_semitrailer	machine	motor; forklift	agri_forest
Object - New	67%	19.4%	59.4%	84.5%	84%
Object - Used	33.1%	80.6%	40.6%	15.5%	16%
Fraud/ Default	10.7%	12.3%	17.1%	9.8%	18.5%

Source: Authors, using leasing dataset

Each cluster is described based on the Leasing object attribute used in the analysis: Cluster 1 is labeled as Cars, Cluster 2 as Trucks and trailers, Cluster 3 as Machines, Cluster 4 as Other leasing objects and, finally, Cluster 5 is labeled as Agricultural machines and tractors.

The highest percentage of old clients is in Cluster 4 (61.5%), and highest percentage of new clients is in Cluster 5 (67.9%).

In Cluster 1 41.9% of clients perform trade activities, and in Cluster 4 there is 46,8% of such clients. In Cluster 1 clients performed other services activities (27.9%), construction activities (17.3%) and others were in a smaller percentage. Cluster 2 contains the highest percentage of clients that performed other services activities (56.2%). This percentage is high for Cluster 3 (31.4%) as well. Construction activities are the most common activity of clients of Cluster 3 (43.3%). Cluster 5 contains the highest percentage of clients that perform agricultural activities (75.3%), followed by trade (16.5%).

Clusters differ significantly according to attribute Client Sector. The highest percentage of new leasing objects is present within Cluster 4 (84.5%), and the highest percentage of old leasing objects is present within Cluster 2 (80.6%).

B. Cluster analysis according to fraud and default

In this section cluster members according to chosen attributes and occurrence in fraud/default are presented.

Table III presents members of each cluster according to the status of clients (new/old) and occurrence of fraud or default. For Cluster 1 there is 60.1% of cases in which fraud/default occurred in contracts with new clients. Within Cluster 5 there is even higher percentage of new clients with fraud or default. Chi-square test indicates that these differences are statistically significant for both Cluster 1 and Cluster 5 at 1% and 5% level respectively.

TABLE III. CLUSTER MEMBERS ACCORDING TO STATUS OF CLIENT (NEW/OLD) AND OCCURRENCE OF FRAUD OR DEFAULT

		Fraud/default			
Cluster	***Client new/old***	***No***	***Yes***	***Total***	***Chi-Square/ p-value***
C1	***New***	47.1%	60.1%	48.5%	61.096 (0.000**)
	Old	52.9%	39.9%	51.5%	
C2	***New***	44.3%	44.2%	44.3%	0.001 (0.971)
	Old	55.7%	55.8%	55.7%	
C3	***New***	42.5%	42.6%	42.5%	0.000 (0.985)
	Old	57.5%	57.4%	57.5%	
C4	***New***	38.1%	43.3%	38.6%	0.622 (0.430)
	Old	61.9%	56.7%	61.4%	
C5	***New***	64.6%	82.2%	67.9%	5.197 (0.023*)
	Old	35.4%	17.8%	32.1%	
Total		**100 %**	**10%**	**100 %**	

Source: Authors, using leasing dataset
Note: ** statistically significant at 1%; * 5%

Table IV shows members of each cluster according to client sector (trade, other services, construction, agriculture, tourism, public, financial, chemical) and occurrence of fraud/default according to client sector. In Cluster 1 highest percentage of frauds or defaults were committed by clients doing business in trade sector (31.8%), other services (26.4%) and construction sector (26.4%). Results related to construction sector are especially interesting since clients from this sector make 17.3% of the cluster. For Cluster 2 it is noticeable that clients doing business in construction sector committed highest percentage of frauds or defaults (44.4%), followed by other services sector 30.2%. Cluster 5 contains the highest percentage of clients from agricultural sector (75.3%) who committed 97.8% of frauds or defaults. Chi-square value shows a significant association between the occurrence of frauds or defaults and clients' sector for Clusters 1 and 5 at 1%, and for Cluster 4 at 5% level.

TABLE IV. CLUSTER MEMBERS ACCORDING TO CLIENT SECTOR AND OCCURRENCE IN FRAUD OR DEFAULT

		Fraud/default			
Cluster	***Client sector***	***No***	***Yes***	***Total***	***Chi-Square/ p-value***
C1	***Agriculture***	5.5%	6.7%	5.7%	97.087 (0.000**)
	Chemical	0.3%	0.1%	0.3%	
	Construction	16.2%	26.4%	17.3%	
	Financial	0.5%	0.6%	0.5%	
	Other Serv.	28%	27.4%	27.9%	
	Public	2.2%	0.8%	2%	
	Tourism	4.7%	6.2%	4.9%	
	Trade	42.6%	31.8%	41.4%	
C2	***Agriculture***	0.4%	1.3%	0.5%	6.771 (0.148)
	Construction	16.7%	11.6%	16.1%	
	Other Services	55.9%	58.5%	56.2%	
	Tourism	0.7%	0.4%	0.7%	
	Trade	26.2%	28.1%	26.5%	
C3	***Construction***	43%	44.4%	43.3%	0.142 (0.932)
	Other Serv.	31.6%	30.2%	31.4%	
	Trade	25.4%	25.3%	25.4%	
C4	***Agriculture***	3.1%	3.3%	3.1%	14.498 (0.013*)
	Construction	14%	30%	15.5%	
	Other Serv.	29.9%	20%	29%	
	Public	0.2%		0.2%	
	Tourism	6%		5.4%	
	Trade	46.8%	46.7%	46.8%	
C5	***Agriculture***	70.2%	97.8%	75.3%	15.050 (0.005**)
	Construction	2.5%		2.1%	
	Other Serv.	6.6%		5.3%	
	Tourism	1%		0.8%	
	Trade	19.7%	2.2%	16.5%	
Total		**100 %**	**100%**	**100 %**	

Source: Authors, using leasing dataset
Note: ** statistically significant at 1%; * 5%

Table V presents members of each cluster according to a leasing object and occurrence of fraud/default according to leasing object. For Cluster 1 it is noticeable that cars were the subject of fraud/default in 62.5% of cases and light commercial vehicles are second with 31.3%. Trucks and tugboats (62.5%) occurred most often in frauds or defaults of Cluster 2. Finally, within Cluster 4 65% of frauds or defaults were related to forklifts. Association between the occurrence of frauds or defaults and a type of leasing object for Clusters 1, 2 and 4 is significant at 1% level.

TABLE V. CLUSTER MEMBERS ACCORDING TO LEASING OBJECT AND OCCURRENCE IN FRAUD OR DEFAULT

		Fraud/default			
Cluster	***Leasing Object***	***No***	***Yes***	***Total***	***Chi-Square/ p-value***
C1	***Car***	67.4%	62.5%	66.8%	21.916 (0.001**)
	Equipment	5.7%	4.2%	5.6%	
	Light commercial vehicle	25.2%	31.3%	25.8%	
	Machine	0.8%	0.8%	0.8%	
	Truck_ tugboat	0.9%	1.3%	1%	
C2	***Public***	4.2%	0.9%	3.8%	22.395 (0.000**)
	Trailer_ semitrailer	23.3%	36.6%	24.9%	
	Truck_ tugboat	72.4%	62.5%	71.2%	
C3	***Machine***	82.9%	17.1%	100%	/
C4	***Forklift***	34.5%	65%	37.5%	24.635 (0.000**)
	Motor	43.7%	15%	40.9%	
	Other	0.4%		0.3%	
	Vessel	21.4%	20%	21.3%	
C5	***Agri_forest***	81.5%	18.5%	100%	/
Total		**100 %**	**10%**	**100 %**	

Source: Authors, using leasing dataset
Note: ** statistically significant at 1%

Table VI describes members of each cluster according to the status of leasing objects (new/used) and occurrence of fraud/default payments according to the status of leasing object. New leasing object (86.5%) occurred most often in frauds or defaults of Cluster 5. Association between the occurrence of frauds or defaults and type of leasing object status (new/old) are shown to be significant at 1% level.

TABLE VI. CLUSTER MEMBERS ACCORDING TO STATUS OF LEASING OBJECT (NEW/OLD) AND OCCURRENCE OF FRAUD/DEFAULT

		Fraud/default			
Cluster	***Leasing object New/Used***	***No***	***Yes***	***Total***	***Chi-Square/ p-value***
C1	***New***	66.6%	69.5%	66.9%	3.327 (0.068)
	Used	33.4%	30.5%	33.1%	
C2	***New***	18.6%	25%	19.4%	5.079 (0.024*)
	Used	81.4%	75%	80.6%	
C3	***New***	59.1%	60.5%	59.4%	0.103 (0.749)
	Used	40.9%	39.5%	40.6%	
C4	***New***	84%	86.7%	84.5%	0.249 (0.618)
	Used	15.8%	13.3%	15.5%	
C5	***New***	88.9%	62.2%	84.%	19.352 (0.000**)
	Used	11.1%	37.8%	16%	
Total		**100 %**	**10%**	**100 %**	

Source: Authors, using leasing dataset
Note: ** statistically significant at 1%; * 5%

Additional analysis was made based on brand or other detailed description of leasing objects. Table V describes members of each cluster according to brands of leasing object and occurrence of fraud/default payments according to it. For Cluster 1 it is noticeable that VW vehicles were leasing object in 11.2% of cases when frauds or defaults occurred. Peugeot vehicles appeared in 9.7% of such cases and Citroen in 9.1% of such cases. MAN trucks occurred most often in frauds or defaults of Cluster 2. For Cluster 4 it is noticeable that in 6% of cases in which fraud/default occurred forklift was subject to leasing agreement. There is a significant association between the occurrence of frauds or defaults and leasing object-detailed for Clusters 1, 2 and 4 at 1% level according to brands of leasing objects.

TABLE VI. CLUSTER MEMBERS ACCORDING TO LEASING OBJECT - DETAILED AND OCCURRENCE OF FRAUD OR DEFAULT

		Fraud/default			
Cluster	***Leasing object - detailed***	***No***	***Yes***	***Total***	***Chi-Square/ p-value***
C1	***VW***	9.3%	11.2%	9.5%	98.707 (0.000**)
	Peugeot	8.7%	9.7%	8.8%	
	Citroen	7.2%	9.1%	7.4%	
	Fiat	3.7%	6.8%	4%	
	Renault	7.5%	6.4%	7.4%	
	BMW	5.7%	5.8%	5.8%	
	Opel	5.1%	4.3%	5.1%	
	Other	52.8%	46.7%	52%	
C2	***Mercedes-Benz***	23.8%	12.1%	22.4%	60.825 (0.000**)
	MAN	18.8%	18.3%	18.8%	
	IVECO	11.5%	12.1%	11.6%	
	Other Trailers	8.2%	14.3%	9%	
	Other Trucks	8.4%	2.7%	7.7%	
	Schmitz	6.4%	5.4%	6.3%	
	Volvo	4.7%	7.6%	5.1%	
	Other	18.2%	27.5%	19.1%	
C3	***Construction***	28.6%	35.2%	29.7%	14.741 (0.142)
	JCB	18.4%	19.1%	18.5%	
	Komatsu	8.9%	10.5%	9.2%	
	Machines Print	8%	6.8%	7.8%	
	Catterpillar	5.6%	7.4%	5.9%	
	Mach. Metal	5.7%	3.7%	5.4%	
	Other	24.8%	17.3%	23.5%	
C4	***Motor***	43.7%	15%	40.9%	27.751 (0.000**)
	Forklift	33.2%	60%	35.8%	
	Other	23.1%	25%	23.3%	
C5	***Agri Machines***	69.2%	57.8%	67.1%	2.163 (0.141)
	Tractor	30.8%	42.2%	32.9%	
Total		**100 %**	**10%**	**100 %**	

Source: Authors, using leasing dataset

IV. DISCUSSION AND CONCLUSION

SOM-Ward algorithm implemented in Viscovery SOMine software was used to cluster business clients of the leasing company. SOM-Ward algorithm extracted five clusters. In analyzing and interpreting the clusters, we first described each cluster descriptively according to the all clustering attributes. Second, we applied Chi-Square for testing association between the attributes' modalities and occurrence of fraud/default within the clusters. We detected significant associations between the modalities of chosen attributes and occurrence of fraud/default within each cluster. Leasing companies can develop their internal analysis based on the presented methodology and develop profiles of contracts that are particularly suspected of fraud. Table VII presents significant associations between modalities of attributes and occurrence of fraud/default within each cluster. Members of clusters have following characteristics, which are related with the fraud/default in leasing at 1% or 5% level of significance. In Cluster 1 there are mainly new clients that operate in construction and

trade industries, and buy mainly cars and light commercial vehicles, while Cluster 3 contains same industries, buying forklifts. In Cluster 2, there are mainly companies buying used trailers, semitrailers, trucks, etc. Cluster 5 contains mainly new clients from agriculture sector that bought new equipment. It can be concluded that sectors that are the most fragile to crises period, due to their tight relationship with economic cycles (trade, construction, agriculture) are the most likely to generate fraudulent behavior related to leasing contracts. In addition, special types of vehicles are also related to these industries, such as light commercial vehicles, trailers, semitrailers, trucks and tugboats, as well as forklifts. These results indicate that SMEs (especially new clients) should be double-checked before signing a contract. Cars are occurring as prone to risk only when they are bought by new clients operating in construction and trade, which poses an area for additional checking.

TABLE VII. SIGNIFICANT ASSOCIATIONS BETWEEN MODALITIES OF ATTRIBUTES AND OCCURRENCE OF FRAUD/DEFAULT WITHIN CLUSTERS

Cluster	Client New / Old	Client sector	Leasing object	L.Object New/ Used
C1	✓ (1%, new)	✓ (1%, construction, other, trade)	✓ (1%, cars and light commercial vehicles)	∅
C2	∅	∅	✓ (1%, trailer_semitrai; truck_tugboat)	✓ (5%, used)
C3	∅	∅	∅	∅
C4	∅	✓ (5%, construction, other, trade)	✓ (1%, forklift)	∅
C5	✓ (5%, new)	✓ (1%, agriculture)	∅	✓ (1%, new)

Source: Authors, using leasing dataset
Note: ✓ Statistically significant at 1% and 5%; ∅ - no significance

When taking into account results of our research; several limitations have to be taken into account: we used data of one leasing company, focusing only on SMEs and sole proprietorships; and we used expert knowledge for selecting number of clusters. However, these limitations also provide fruitful directions for future research, which lies in the following. First, data from multiple companies and a broader range of clients should be used in order to test our findings. Second, expert knowledge as a method for selecting clusters should be compared with the formal procedure, such as the one by Levine et al. [24].

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Author clustering on Persian text

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***Abstract* - Several authorship analysis tasks require the decomposition of multi-authored text into its authorial components. In this paper, we focus on unsupervised authorship analysis and provide an evaluation framework and a baseline to compare different approaches. In this work, given a collection of short documents, we approach the author clustering task to determine which documents are written by the same author. The number of clusters is determined through the computation of silhouettes for some approaches. Several approaches are compared but Affinity Propagation has the best result with 0.51 average BCubed F-score. Several features including POS tags frequency and function words are extracted from data. Text data are gathered from 6 different Persian newspaper authors.**

Keywords - Authorship clustering; stylometry; authorship analysis; text mining

I. INTRODUCTION

In authorship analysis, the goal is to gain information about the authors of a set of documents. There are several supervised tasks where documents and related information about its authors are provided that can be used to train a model to extract this information from other documents. Common examples are authorship attribution (extract the identity of authors) [1] and author profiling (extract demographics like age and gender of authors) [2]. The vast majority of published work focus on these two tasks. However, there are some cases where information related to authorship is not available. So unsupervised tasks come into play. Some examples of unsupervised tasks are intrinsic plagiarism detection (identification of plagiarized parts within a given document without a reference collection of authentic documents) [3], author clustering (grouping documents by authorship) [4, 5] and author diarization (decomposing a multi-authored document into authorial components) [6, 7, 29]. Unsupervised authorship analysis tasks are more challenging but they can be applied to every authorship analysis case because they do not require any training material.

Authorship identification is an important task within stylometry that can be applied to many cases. For example, determining the author of a ransom note can save someone's life, discovering whether all the uploaded assignments of a student are classified as their own work can reduce the amount of plagiarism, but it can be also applied in arts to identify an author of an old text. The documents clustering task, by author's linguistic style, is also of vital importance in forensic applications. A practical example would be the author identification in a collection of groups of documents where each group of documents has been written by a single author.

The author clustering problem which is also defined in [9] is the task of partitioning a given set of documents in such a way that all documents in each partition are written by the same author, and clusters are maximal with respect to this property.

This paper will start with introducing related works with this paper. Afterwards, our methodology including data collection, extracted features, clustering methods and evaluation results will be explained. Finally, a conclusion with alternative options for future research is provided.

II. RELATED WORKS

Previous work on author clustering (also called author-based clustering, authorship clustering, or authorial clustering), as it is defined in this paper, is limited. Iqbal et al. [10] describe an approach based on k-means clustering which requires that the number of authors is known and apply it to a collection of e-mail messages. Layton et al. [4] propose a method that can automatically estimate the number of clusters (authors) in a collection of documents using the iterative positive silhouette method. The latter has been demonstrated to be useful for clustering validation purposes [11]. These techniques have been applied to literary texts (either books or book samples). Samdani et al. [5] analyze postings in a discussion forum using an online clustering method. Daks & Clark [12] use POS n-grams and spectral clustering and tested their method in a variety of corpora including newspaper articles, political speeches, and literary texts.

A couple of works are done at the Author Identification task at PAN-2017 [13]. Research teams in Cuba [14], Germany [15], the Netherlands [16], Mexico [17], Poland [18] and Switzerland [19] have submitted for this task. In general, all submissions follow a bottom-up paradigm where first the pairwise similarity between any pair of documents is estimated and then this information is used to form clusters. Gómez-Adorno et al. [17] use hierarchical agglomerative clustering while García et al. [14] use β-compact graph-based clustering. Kocher & Savoy [19] apply some merging criteria in the pairwise similarities. Alberts [16] proposes a modification of a similar method submitted to PAN-2016 [20]. Halvani & Graner [15] use the k-medoids clustering algorithm and Karas et al. [18] are based on a variation of locality-sensitive hashing.

A couple of research works are done on Persian language documents that are mostly related to authorship attribution. In [21], a complex networks approach is used for authorship attribution on books of five Persian litterateurs. A study is done on intelligent authorship methods in [22] on two datasets, one of them consisted of texts from books and articles written by eight recent Persian authors and another containing students' texts. The effects of textual features are evaluated on authorship attribution accuracy in [23] using 29 different textual features on Persian corpora. Author clustering task has never been analyzed for Persian before.

III. METHODOLOGY

A. Data

We tried to make our data collection similar to PAN-2017 [13] author clustering task in order to compare results with submitted works. However, since our dataset and PAN-2017 dataset are not exactly the same, the results are not fully comparable. Articles are written by 6 different authors extracted from two Persian newspapers. For each author, there are at least 3 different articles. Documents are articles' paragraphs with more than 30 words. 20 different clustering problems are made. In each problem, there are 24 different documents (paragraphs) which are 4 randomly selected paragraphs from 6 authors.

B. Pre-processing

We do a pre-processing before extracting stylometric features from the texts. The pre-processing part should be done carefully so that we do not lose stylometric features which are needed for differentiating the writing styles.

We used Hazm's [24] normalizer to normalize texts. This normalizer changes English numbers to Persian numbers, removes extra spaces, replaces some annotation characters to their equivalent in Persian, replaces some Arabic characters to their equivalents in Persian, etc. So after that, we can process text and make calculations.

C. Features

After pre-processing we extract sentences from texts and then tokenize them into tokens. Tokens can be a noun, verb, preposition, etc. For Part of Speech tagging we used models provided in [24], So we used this tagger to compute verbs, punctuations, determiners, adjectives, adverbs, conjunctions and postpositions frequencies. We tried to extract features from the text as much as it is possible using available tools. Used features are listed below:

- Prepositions frequency: Number of prepositions used in the document divided by the number of tokens in the document. A preposition is a word governing, and usually preceding, a noun or pronoun and expressing a relation to another word or element in the clause. Some examples of Persian prepositions are "به", "با", "از", "بر", "تا", "در", "اندر" and "نزد".
- Stop words frequency: Number of stop words used in the document divided by the number of tokens in the document. "Stop words" usually refers to the most common words in a language. We used Mojiry list of stop words provided in [25]. This list includes some Persian stop words like "آن", "از", "اگر", "اما", "این" and some punctuation marks.
- Verbs frequency: Number of verbs used in the document divided by the number of tokens in the document.
- Punctuations frequency: Number of punctuations used in the document divided by the number of tokens in the document.
- Determiners frequency: Number of determiners used in the document divided by the number of tokens in the document.
- Adjectives frequency: Number of adjectives used in the document divided by the number of tokens in the document.
- Adverbs frequency: Number of adverbs used in the document divided by the number of tokens in the document.
- Conjunctions frequency: Number of conjunctions used in the document divided by the number of tokens in the document.
- Postpositions frequency: Number of postpositions in the document divided by the number of tokens in the document. Postposition here is considered to be a word placed after the word it governs.
- Foreign words frequency: Number of foreign words used, mostly Arabic or English, in the document divided by the number of tokens in the document. Language detection tool named "langdetect" [26] is used to detect the language of every token.
- Small tokens frequency: Number of small length tokens in the document divided by the number of tokens in the document. Tokens with the length of 3 or fewer characters considered to be small. Some examples of small tokens are "این", "آن", "از", "یا", "و", "." and "،".
- Positive, Negative and Neutral tokens frequency: Number of tokens with positive, negative or neutral polarity in the document divided by the number of tokens in the document. Polyglot library [27] is used to determine the polarity of words. For example words like "خوب", "زیبا", "خوشحال" and "مهربان" are positive words but "بد", "زشت" and "ناراحت" are negative words.
- Plural word endings frequency: Number of tokens with "ها", "ان" or "ات" ending in the document divided by the number of tokens in the document. These endings are mostly used for plural construction in the Persian language.
- Noun Phrase, Verb Phrase, Prepositional Phrase, Adjective Phrase and Adverb Phrase frequency: Number of each grammatical phrase in the

document divided by the number of sentences in the document. Sentences were segmented into phrases which may be a noun phrase, verb phrase, prepositional phrase, an adjective phrase or adverb phrase. In order to extract these features, we used the Chunker provided in Hazm [24].

- Vocabulary richness: Number of items in document's stemmed lemmatized tokens set divided by the number of tokens in the document. In linguistic morphology stemming is the process of reducing inflected words to their base or root form. For example, the stem of "کتابی", "کتاب‌ها", "کتاب‌هایی" and "کتابهایشان" is "کتاب". In computational linguistics, lemmatization is the algorithmic process of determining the lemma of a word based on its intended meaning. Lemmatization is closely related to stemming. The difference is that a stemmer operates on a single word without knowledge of the context, and therefore cannot discriminate between words which have different meanings depending on part of speech. With lemmatization, we can reduce different conjugations of a verb to a base form.
- Average tokens' length: Average length of all tokens in the document. Token may be word, punctuation etc. Length of tokens is calculated in terms of characters.
- Average sentences' length: Average length of all sentences in the document in terms of the number of tokens used in the sentence.
- Function words appearance: Function words' appearance in the document is determined. Used function words are a list of 318 commonly used tokens in the Persian language. "به", "پس", "از", "و", "برای" and "که" are some examples of function words.

D. Dimensionality Reduction

In order to reduce the number of dimensions, we used truncated singular value decomposition method in Scikit-learn [28] toolkit which performs linear dimensionality reduction.

We set it to extract 5 components from features because it provided better results. For each component, it used more than 130 features for each component.

According to this method, we observed that some features like Average tokens' length, Vocabulary richness, Small tokens frequency, Stop words frequency, Verbs frequency, Prepositions frequency, Foreign words frequency, Adjectives frequency, Conjunctions frequency and function words like "در", "و", "از", "را", "با" and "به" were most important and useful.

On the other hand, features like Adjective phrase frequency, Adverb phrase frequency, Noun phrase frequency, Verb phrase frequency, Prepositional phrase frequency, Plural word endings frequency and function words like "مثلا", "لااقل", "هست", "درباره" and "همچنین" were least important.

E. Clustering Methods

Scikit-learn [28] toolkit is used for clustering data. This toolkit contains some clustering algorithms which is an automatic grouping of similar objects into sets. Affinity Propagation [29] and Mean shift [30] clustering methods are used from this toolkit. These methods do not need the number of clusters.

Affinity Propagation creates clusters by sending messages between pairs of samples until the convergence occurs. A dataset is then described using a small number of exemplars, which are identified as those most representative of other samples. The messages sent between pairs represent the suitability of one sample to be the exemplar of the other, which is updated in response to the values from other pairs. This updating happens iteratively until the convergence occurs, at which point the final exemplars are chosen, and hence the final clustering is obtained.

In Affinity Propagation algorithm, the messages sent between points belong to one of two categories. The first is the responsibility $r(i, k)$, which is the accumulated evidence that sample k should be the exemplar for sample i. The second is the availability $a(i, k)$ which is the accumulated evidence that sample i should choose sample k to be its exemplar, and considers the values for all other samples that k should be an exemplar. In this way, exemplars are chosen by samples if they are (I) similar enough to many samples and (II) chosen by many samples to be representative of themselves.

More formally, the responsibility of a sample k to be the exemplar of sample i is given by

$$r(i, k) \leftarrow s(i, k) - max\,[a(i, k') + s(i, k')\ \forall k' \neq k]. \quad (1)$$

Where $s(i, k)$ is the similarity between samples i and k. The availability of sample k to be the exemplar of sample i is given by

$$a(i, k) \leftarrow min\,[0, r(k, k) + \Sigma_{i'\,s.t.\,i' \notin \{i,\,k\}}\, r(i', k)]\,. \quad (2)$$

To begin with, all values for r and a are set to zero, and the calculation of each iterates until the convergence occurs. As discussed above, in order to avoid numerical oscillations when updating the messages, the damping factor λ is introduced to iteration process. Calculation formulas of responsibility and availability of a sample k are given in (3) and (4) respectively.

$$r_{t+1}(i, k) = \lambda \cdot r_t(i, k) + (1-\lambda) \cdot r_{t+1}(i, k) \quad (3)$$

$$a_{t+1}(i, k) = \lambda \cdot a_t(i, k) + (1-\lambda) \cdot a_{t+1}(i, k) \quad (4)$$

Where t indicates the iteration times.

Mean shift clustering aims to discover blobs in a smooth density of samples. It is a centroid based algorithm, which works by updating candidates for centroids to be the mean of the points within a given region. These candidates are then filtered in a post-

processing stage to eliminate near-duplicates to form the final set of centroids.

Given a candidate centroid x_i for iteration t, the candidate is updated according to (5).

$$x_i^{t+1} = x_i^t + m(x_i^t) \quad (5)$$

$m(x_i)$ is the mean shift vector that is computed for each centroid that points towards a region of the maximum increase in the density of points. $m(x_i)$ is computed using (6), effectively updating a centroid to be the mean of the samples within its neighborhood. In this formula, $N(x_i)$ is the neighborhood of samples within a given distance around x_i.

$$m(x_i) = \Sigma_{x_j \in N(x_i)} K(x_j - x_i) x_j / \Sigma_{x_j \in N(x_i)} K(x_j - x_i) \quad (6)$$

The algorithm automatically sets the number of clusters, instead of relying on a parameter *bandwidth*, which dictates the size of the region to search through. This parameter can be set manually but can be estimated using the provided *estimate_bandwidth* function, which is called if the bandwidth is not set.

The algorithm is not highly scalable, as it requires multiple nearest neighbor searches during the execution of the algorithm. The algorithm is guaranteed to converge, however, the algorithm will stop iterating when the change in centroids is small. Labelling a new sample is performed by finding the nearest centroid for a given sample.

Texts can be viewed as time-series. With this view, Time-Series KMeans clustering method is applied using tslearn [31] which is a machine learning toolkit dedicated to time-series data.

The KMeans algorithm clusters data by trying to separate samples in n groups of equal variance, minimizing a criterion known as the inertia or within-cluster sum-of-squares. This algorithm requires the number of clusters to be specified. It scales well to a large number of samples and has been used across a large range of application areas in many different fields.

Silhouettes [32] are used to determine the number of clusters. The Silhouette Coefficient is calculated using the mean intra-cluster distance (a) and the mean nearest-cluster distance (b) for each sample. The Silhouette Coefficient for a sample is

$$(b - a) / max(a, b). \quad (6)$$

To clarify, b is the distance between a sample and the nearest cluster that the sample is not a part of. Note that Silhouette Coefficient is only defined if the number of labels is

$$2 \leq n_labels \leq n_samples - 1. \quad (7)$$

TABLE I. OVERALL AUTHOR CLUSTERING EVALUATION RESULTS

Method	***Bcubed F-score***
Gómez-Adorno et al. [17]	0.57
Affinity Propagation	0.51
Mean Shift	0.46
Time Series KMeans	0.46
PAN-2017 BASELINE-Random	0.45
Our Random-Baseline	0.37

F. Evaluation

To understand the effectiveness of different clustering approaches, a Random-Baseline method is applied to data. Given a clustering problem including a set of documents, the method considers it to be written by 6 different authors and randomly assigns each document to one of the authors. Finally, the average BCubed F-score of 20 runs is recorded.

For evaluation, average BCubed F-score [33] of all clustering problems is calculated. Table I shows evaluation results including Gómez-Adorno et al. [17] results from PAN-2017 which has best results compared to others at PAN-2017. As our dataset is different from the PAN-2017 dataset, the results can roughly be comparable.

For statistical testing, we used Student test [34] which is a significance test for the mean value of a normal distribution. We considered Affinity Propagation method for comparison with our random baseline and the t value obtained was 10.56. As the degree of freedom for our problem is 38, it passes the two-tailed test with 5% significance level and also passes the test with 0.1% significance level. We considered Affinity Propagation method for comparison with Mean Shift method and the t value obtained was 3.28, so it passes the two-tailed test with 1% significance level. We considered Affinity Propagation method for comparison with Time Series KMeans method and the t value obtained was 5.51, so it passes the two-tailed test with 0.1% significance level. We considered Mean Shift method for comparison with Time Series KMeans method and the t value obtained was 3.83, so it passes the two-tailed test with 0.1% significance level.

IV. CONCLUSION

To conclude, some stylometric features including a set of function words extracted from text data gathered from Persian newspapers in order to cluster short segments of text according to author's writing style.

Data dimensionality was reduced to 5 linear combinations of features using truncated singular value decomposition method to value features according to their importance and usefulness.

Resulting data clustered using Affinity Propagation, Mean Shift and Time Series KMeans methods. Affinity

Propagation performed as the best method with 0.51 Bcubed F-score on the provided dataset.

In future research, features set may be developed to cover verb aspects, tenses, and more function words. More clustering methods may be used and modified in order to be more suitable for this type of clustering. Similarity measures also may be defined to be used in clustering algorithms.

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Semantic Web Technologies and Big Data Warehousing

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Abstract - Research in data science field has pointed out analytical potentials contained in big data on numerous occasions. The new paradigms in data storage and processing emerged with the goal of handling big data, but also pushing traditional, already present systems out of focus and creating a gap between the old and the new. That was also the case with traditional data warehouses and emergence of NoSQL data stores, whose integration has shown to be quite problematic due to NoSQL and big data features. Latest research has been trying to overcome this gap in various ways, mostly by system integration on various levels or introducing completely different new ones, but due to the data warehouse's particular nature and strict process of data modelling and acquisition, this problem must be approached on a conceptual level, capturing the essence of the domain which is to be analysed. The lack of schema in NoSQL databases makes them less comprehensible for integration and analysis, which motivated the idea of employing semantics to enrich NoSQL database contents, making them more suitable for integration. This paper analyses ways in which semantics could be applied as an asset in bringing together data warehouses, NoSQL databases, and big data.

I. INTRODUCTION

Combining data from various sources enables creating a wider, more informative picture of the matter of interest. The basic concept for achieving this enriched knowledge is data integration. Data integration problematics have been tackled for many years, especially because they enable (advanced) analytics and discovering knowledge that is not visible *in plain sight* right from just looking at the data. Significant advance is this area was the emergence of data warehousing, which is a typical example of data integration for analytical purposes. As data storage technologies and paradigms changed and advanced, so did the research in data integration and data warehousing: at first, data warehouses (DWHs) integrated data coming from structured relational databases (RDBs); then due to their wide application in business processes, semi-structured data sources such as XML documents were integrated as well; from research in semantic web emerged semantic data warehouses. Data warehousing has survived for almost three decades, and since a couple of years ago has to face nowadays' trends in data storage, NoSQL databases (NoSQL DBs).

DWHs have proved to be of great use in various analytically interesting areas that surround our everyday life: business, sales, education, etc. After the establishment of DWHs and ERP systems, every larger company had implemented them to improve their business, and so did the universities. In the literature, there are cases of DWH purposed for research work evaluation, evaluation of didactic methods, and management of all kinds of resources [1], and with the emergence of new teaching methods like massive open online courses enabled by technological advances, new data sources – not necessarily containing relational data – have become available. These data also hold analytical potential and a way to integrate them needs to be found.

Due to their diversity and lack of clear schema, integration of NoSQL DBs with RDBs – and consequently, traditional DWHs – has proved to be problematic. There have been many attempts of integration at physical level (data integration) and even change in storage paradigms, but in data warehousing that is only the final step: the preceding steps are stricter and supervised as they include conceptual and logical modelling – a schematic integration. Schematic integration is necessary to ensure data quality and enhance the chances of successful DWH implementation.

The current research in this area has turned to semantic web technologies to compensate NoSQL databases' lack of schema, and to boost the DWH design overall. This paper discusses use of semantics in data integration and their potential in the data warehousing, and provides some considerations regarding their application in integration of NoSQL DBs. The paper is organized as follows: section two provides important considerations in DWH integration of NoSQL DBs; section three discusses possible application of semantics in data warehousing; section four provides a general summary and discussion of the highlighted *big data warehousing* matters; section five concludes this paper.

II. IMPORTANT CONSIDERATIONS IN DWH INTEGRATION OF NOSQL DATABASES

NoSQL DBs are usually divided in four main families: document, column, and key-value stores, and graph databases. Although they differ significantly in features, they do have some in common: they contribute to the scalability in the distributed environments and have good fault tolerance and relaxed consistency. They are free of strict schema imposed on the data before their loading, and they lack a unified model and a declarative query language. Since they are the storage of choice for big data, we consider they inherently posses *V-features* of big data

and we highlight the problems emerging from them. Integration of NoSQL databases with DWHs (and RDBs) is in general not very different from any other integration scenario. The difference lies in the complexity of the integration steps and necessary means.

In this context, *big data warehousing* denotes integration of NoSQL data sources and DWH into a *big data warehouse* (*BigDWH*) and generally dealing with big data features in the context of data warehousing. Still, if this problem is approached on a high level, important integration considerations remain the same: heterogeneity of data, integration level and approach, and automatization of the processes.

A. Heterogeneity

1) General consideration

Considering document stores (but also applicable to any kind of storage intended for integration), three types of heterogeneity [2] can be met:

Structural – Instances of a considered entity may not have the same, consistent structure within the same database. E.g. considering an attribute's position within an entity, it may be nested or subordinated in a flat manner. Consequently, its path is not designated uniquely, which imposes ambiguity in inferring a schema and addressing such attributes in queries.

Syntactic – Occurs when a concept (e.g. an attribute) is not named uniquely in instances overall, e.g. an item's ID is named *id* in one instance, and *item_no* in another.

Semantic – Oppositely from syntactic heterogeneity; one attribute denotes different concepts, depending on context (kind of the instance); e.g. attribute *name* may be used for naming a person or an item, depending on its position (within a *person* or an *item* instance).

2) NoSQL consideration

In a typical NoSQL storage, e.g. a document store, all three types of heterogeneity are expected. Variety is a typical feature of such (big) data, and is the consequence of schema loosening or complete absence of imposed schema. Since the process of DWH integration begins with schema analysis, integration of NoSQL data source may demand a schema reengineering process, i.e. defining a schema from originally *schemaless* data. Great level of heterogeneity may be present in such data, which imposes a new schema integration problem before the DWHs.

B. Levels of integration

1) General consideration

Data sets can be integrated in multiple ways and on multiple levels, which can be roughly categorized in three levels:

Physical level – Integration at physical level is pure data integration (storage-level integration) by choosing a common data storage for storing the data coming from all included sources. It implies usage of a common data model. Data from all sources are usually copied to the chosen storage, and their transformation process during ETL phase includes either slight or significant change of structure along with other cleansing procedures.

Middle/Interface level – A lot of research has been done in data integration at *middle* level – using a common user interface, integration application, middleware interface, or providing uniform access to multiple and various data storages [3]. The main strategy is to hide complexities of integrated systems from users and unburden them from learning multiple query languages, underlying systems' specifics, unifying result sets from multiple storages, etc. Users usually access the system via only one, common interface provided by a middleware, and query the common, *virtual schema*. This type of integration includes query mediation approach, where the query submitted by the user is split into subqueries, which are forwarded (pushed down) to be ran on the underlying systems natively storing the data. The result sets are returned to the middleware, which unifies them and returns them as a singular result set to the user.

Schema level – In traditional DWH design, conceptual modelling i.e. designing warehouse's star schema (or in case of data marts, one of the star schemas) is the first step of the design process: high-level integration of the involved data sources occurs – their (parts of) schemas are modelled and joined to form the common, star schema. Such conceptual modelling is the prerequisite for logical model, which is precedent to ETL process and final (data) integration at the physical level.

Star schema is the main trademark of DWHs and was invented for improving analytical performance. The whole modelling process is important to include only analytically important concepts in the DWH model, and it needs to be done in a sensible and supervised way. The physical integration usually does take place during the DWH implementation, but the mere physical unification of the data sources – plain physical integration – would not be enough to achieve the crucial quality of DWH contents.

2) NoSQL consideration

In the context of integration on a physical level, an exemplary scenario is the integration of relational, NoSQL and semantic data source into a semantic DWH. The designated data model would be RDF. Despite the popularity semantic DWH [4] gained during the semantic research era, it remains questionable whether RDF model is suitable for storing natively relational data, let alone NoSQL data, because their native storage and processing engines were tailored to handle their features best.

Integration on a middleware level was applied in multiple researches that aimed to bring big data processing engines to relational and non-relational storage [5], [6]. The main reasoning for this approach was minimizing data movement (from storage to processing engine), the cost of which grows with the growth of data volume and complexity. Second benefit of this approach is processing data in engine that does it the best, which is usually within the very same system that stores them.

Considering integration of schema level, including it somehow in *BigDWH* design process would aid to make sense from the presence of big data in DWHs. Due to absence of a clear schema in NoSQL databases, it is a research problem how to adjust the traditional modelling process to include NoSQL database models.

C. Automatization of design process

Automatization in DWH modelling and overall design was and still is the subject of research [7]–[9]. Some of the research advances were semi- or full automatization of processes which had to be done manually. Automatization is desirable because it reduces human, error-prone involvement, especially in tiresome repetitive tasks. Considering the design automatization in the context of NoSQL integration, the more complex data are integrated, the harder it is to achieve automatization of the design steps. They can be (independently from each other) automated to a certain level, e.g. schema inference, schema-level integration, deriving multidimensional concepts from common schema, etc.

D. Approach

1) General consideration

Data warehouses are designed by applying either of the following three approaches:

Data-oriented – This approach is about remodelling of the data copied from the data sources and considering original functional dependencies to extract multidimensional schema. The main problem of this approach lies in lack of consultations with the end user and consideration of their requirements. Surely, through this approach DWH is physically implementable, but it may end up completely useless to the end users due to not fulfilling their needs.

Demand/requirement-driven – In this approach, end users are consulted for their requests and business goals. Based on them, a multidimensional schema is defined. In this case, problems occur in the phase of data source exploration, attempting to find (map) multidimensional concepts to concrete elements within them, as there might be a situation that the requested concept cannot be found. Another flaw of this approach might be a missed opportunity in discovering an analytically interesting concept offered by data, but not stated in the requirements.

Hybrid – This approach combines the best features of the previous two. It is more complex, as it reconciles available data sources with the requirements. Still, this approach is promising for it may significantly reduce design efforts and recent research works in this area advocate it [1], [7], [10], [11], and there have been significant attempts of its automatization.

2) NoSQL considerations

Attempts on NoSQL DWH schema-level integration have mostly applied hybrid approach. In terms of data-oriented approach features, data from the NoSQL source were used to define the source schema, which due to the data heterogeneity and variety may be marginally comprehensible to a human. The problem was addressed as *dimensionality explosion*. For these reasons, researchers applied features of requirement-driven approach, which has twofold benefits: it helps in reducing the large reengineered schema, and it focuses the designer's view on the analytically relevant subset of data (concepts). A great deal of research was also focused on automatization of the hybrid approach.

III. The Potential Role of Semantics in Big Data Warehousing

We are considering possible role and reviewing use-cases of semantics in the DWH design phases or in the semantic-based integration scenarios. Research was mostly done with relational and semantic data sources [12], and not all of the reviewed work dealt with integration of NoSQL DBs. Still, they all have presented some interesting ideas that could potentially be applicable.

A. Data source schema extraction

Using ontologies for description of data sources' schemas makes them *schematically comparable*, for each one of them would be represented by its local ontology (sometimes called modular ontology).

Schema extraction from a relational source is a matter of querying the system tables. Research during semantic web popularity has already yielded tools and rules for imposing an ontology on a relational data source (e.g. RDBtoOnto), and semi-structured files [13]. Currently, research is still being done in this area, mostly to reconcile data with the requirements in the earliest stage possible.

In NoSQL DBs, a simple query to the system to get the schema is not possible. Parts of structure definition are mixed with the data (e.g. keys in key-value format) and due to possible inconsistency and unstructuredness of the data, mere extraction of the keys would not be enough. The lack of formal schema in NoSQL DBs can be compensated by ontologies used as meta-data. Research was done in *semantification* [14] of big data, giving them a virtual layer of a high-level description. Document stores were mostly in focus; [15] is important work that integrated column and document stores. Similar research focused on column stores and other types is another open research question.

There is a variety of approaches to data source ontology extraction. Approach in [10] included using OntoLT (linguistic-based ontology extraction) tool and WordNet to create tagged ontologies; in [16] and [17] ontology was learned from the data using a genetic algorithm; in approach presented in [8] data from the sources were replicated in materialized views from which the ontology was extracted. Some works involved manual definition of data source ontology, but that is inapplicable to NoSQL integration. This is an active research area and improvement and automatization of this step would aid in ontology-based integration of NoSQL DBs with DWHs.

B. Integration of data source schemas

Assuming all data sources' schemas are expressed through an ontology, integration of schemas becomes the problem of ontology matching and alignment. We consider this problem to be whole another research area of matching/reasoning algorithms, engines and tools (e.g. long-established like COMA++, FaCT++, LSD, OLA, AROMA, etc. or newer ones like MOOM [16] or CroMatcher [18]) and benchmarks for them. DWH designer could consider ontology alignment as a *black box*, and would not necessarily have to have the expertise in this area. Still, there may be a need for the designer's supervision during the matching process.

C. Schema reduction

As it was previously emphasized, unstructuredness of a NoSQL data source can affect the extracted schema to be large and have ambiguous concepts, some of which will be analytically important. There may be different paths (locations) to the same concept of interest. For these reasons, schema needs to be sized-down only to the concepts of domain of interest, which can be achieved by inclusion of user requests. That implies adopting requirement-driven approach – or at least partially as a hybrid approach – in DWH schema design, which was mostly done in the research work [1], [7], [9]–[11].

There are many strategies to include requirements in hybrid approach to schema design. First main concern is timing: the design can start with requirement analysis; data- and requirement-driven approaches can take place parallelly; requirements can be applied on each local ontology after its generation or on a global ontology after the merge of local ontologies. Early reconciliation of data sources is often highlighted as a good approach, thus many works included applying requirements on the local ontologies. Another possible approach is to incrementally integrate conceptual schemas (requirement- and data-based) [7]. Second main concern is expressing the requirements: if the requirements were expressed in a formal format, that would pave the way toward automatization. For that reason, many works have been based on formalization frameworks e.g. *i** [7], [9] and/or description logic [15], in which different approaches were used to obtain a formalized format of requirements. In [10], [11] design process starts by having requirements in natural language format and converting them to logical/normalizing them. Additionally, they may also be described using semantic resources [9], which is similar to another approach – *semantification* of the stated requirements i.e. creating a requirement ontology [8], [9], so they could be included in merger with other ontologies. In works that adopted more traditional approach, design starts by having clearly stated workload of queries which implicitly define multidimensional concepts, but applicability of such approach in case of NoSQL data source is questionable because the general idea of applying semantics to NoSQL DBs should be to provide the designers an exploratory tool to aid them in design.

D. Outlining multidimensional concepts

Assuming integration of data sources' schemas (local ontologies) took place along with the schema reduction using users' requirements, the final product of those processes is a global ontology that contains concepts from the domain of interest. Next step would be to derive multidimensional concepts (facts, dimensions and hierarchies) needed for the DWH schema definition.

The most primitive and very error-prone approach would be to hand-pick them. Opposite from that, these concepts could be (semi-)automatically detected through data inspection and/or reasoned from a global ontology. In [19] a heuristic approach was presented, based on measures calculated from CWM model and formalized by *Query–View–Transformation* rules; facts are detected by inspecting relationship cardinalities and calculating in-degree of tables. In [10] facts are first recognized as attributes whose share of numeric instances exceeds a threshold specified by the designer. After derivation of the facts, dimensions are detected through the n:1 cardinality relations to the facts. In other approaches such as [8] multidimensional concepts are deducted directly from the requirements, but that requires an *apriori* clear vision of analysis scenarios we want to implement. In [11] multidimensional concepts are discovered based on automatized heuristics and using tables' PKs and FKs to detect dimensions. DWH design methodology presented in [7] utilizes a graph-based representation of merged data sources' schemas called *attribute tree*, which is an input to a remodelling algorithm that produces an attribute tree representation of a multidimensional cube. Afterwards, a star schema is easily defined using the tree.

DWH ontology could remain as a higher-level representation of the DWH schema, regardless of DWH's physical implementation, to be later used for mediated querying. Also, after the multidimensional concepts are defined, using RDF Data Cube Vocabulary[1] could be an option if RDF was chosen as a target data format. If not, perhaps the concepts from the vocabulary could be helpful along the way during the design of DWH ontology. Similarly, there is also an extension of the vocabulary called *qb4olap*[2] for which a high-level OLAP language called *QL* was created, containing well-known OLAP operators – slice, dice, roll-up and drill-down.

Aforementioned approaches [8], [10], [11] do not share a common customary procedure or approach, but they all strive to achieve the highest possible degree of automation to support DWH designer in forms of certain solutions and possible suggestions, which then need to be resolved by them. This is still an open research question.

1) Schema maintenance

Having NoSQL DBs, there is a high probability of changes on the data source models. Also, a possibility for adding new data sources [16] after the initial schema design should be considered as well as the problematics of change in user requirements, which is an ongoing research question regardless of NoSQL DB integration [20]. For these reasons, a strategy for handling these changes on the DWH side is needed. Common strategies to this problem are: schema evolution (schema and data are updated along with the changes i.e. changes are propagated from the sources to the warehouse [20]), versioning (creating different versions of the whole DWH [21]), and view maintenance (using materialized views to represent data sources in all states). So far, schema evolution approach alongside an ontology was mostly used [9], [22]. This is a tricky question and mixed opinions are to be expected, especially coming from the DWH *traditionalists*.

2) Schema evaluation

Evaluation of global ontology and/or designed DWH schema should be considered as a last check before start of the ETL process because due to DWH's more complex implementation (over multiple heterogeneous sources) the cost of error could be much higher than before. One way of schema evaluation, applied in [10] is based on three

[1] https://www.w3.org/TR/vocab-data-cube/

[2] https://github.com/lorenae/qb4olap/wiki

criteria – *disjointness*, *orthogonality* and *summarizability* [23]. In [16] authors performed terminological evaluation of global ontology against the concepts from the domain of interest. Also, efficiency of the approach could be evaluated. Approach presented in [22] evaluated efficiency based on the costs of manual involvement and ontological approach. In [24] metrics for the evaluation of DWH design methodology in the context of big data were presented, whose criteria were most of the integration considerations we have mentioned in section two.

IV. DISCUSSION

Previous two sections show that integration of NoSQL DBs with a traditional DWH is problematic in many aspects, but a lot of research is being done to overcome these issues. One approach is to use semantic web concept – ontologies. They show potential in handling data variety of NoSQL DBs, but also volume and velocity features should not be ignored. Authors in [16] also advocate the independence of the data sources and interact with them only by copying them. This approach to pre-schema storing may be useful considering the possible speed of data that could impede the data source exploration.

The goal is to automatize DWH design process as much as possible and most of the reviewed work in this paper presented approaches that included some degree of automation. However, considering the ambiguities of a NoSQL schema, it would be realistic to expect utmost the semi-automation of the design process, because it would need to be at least supervised due to uncertainties of the real data usefulness (big data's questionable *value* feature). Ontologies could be of great use, having the role of data sources' schema representative. Using them as requirements' representation should also be considered. Another application scenario is using ontologies to find missing data (requested by the requirements, but not present in the data source), and also finding *hidden semantics* (interesting concepts available in the data, but not requested by the requirements). The general idea is to utilize them in creation of a tool that would enable the designers to explore new types of data sources – provide them an *exploratory* approach [25]. All this can be automated to a certain level and achieved by combining ontology alignments, data-oriented and requirement-oriented approach. However, obtaining the ontological data source representation remains the most important research matter, in which new insights from the area of NoSQL data modelling could come in aid. Another important consideration is when to reconcile available schemas with the data sources – on local ontologies or on the global one. Ontology matching should not necessarily need to be DWH designer's expertise, but some insight on the used matching algorithms is necessary because the quality of the global ontology depends on it, e.g. whether the matching is lexically-based, structure-based, etc. There is a previous, about a decade-long era of researching automatized approaches for detection of multidimensional concepts. Approaches used now bear some resemblance to those previously used, and the latter should be examined more closely for the upgrades that would enable them coping with new types of data.

DWH schema maintenance should be taken care of, especially if we plan to integrate a NoSQL data source to a DWH. Perhaps, this is a more realistic starting point to *DWH-to-BigDWH* transformation. It is noticeable that all of the reviewed approaches begin the DWH design from scratch. We believe that another, perhaps more realistic scenario needs to be considered – adding a NoSQL data source to an existing DWH. Since building and maintaining a DWH requires a significant and constant investment of resources, it is hardly to expect that decision makers would agree to make a complete redesign. Possible consideration is the schema evolution approach, enabling the traditional DWH schema to evolve and integrate NoSQL data source in a dynamic way [16].

Since the stakes invested in the DWH implementation are higher with the addition of NoSQL data, design phase becomes even more critical than before. For that reason, evaluation should be performed before initiating ETL process. Means for evaluation are also the subject of research and until now various metrics have been proposed, imposing the question what should be evaluated – design approach overall, global ontology, designed schema, all of them together, or something else.

There are opinions ETL should also be *semantified* and that it should evolve with the DWH schema evolution [9]. Thus, further (semantic) research of ETL and its automatization [7] is expected. Research of transformation and loading phases is also being conducted in terms of processing and storage technologies. Storage strategy i.e. physical layer of the *BigDWH* is another important research question. For the target storage, having a unified system is probably not a wise approach, e.g. storing everything as RDF, or in RDB, or in NoSQL DB. Support of multiple scenarios must be considered because NoSQL data may end up as a new dimension or its attribute; a new set of facts; or an entire new star schema. Research is being done in multistore approach to bringing together various storage engines, along with the query mediation, where the main strategy is to build a bridging query language (e.g. *BQL* in [15]) or generalized query functions (e.g. *GQF* in [26]), which provide back-and-forth query translation to the native query languages of the involved storage systems. DWH ontology (as an intermediate product of ontology-based design approach that is already at disposal) could also have the role of virtual schema and be used instead or alongside the bridging query language.

V. CONCLUSION

This paper reviews possible role of semantic web technologies in bridging the gap between the traditional data warehouses and big (NoSQL) data, providing the designers tools for data source inspection and exploration, and aid in the design, e.g. recognizing multidimensional concepts and suggesting the potential ones. The most promising concept are ontologies, not just for being easily updateable, but because they can be reasoned upon to resolve heterogeneity conflicts, detect multidimensional concepts and discover hidden semantics, explore large volumes of unstructured data which is impossible to do manually, etc. Since ontologies by the definition bear the feature of formalism, i.e. computer readability, all these actions can be automated to a certain degree and by doing

so disburden the designers, thus a lot of research is focused on automatization of the design phases. Still, the design should be supervised, so we believe semi-automatization would be the best choice. Also, to the best of our knowledge, research approaches done in this field considered (big) data warehouse design only from scratch – we believe this should be reconsidered to resemble a more realistic scenario of adding NoSQL data source to the existing data warehouse. Most of the research was done regarding the document stores, so further research can be expected on applying similar approaches to column stores and other NoSQL families.

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An Empirical Comparison of Customer Behavior Modeling Approaches for Shopping List Prediction

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***Abstract* - Shopping list prediction is a crucial task for companies as it can enable to provide a specific customer a personalized list of products and improve customer satisfaction and loyalty as well. To predict customer behaviors, many studies in the literature have employed customer behavior modeling approaches which are individual-level and segment-based. However, previous efforts to predict customers' shopping lists have rarely employed these state-of-the-art approaches. In this manner, this paper introduces the segment-based approach into the shopping list prediction and then presents an empirical comparison of the individual-level and the segment-based approaches in this problem. For this purpose, well-known machine learning classifiers and customers' purchase history are employed, and the comparison is performed on a real-life dataset by conducting a series of experiments. The results suggest that there is no clear winner in this comparison and the performances of customer behavior modeling approaches depend on the machine learning algorithm employed. The study can help researchers and practitioners to understand different aspects of using customer behavior modeling approaches in the shopping list prediction.**

Keywords - Shopping list prediction; next basket prediction; customer behavior models; machine learning; personalization

I. INTRODUCTION

In today's business, customized services and one-to-one marketing actions play important roles for companies to succeed higher customer satisfaction and gain a stronger competitive position. To effectively implement and launch such services, predicting customers' next shopping basket is essential for retail companies. This task is estimating the set of items that a customer could probably buy in the next visit. In recent years, there has been an increasing number of research works done in next basket prediction/recommendation [1]–[4].

Most of the existing studies have taken customers' sequential buying behaviors into consideration to predict their next baskets. In this manner, Markov chain is a popular method employed for sequential prediction. For example, Rendle et al. [2] employed both the Markov chain model and the matrix factorization, while [1] extended Markov chain based method by utilizing representation learning to predict customers' behaviors in the next transaction. Differently, [3] and [4] employed Neural Networks (NN) and Recurrent Neural Networks (RNN) respectively. Although such methods have been successfully employed for basket prediction, they are mainly based on transactional data of whole customers.

On the other hand, there are two popular customer behavior-modeling approaches: individual-level approach and segment-based approach. Individual-level approach constructs a unique prediction model for each customer separately, while in the segment-based approach, the predictive models of customer behavior are built for each customer group that consists of customers sharing similar characteristics. Several research efforts [5]–[13] have employed segment-based approach, whereas to build more effective predictive models so as to maximize the predictive accuracy, many studies [6], [8], [10], [12]–[15] have used individual-level approach. Among these prior studies, only [14], [15] used individual-level customer behavior modeling approach in the shopping list prediction by building prediction models for each customer-product pair and employing some of primitive classifiers (e.g. Perceptron, Winnow, etc.).

Given the growing body of research on shopping list prediction, it is surprising that only a few number of studies have applied individual-level customer behavior modeling approach, and there is no previous research that has employed segment-based approach in this field. This study, therefore, aims to fill this gap by employing two conventional customer behavior modeling approaches in the shopping list prediction and empirically comparing their performances. For this purpose, well-known machine learning classifiers are used for the prediction generation. The comparison is performed on a real-life dataset by conducting a set of experiments on a real-world dataset obtained from a grocery retailing company.

The paper is organized as follows. Section 2 describes the methodology used for shopping list prediction. Section 3 describes the experimental setup and results. Finally, Section 4 draws conclusions, summarizes the contributions of this work and outlines directions for future research.

II. PREDICTION METHODOLOGY

In order to predict the shopping lists of customers, this study uses customer behavior modeling approaches. These approaches build predictive models by utilizing customers' past purchase transactions and prominent predictive

algorithms. Prediction models built by the predictive modeling approaches estimate the probability that a certain product will be purchased in a transaction. The products having a probability value above 0 are sorted according to their probability values in the decreasing order. Thus, ranked shopping list is formed by selecting the top-N products from the resulting ranking.

In the subsequent subsections, we will give the details about, customer behavior modeling approaches, complementary method, predictive features and predictive algorithms, which are used in this study, respectively.

A. Customer Behavior Modeling Approaches

In this study, the predictive models of customer behavior are learnt in the following form:

$$y = f(x_1, x_2, \dots, x_n) \qquad (1)$$

where (x_1,x_2,. . .,x_n) are all the features which affect and describe a customer's purchase behavior, function f is a predictive model that can be learned via predictive algorithms and y is the probability that a particular product will be purchased in a particular transaction.

1) Individual-level Approach

The individual-level approach in this study builds a predictive model for each customer-product pair using past purchase transactions on a particular product of a particular customer.

2) Segment-based Approach

In this study, segment-based approach builds a predictive model for each <customer segment-product> pair utilizing the entire historical behavior data on the target product belonging to the customers of the target segment in an aggregated manner.

To use segment-based approach, customer segments must be formed. For this purpose, this study employs two-stage cluster analysis suggested by [16] and utilizes three features proposed by [17]. These three features relate to customers' purchasing behavior and they are namely, "average inter-purchase time", "average basket size" and "product variety". According to two-stage cluster analysis, Ward's hierarchical method is first used to determine the number of clusters (k) and K-means clustering method is then performed to separate the data into k groups.

B. Complementary Methods

Both individual-level and segment-based customer behavior modeling approaches suffer from data sparsity problems and thereby they may not produce predictions in some cases. In addition to this, they can generate prediction lists in different sizes. In such situations, it is impossible to make a fair comparison among these approaches. For the above reasons, we proposed a simple complementary method for each predictive modeling approach to add products to the top-N prediction list, when the number of predicted products is less than N.

For complementary methods, we chose the Most Popular (MP) technique (also known as most-frequent method in the domain of recommender systems [18]) which sorts the products according to their purchase frequency and simply returns N frequent products from this ranked list as recommendation. We proposed the MP method in three forms – individual popular (i.e. ranked products of each customer obtained from the customer's past records), segment popular (i.e. ranked products of each customer segment obtained from the customer's past records), and aggregate popular (i.e. ranked products of the whole customer base). All of these methods generate lists containing frequently purchased products that are potentially relevant to customers.

The complementary of each predictive modeling approach utilizes different MP techniques and Table I summarizes which predictive approach uses which MP techniques.

TABLE I. COMPLEMENTARY METHODS

MP techniques/Pred. Approaches	***Individual-level***	***Segment-based***
Individual Popular	1	na
Segment Popular	2	1
Aggregate Popular	na	2

According to Table I, the complementary method of individual-level approach uses individual popular and segment popular methods respectively to form the prediction list. For the same purpose, the segment-based complementary method utilizes segment and aggregate popular techniques respectively.

Each complementary method is used to reach desired prediction list size (N), and for this purpose, products, which are extracted by picking the top ranked items from the list formed by complementary method, are added to the end of the prediction list formed by the predictive modeling approach. Thus, both predictive modeling approaches with their complementary method can construct a prediction list, which contains a desired number (N) of products. Accordingly, the prediction lists produced by both approaches are in equal sizes, and it is possible to make a fair comparison among their performances.

C. Predictive Features

We determined nine features relevant to customers' shopping behavior (e.g. temporal information of the transaction, purchase interval time, the number of products purchased and the amount of money spent in the previous shopping occasion, etc.). We refer the reader to our previous study [17] for further details about features' types and definitions

D. Predictive Algorithms

In this study, five widely used and popular ML classifiers were employed for building predictive models. These are: logistic regression (LR), decision trees (DT), random forests (RF), support vector machines (SVM), and neural networks (NN). We chose the well-known C4.5 algorithm and the RBF kernel function for DT and SVM classifiers respectively. For neural network classification, we implemented a multi-layer perceptron (MLP) neural network with the back propagation algorithm which is the most widely used neural network [19]. Moreover, regarding MLP, we chose a single-hidden-layer network topology with a logistic activation function. Input layer of our network consists of nine neurons, one for each of the

predictive features, whereas the output layer has a single neuron which represents the target binary variable.

III. EMPRICAL COMPARISON

A. Data Description and pre-processing

The data used in this study has been extracted from the loyalty card system of a grocery chain and it contains almost 2 million purchase transactions of 16024 customers between October 1, 2012 and August 31, 2014. As part of preprocessing procedures, missing values and duplicate records were eliminated, and transaction records in the same day were aggregated for each customer. Moreover, all predictive features were generated for each record and, similarly, the features of customer segmentation were generated for each customer. Further details about the dataset and preprocessing procedures can be found in our prior study [17].

B. Experimental Setup

To conduct experiments, we used time-aware community-centered approach. In this manner, we sorted all transactions of the dataset according to their timestamps. Then, we used the first 60% of data as the training set and the next 20% of data as the validation set. The final remaining part (roughly 20%) of data was used as test part.

We built the predictive models using the training set and tuned the predictive algorithms' parameters achieving the best prediction accuracy on the validation set. Predictions were generated for each instance in the test set and the predicted results were compared with the true ones by computing corresponding performance metrics. Both training and validation sets (the first 80% of data) were also used for customer segmentation.

C. Evaluation Measures

For the performance evaluation, we used F-measure [20] and mRHR [21]. F-measure is the harmonic mean of precision and recall. These two measures are defined for our case as follows:

$$Recall@N = \frac{|pred@N \cap purc|}{|purc|} \qquad (2)$$

$$Precision@N = \frac{|pred@N \cap purc|}{|pred@N|} \qquad (3)$$

In these formulas, pred@N donates the Top-N prediction list for a particular transaction, and purc is the actual product set that the customer has purchased in that transaction. Both recall@N and precision@N measures were computed by using micro-averaging method. For his purpose, firstly, pred@N, purc and |pred@N ∩ purc| values were computed for each customer's transaction separately, and then these calculated values of all the transactions were aggregated. Finally, recall@N and precision@N measures were computed based on these aggregated values, and F-measure was calculated using these two measures.

mRHR was another metric used in this study and it is a modified version of average reciprocal hit-rank (ARHR) metric which can be used for the ranking evaluation of in top-N prediction and recommendation lists in the cases where users or customers have multiple preferences at a time or a specific time interval. It shows how close the predicted items to the top of the ranked prediction list. It is calculated as follows:

$$mRHR = \frac{1}{\#\ of\ preferences} \sum_{i=1}^{N} \left(\frac{hit_i}{rank_i}\right) \qquad (4)$$

where hit_i donates if the predicted product preferred by the user, then it gets true (1), otherwise it gets false (0). N is the length of ordered prediction list and $rank_i$ is the ranking position of the preferred product in the list. Similarly, this measure was calculated via micro-averaging method. The values of number of preferences and (hit_i / $rank_i$) were recorded for each customer's transaction distinctly, and their values pertaining to whole transactions were aggregated. Thus, mRHR metric was computed based on these aggregated values (for details on mRHR metric see [21]).

D. Customer Segmentation

According to this dendrogram produced by Ward's hierarchical method, the best number of clusters is three, and then customers were segmented into three groups using K-means clustering method. Thus, segment-based approach used these resulting customer groups in the experiments conducted in testing phase.

E. Parameter Settings

To determine the best combination of parameter values for each algorithm (except for LR), we used a trial and error approach in which an exhaustive search is performed with a range of parameter values. Therefore, training-validation procedure was repeated multiple times and best parameter values were picked based on the maximum predictability of the predictive algorithms for the validation set. The parameter estimation results of four learning algorithms namely, SVM, ANN, DT and RF are presented in Table II and the best values of each parameter were used for each predictive algorithm in the experiments conducted in testing phase.

F. Results

In this section, we report the experimental results to evaluate the performance of customer behavior modeling approaches in the shopping list prediction. Figures 1-5 demonstrate the F-measure and mRHR results for each approach with different machine learning techniques across a wide range of prediction list sizes.

TABLE II. PARAMETER ESTIMATION RESULTS

Predictive Algorithms	*Parameters*	*Range of values*	*Best Value for Individual-level*	*Best Value for Segment-based*
SVM	cost	1, 10-90 (an increment of 10)	70	70
	gamma	0.001, 0.01, 0.1, 0.5, 1	0.001	0.5
NN	# of hidden layer nodes	1-10 (an increment of 1)	3	3
	learning rate	0.1-0.9 (an increment of 0.1)	0.2	0.9
DT	min # of instances per leaf	2-9 (an increment of 1)	2	2
RF	# of trees	50-500 (an increment of 50)	400	400

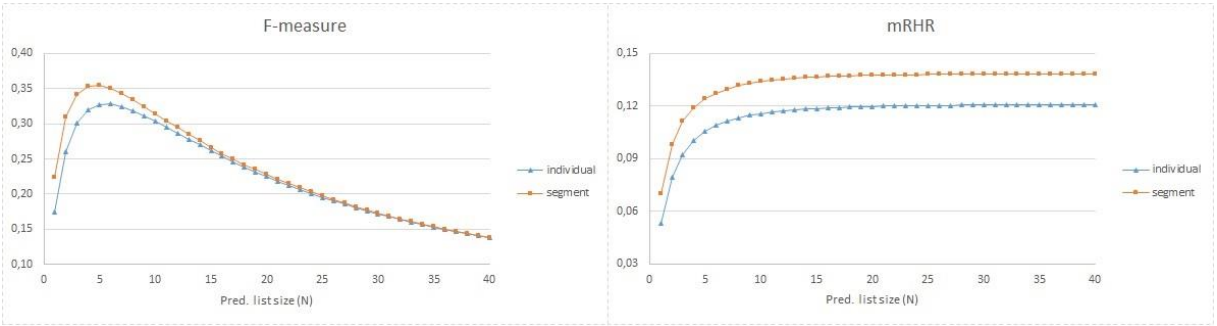

Figure 1. Comparison of customer behavior modeling approaches with LR

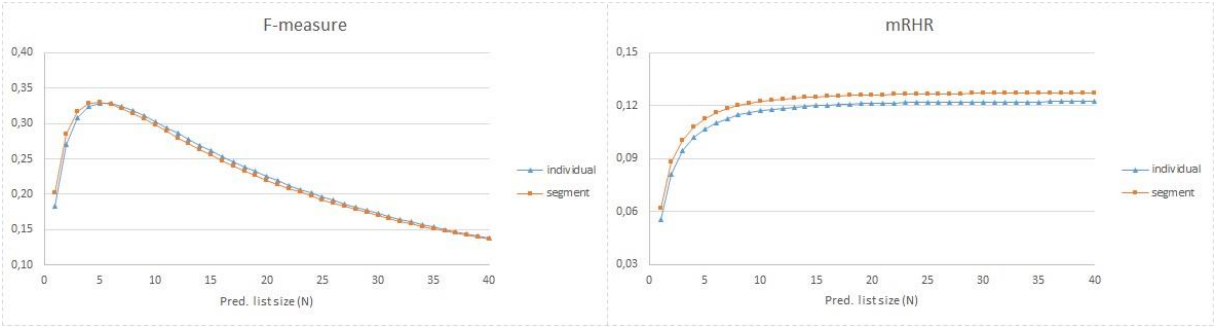

Figure 2. Comparison of customer behavior modeling approaches with DT

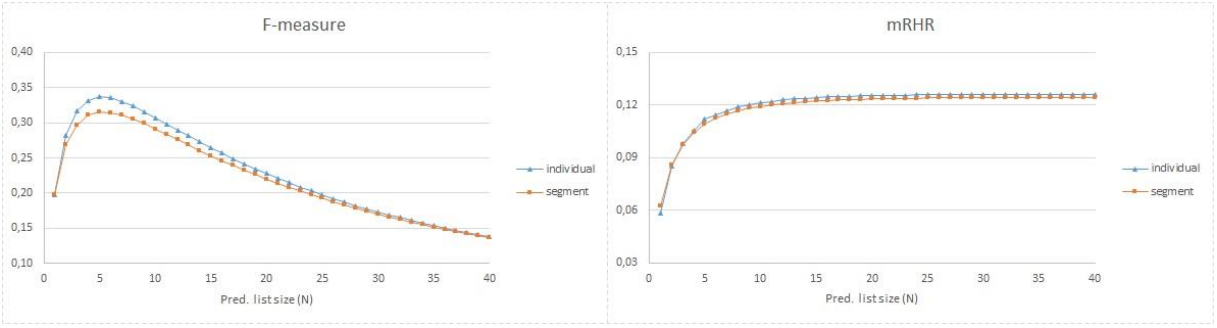

Figure 3. Comparison of customer behavior modeling approaches with RF

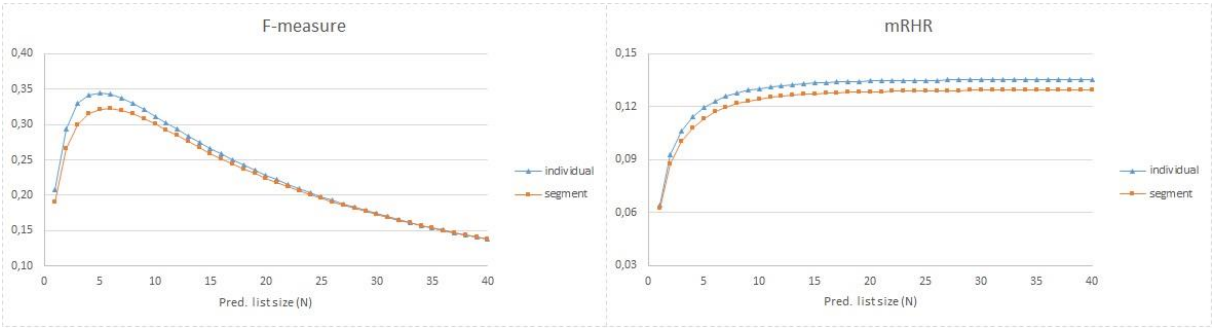

Figure 4. Comparison of customer behavior modeling approaches with SVM

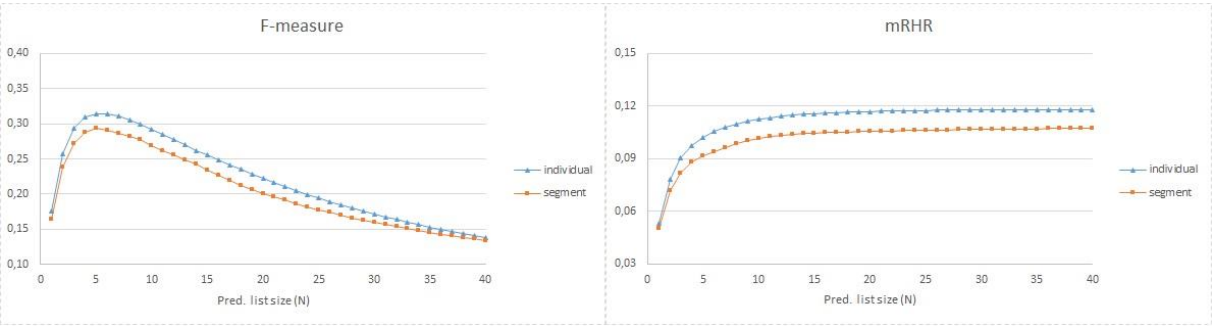

Figure 5. Comparison of customer behavior modeling approaches with NN

In our case study, the results show that comparison among the customer behavior modeling approaches varies depending on the machine learning techniques used. It can be observed from the plots that the individual-level approach dominates segment-based approach when they use RF, SVM, and NN. In contrast, segment-based approach outperforms the individual-level approach when LR and DT classifiers are used with these approaches. Therefore, in the shopping list prediction, SVM is better suited for individual-level approach, while LR is more suitable for segment-based approach.

Additionally, it is clear from the curves that prediction list size (N) influences the performance. Performance of both measures exhibit a certain pattern which is consistent for both predictive modeling approaches with all machine learning algorithms. As seen in the plots, when N is small, there is a gradual increase in F-measure. It reaches its maximum value at around N=5 and starts decreasing thereafter. Similarly, for the curves of mRHR, the increases are drastic at the beginning, but gradually slow down, after N exceeds around the values of 5. Further, with higher values of N, the value of mRHR becomes constant. Therefore, results of both F-measure and mRHR imply that 5 would be an optimal value for prediction list size (N) in our case study.

A performance comparison of customer behavior modeling approaches with each machine learning classifier is presented in Table III. Note that, for these results N was taken as 5 since this value is the optimum for the prediction list size as stated before.

TABLE III. COMPARISON OF CUSTOMER BEHAVIOR MODELING APPROACHES WITH DIFFERENT ML ALGORITHMS

Approach	***ML Algorithm***	***F-measure***	***mRHR***
Individual-level	LR	0.328	0.100
	DT	0.329	0.107
	RF	0.337	0.112
	SVM	**0.345**	**0.120**
	NN	0.314	0.102
Segment-based	**LR**	**0.355**	**0.124**
	DT	0.330	0.112
	RF	0.315	0.109
	SVM	0.322	0.113
	NN	0.293	0.092
(prediction list size (N)=5)			

For each approach, ML classifier giving the best performance is bold-faced in the table. As seen in Table III, segment-based approach exhibits the best performance among all performances, when it uses LR classifier as the predictive algorithm. Using LR classifier, segment-based approach improves the F-measure from 0.328 to 0.355, and mRHR from 0.1 to 0.124. They are improvements of 8.2% and 24% respectively. The individual-level approach with SVM algorithm follows this best version respectively.

Regarding the performance of machine learning techniques in the shopping list prediction, we can observe from Figure 1-5 and Table III that SVM is the best by providing remarkable performances for both customer behavior modeling approaches. Moreover, in this study, LR

and RF are other algorithms performed well with each approach.

IV. CONCLUSION

Accurate prediction of customers' shopping baskets provides an important contribution to effective customized services and one-to-one marketing actions in retail industry, and thereby can lead to maximize customer satisfaction and company profitability. In this context, this study proposes an empirical comparison of two state-of-the-art customer behavior modeling approaches for customer's individual shopping list prediction. The prediction performances of these approaches has been evaluated on a real-world dataset obtained from a grocery retailing company by applying different machine learning classifiers.

The results show that the individual-level approach outperforms the segment-based approach when certain machine learning classifiers are used, and is inferior when the other machine learning classifiers are employed. This indicates that the performance of customer behavior modeling approaches depends on the machine learning algorithm used, and we can conclude that testing different ML algorithms is important, before making a choice for the customer behavior modeling approach in a shopping list prediction problem. Moreover, in our case study, the best prediction performance is obtained when the segment-based approach is used with LR algorithm. SVM, as compared to the other classifiers, mostly perform well for both customer behavior modeling approaches. Another interesting finding of this study is that the high accuracy can be achieved using a prediction list size (N) covering only a fraction of items (around 5 items).

This study provides practitioners with a suggestion on how to pick the optimum customer behavior modeling approach for the shopping list prediction in an effective manner. This study also presents guidance for researchers in predicting shopping lists using customer behavior modeling approaches. In addition to these notable implications, a couple of directions can be drawn from this study for further studies. In this study, the performance comparison of customer behavior modeling approaches have been applied for the supermarket-shopping domain. In further studies, it is worthy applying these approaches to other shopping domains to validate the findings drawn from this study. Another future research issue would be to test the performance of customer behavior modeling approaches with different set of features and other machine learning classifiers.

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SNA-based artificial Call Detail Records generator

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***Abstract* - Research involving Big Data often has to deal with the problem of data availability. Real-life data involving people and their activities is usually tied with various issues of privacy, security and secrecy, which results in difficult barriers which need to be overcome before the research can even start. In this paper we suggest an approach which can reliably provide researchers with an arbitrary amount of synthetic Call Detail Records (CDR) data which would exhibit a high level of similarity with a corresponding real-life dataset. We base our approach on a simulator whose functionality is derived on results of an exploratory analysis performed on a real-life dataset which represents a social network of users with records of their activities. In this paper we concentrate on generating CDR data used in telecommunications industry, although the approach is applicable in the other domains too.**

Keywords – Big Data; CDR; social network; SNA; synthetic data; exploratory analysis

I. INTRODUCTION

Today's research in the field of Big Data commonly approaches the problem of data availability. This is especially true for real-life data which involves information about people and their everyday activities. The cause of this problem are people's concerns about protection, security and secrecy of their private information. For these reasons, we suggest an approach which can provide researchers and analysts with synthetic datasets that have a high degree of similarity to real-life datasets. Additionally, for the fraud and anomaly detection research to be possible, these datasets must have such frauds and anomalies adequately incorporated within them. Although this approach is applicable in various domains, in this paper, we focus on generating CDR data.

CDR stands for Call Detail Records, which are records that are widely used in the telecommunications industry for numerous reasons, such as billing and fraud detection. This paper suggests the development of a parameterized generator of synthetic CDR files that can later be used for testing predictive analysis algorithms. Furthermore, the generator could produce an arbitrary amount of data which could help in implementing and testing information systems based on Big Data technologies that utilize the concepts of parallel processing and linear scalability.

It is crucial that artificially created records have a high level of similarity to real-life patterns and emulate people's habits. Because of this, an approach based on social network analysis (SNA) is suggested. Concretely, this means that real-life CDR dataset is used as data for exploratory analysis of user patterns. This exploratory analysis involves creating a social network of users to which the CDR data adheres to, and then applying SNA techniques in concordance with regular exploratory analysis to gather information about users' habits and create user profiles which concisely describe how the users use the telco network, in other words – their behavioral patterns. After creating various types of profiles, they can be assigned to the CDR-based social network, or a completely new social network which is artificially created or collected from another source.

But, the data must not be too similar to the actual starting real-life CDR dataset, because otherwise it would not be useful for exploring new ideas in fields such as fraud detection. With that in mind, we propose the idea of a CDR generator which works stochastically within certain constraints. The input of the generator is a social network represented with a directed graph, and two lists, one of user types and their probabilities of existence extracted in the exploratory analysis and the other of call likeliness for each user type in different times of day.

The paper is structured as follows: Section II presents related work on this subject. Section III provides an overview of the implemented generator from a high level of abstraction. In Section IV, the reference implementation of the CDR generator is described. Finally, in Section V, a conclusion is given.

II. RELATED WORK

We have analyzed two types of related work to this paper: works focused on synthetic data and its usage and works focused on analyzing telecommunication datasets.

Using a synthetic data generator can provide a valuable insight into the original data and the analysis of it. The primary target of a synthetic data generator are fields with expensive, sparse or unavailable data, in which Telco data belongs to, due to tightening privacy laws and competition between companies. A general-purpose generator might be possible to achieve using different data definition languages, semantic graphs and generation scenarios. [1]

The generator should be focused on parallel processing and matching patterns between original and generated data. [2]

While both of those abstract synthetic data generator definitions include points, we have implemented in the current version or plan to implement in next versions, we do believe that, in this particular problem, there should be a large amount of data pre-processing and thus a more direct approach is the right one.

The article [3] shares a lot of similarities with our problem, authors mention some of the key points why there is a need for synthetic data, they state that simulation is the way to generate CDR, but they do not mention actual strategies of exploratory analysis or implementation details.

In [4] author present their approach of generating synthetic data based on extracted distributions from existing data. Their proposed generator is based on radial basis function networks, which learn sets of Gaussian kernels. One important difference between approach described in this paper and ours is that our intention is not merely to mimic existing data, but also to be able to manually insert behavior not existing in the original data. For example, if we deal with fraud detection, we can willfully insert nodes whose profile adheres to expected fraudulent behavior.

Finally, in [5] an overview of standard synthetic data generation methods, and an approach is suggested similar to the one published in [4]. A comparison between an approach described there and ours can yield similar conclusions as provided in the previous paragraph.

This paper focuses only on CDR data, but with the aim of building a generator which can take any social network as an input (as long as it is in a right format) and generate data such a network would produce, with respect to call likelihoods in our real-life CDR dataset.

III. CDR GENERATOR OVERVIEW

A. High-level system architecture

CDR generator described in this paper is the first step to a solution which would, once implemented, allow for generation of arbitrarily sized synthetic CDR dataset based on pre-existing SNA topology. However, one of the intended goals is also to provide a suitable platform where generators of fraudulent behavior can be integrated into the simulation system and then allow for creation of CDR data which will also contain rows which represent results of fraudulent behavior, but which will not be deterministic due to randomized simulation-based mechanisms used to generate the synthetic dataset.

Figure 1. shows the high-level system architecture which is our ultimate goal. First, available real-life CDR data has to go through an extensive exploratory analysis which will enable profiling users' behavior on individual and aggregated levels. Careful modelling of users' behavior is required. It must be both true to real-life nature of telecommunication services usage by different type of users and concise enough to be implementable as a randomized programming script. An important part of this process is creating a social network from this CDR from which many useful information can be drawn using standard SNA (social network analysis) methods, but which can also serve as a foundation for the simulation-based approach for the CDR generator as the edges of this social network would represent main communication channels between users.

A social network where each node represents a telco user which has an assigned profile to it is then used as an input to the CDR generator. As stated, this social network may be the same one from the real-life CDR data, whereupon we may get a synthetic CDR dataset which can then be used as a stand-in for yet-unavailable future dataset pertaining for the very same telco network we are analyzing. However, we are free to use a completely new social network (in the form of an edgelist which will contain both ids and connections of our chose network), or augment the existing network with additional nodes with specific behavior.

Once the social network with appropriately profiled nodes is prepared, and additional parameters pertaining to the general behavior of the system are inputted, the CDR generator starts a simulated time flow where the nodes randomly create calls to each other. Depending on the profile, a node will create calls in various "times of day", and it will be able to call both nodes it is currently connected with (existing graph connections) but also nodes it doesn't have a pre-existing connection (simulating calls to parties a caller has never called before). Each call is recorded in the form of storing the id of call initiator, call receiver, timestamp when the call was made and length of the call. To simulate the real-world calls, the simulation must ensure that during one call another cannot be made to any of the currently engaged parties, but the attempt should still be recorded so the information about it is not lost.

The analyst has a certain amount of control relating to the size of the dataset through the means of choosing the size of input social network, profiling the nodes or deciding how long the simulated time flow would last. Actual size will be highly dependent of these variables

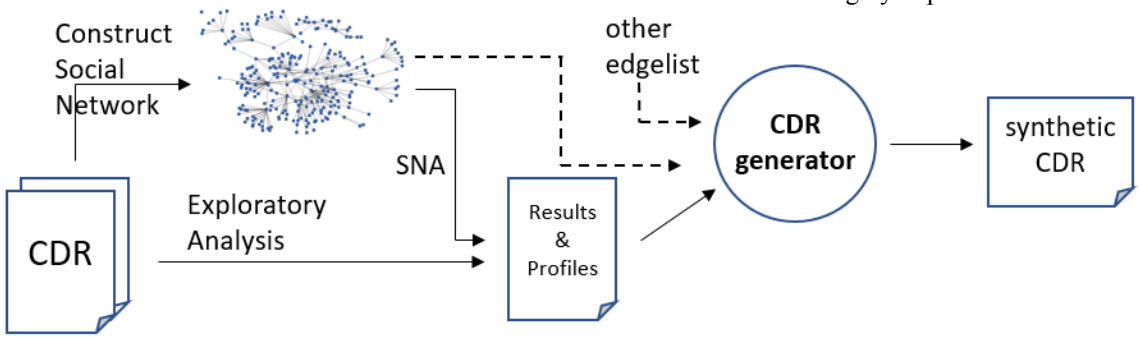

Figure 1. architecture of CDR generator prototype

but also random behavior of the nodes / simulated telco users. For the purposes of various Big Data testing, the analyst can always opt to choose larger networks or longer time periods, although it is expected that at a certain point the issue of scalability will need to be addressed with appropriate introduction of suitable Big Data technologies.

B. Prototype specification

This paper will describe the initial steps taken to implement the feature-full CDR generator described in the previous paragraph. In this first phase of our research, we have procured a sample of a real-life CDR dataset, performed an exploratory analysis on it and implemented the first version of the CDR generator which, while not having still all the intended features, is capable of creating synthetic CDR dataset based on SNA-related input parameters.

Therefore, in the following paragraphs we will describe in detail our 3-phased approach: first extracting the parameters from a real-life CDR dataset, then initializing a generator with extracted parameters and finally, running a generator, which randomly generates a CDR dataset. All phases can be streamlined and merged into one procedure, although the first phase should always give the same results and thus only its output can be used for phase 2.

The real-life dataset we have been working with has ≈ 24 million calls from ≈ 1.5 million users. It is a billing dataset, so there were no missed or denied calls in it, which meant we had to manually create likelihood for missed (unanswered) calls which was made possible through consultations with the domain experts. Likelihood for calls which were denied because the called party was busy are automatically implemented by the nature of our generator algorithm, which will be described later. The dataset has 26 distinct features for each call, some of which are semantical duplicates or not interesting for this type of problem. We have selected *call id*, *call date*, *caller id*, *receiver id* and *duration* to be the relevant features for this task.

Exploratory analysis was focused on extraction of parameters which model likelihood that a user would make a call at specific time on a given day. To tackle the task, we have defined two new call features - the weekday at which the call was made and at which half-hour of the day (0:00-0:30, 0:30-1:00, …) it belongs. Figure 2. shows total number of calls for each weekday at each half-hour. There is a clear interesting outlier on Sunday between 0 and 1 AM which exists due to the New Year's Day of 2017. Based on statistical and visual correlation, we have merged days Tuesday through Friday in our model to improve efficiency and interpretability of the analysis. Finally, we have counted calls by caller, weekday and half-hour and then normalized the data to 0-1 interval by the max value. Then we grouped users by those features and got the intensities for each user group on each weekday at each half-hour.

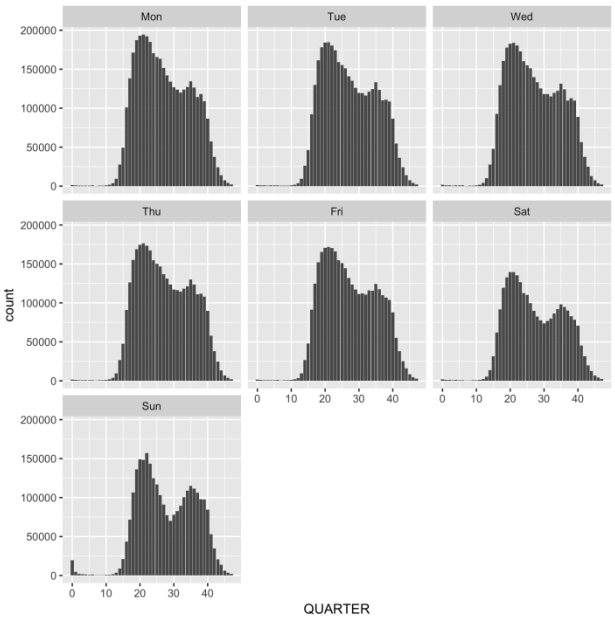

Figure 2. Total call number per weekday/half-hour

The initialization process is fairly simple, yet incredibly powerful: the generator takes in a user social network as a list of nodes and its neighbors (modeled by a directed graph), a list of user groups and the probability of each group and a dataset of intensities for each user-group, on each weekday at each half-hour. After storing the social network, each node is assigned a user-type randomly based on extracted probabilities for the group. Initializing the generator this way solves both problems stated in the beginning of the article - the data is reliably similar to actual data, but it is variable enough for exploring different Telco problems.

The generator goes for each possible time part (second, minute, hour, day, week, etc.), for every user in a time part and then generates a random number which is compared to the likelihood of a user making a call at that particular moment. If the user does make a call, the called party is randomly taken from the user's neighbor nodes (i.e. nodes which the user calls often) or, with smaller probability, from the whole network (because there is always a chance one would call a random, before that, unrelated person). If the called party is busy, the call is declared busy, otherwise another random is generated and compared to the probability of missed call. Both users are then declared busy and cannot initiate a call until their call is over. The duration of the call is also randomly generated based on the duration distribution extracted from initial dataset.

An alternative, more efficient, approach to the generator is that at any given moment, for a user type, a number is generated which represents the amount of people who initiate a call and then the callers are randomly selected out of the free user's pool for the user type.

The result of the generator heavily depends on the underlying social network. We have toyed with different networks and gotten vastly different results. Our final input was a e-mail network from Stanford.[4][5]

The underlying social network can also be extracted from the initial CDR dataset. The SNA approach would be different depending on the features available, but the general idea is extracting close and distant nodes for each node, again, grouping that data into user types and then connecting the users in the dataset into a network. Unfortunately, due to our dataset being only from 3 months, there is a vast majority of users which have made a single digit total number of calls, mostly less than 5 and thus, our own creation of a social network would not result in a useful data. But the possible risk of that approach is overfitting to the original data.

IV. REFERENCE IMPLEMENTATION

Our technologies of choice for implementing the solution were programming languages R and Java.

We used R for the exploratory statistical analysis of a real-life dataset that contained telecommunication records for a period of three months. After completing all the data processing work described in chapter III, we have used k-means algorithm to cluster based on their calling habits. We have tested the clustering both using the algorithms mathematical error and manual inspection of generated clusters and have found the right number of user types to be 7. Again, the recurring problem are users with total number of calls in single digits because they fail to model any actual distribution. They all have been squeezed into a single group with averaged-out likelihoods because k-means algorithms return the center of a cluster as a cluster's features. Figure 3 shows distribution between actual calls and user-cluster they have been assigned to. We can see that the clear majority of users is in cluster 0 (98+%, to be exact), which are those users with single-digit total number of calls. Group 6 is an interesting one because it contains only one user and calls only during weekdays, which clearly means it's a business user.

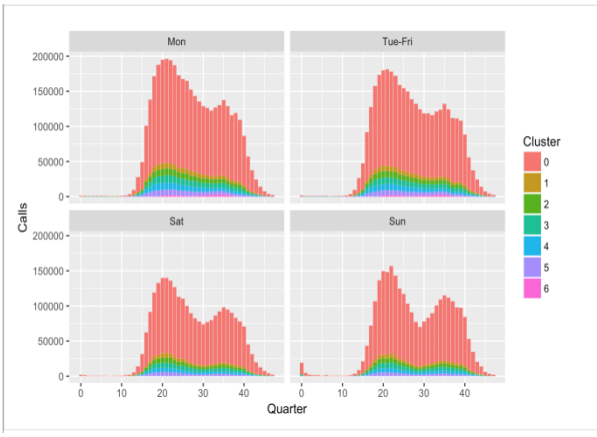

Figure 3. Distribution of total calls per day, per user-cluster

For the generator itself, Java was used. Our generator consists of several custom classes, each with its own separated concern. During the initialization, the generator loads several input configuration files in .csv (comma separated values) format. These files contain the network of anonymized users (a directed graph structure serving as a sample network) and call distributions or intensities for different types of user profiles and week days. After the files are parsed, each user in the input network is assigned with a certain probability to a specific cluster, which makes up this user's profile (essentially the user's calling habits). There are also two more input arguments - the number of days (integer) for determining the wanted period of days for generating data and the desired type of day in a week (different days have different calling patterns; weekends vs working days).

With all input parsed, the generation algorithm starts with iterating over the seconds in a 24-hour interval or more, depending on the number of days parameter given.

Then in each second picks all users in the graph and, taking into account the probabilities of the picked users call profiles, determines if a call event occurs. Call can occur between direct neighbors in the social network or, with the small percentage, between non-adjacent users in the graph. If the call happens, a row in the output CDR file is appended and the user is marked as busy for the length of the call duration. Call duration is calculated randomly. Busy and not responded calls are also noted in the output file, if they occur. A sample of the generated CDR file can be seen on Figure 4.

```
457,294,13:43:26,219
368,150,13:43:28,348
526,232,13:43:38,238
667,264,13:43:49,-1
252,48,13:45:23,308
951,213,13:46:19,53
357,424,13:46:33,381
860,338,13:46:42,51
777,821,13:46:55,8
311,420,13:46:56,42
922,205,13:47:21,33
736,856,13:47:37,132
...
```

Figure 4. Example of resulting synthetic CDR dataset

The first and second columns represent calling and receiving parties, the third column marks the timestamp of the call and the last column shows the duration of the call (in seconds), with special flags for unanswered and busy calls (-2 and -1 respectively).

At the end we executed simple exploratory analysis on the output CDR and found the result to be satisfying.

V. CONCLUSION

In this paper we present the results of our research in the field of exploratory analysis, social network analysis and generation of synthetic datasets. Direct motivation for this is a need for synthetic datasets in telecommunication domain for research purpose on fraud

and anomaly detection. Synthetic data is needed because of privacy concern of real-data users and unavailability of large enough real-life datasets.

In this paper we use real-life telecommunication data for exploratory analysis. In analysis we found different clusters of people with similar behavior. We use results of analysis and social network as input for CDR generator. Each user from social network is assigned to cluster with the probability obtained from analysis. Each cluster has described users call rates, depending on day of the week and time of the day, and with that we realistically simulate real-life people's call habits to output the CDR file.

Research work done in this paper represents the first step in building a full-fledged solution which, while focusing primarily on the telecommunication domain, should also be feasible for implementation in other domains where data relevant for analysis revolves around entities which communicate with each other via various means of communication. Examples of this can be social network platforms (where the communication revolves around messages, photos, likes and comments), internal communications inside companies (using e-mails, internal telephone or messaging systems) etc.

Plans for future research and development on this topic include implementing known and unknown anomalies and frauds, implementation of better scaling using parallelization algorithms, testing new clustering method to try find better results and expend parameterization of the generator. The real-life dataset has geographical information and we plan to do exploratory analysis with a mathematical model of that data. We also plan to abandon half-hour for a model of distinct time-of-day info (early night, morning, noon, etc.) with calls fuzzily belonging to each of those.

We also suspect that the real-life dataset we dealt with, due to all the users with single digit number of calls in 3 months, was poorly sampled and expect the provider to test its sampling method.

ACKNOWLEDGMENT

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Consulting Experience Regarding Business Process Management Software in Croatia – A Case Study

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Abstract **– To the best of our knowledge there is no generally accepted framework for a successful business process management software (BPMS) adoption. The reasons for this are, for sure, complexity and an extensive nature of BPMS. In this paper we describe our work on evaluation of the functionalities of BPMS aiming to define basic guidelines for BPMS selection. The research was based on case studies and gathering insights on consulting and customer experience by using semi-structured questionnaires. The goal of research activities within this broader project part was to systematize, analyze and evaluate the functionalities of business process management software and systems, in order to define guidelines for their selection, and further on to develop a guide that would be used by companies in selecting business process management software. In this paper we present one of the case studies dealing with BPMS from our research as well as key experience factors recognized in Croatia that influence later BPMS selection process.**

Keywords – business process management; BPM software; case study;

I. INTRODUCTION

Business Process Management (BPM) is a systematic approach that unites knowledge from information technology and knowledge from management sciences and applies this to operational business [1]. It has attracted substantial attention in recent years because of its potential for increasing productivity and saving costs. Furthermore, today there is an abundance of BPM software and systems. These systems are generic software systems that are driven by explicit process designs to enact and manage operational business processes [1]. On BPM software market, different names are used to distinguish categories of BPM software such as: BPM software, suite, system and tool. In this paper we use a generic term "business process management software" (BPMS) to describe all these categories.

Selecting the right BPMS for a company can be challenging for several reasons. First, BPM software market is a complex market and features and capabilities vary greatly across vendors. Second, determining what your business needs isn't always straightforward. A variety of possible approaches, instructions and tips on how to find the ideal BPMS for the company can be found. Some of them are presented in [2][3][4].

The foremost indicator of good BPMS selection is achieving improvements in the business outcomes. When the efforts towards BPMS don't produce business outcomes, progressive technology implementation only generates disappointments [5] [6]. To accomplish the benefits from the BPMS, it is essential for the company to first outline the business drivers for BPMS implementation, identify the targeted processes and have a clear schedule on deployment strategy.

Within the PROSPER project we are conducting a research on the application of business process management and business intelligence concepts in companies. One of the objectives of the project is to "systematize, analyze and evaluate the functionality of business process management software, define guidelines for their selection, and develop a guide that would be used by companies in selecting business process management software." For this purpose we have conducted interviews with customers and business process management consultants who have participated in business process management implementation projects. Apart from the Republic of Croatia, we are also conducting this research in Slovenia, Austria and Bosnia and Herzegovina. One of the companies that have participated in the research as well as in the interview is in the focus of this paper.

The structure of the paper is as follows. After the introduction, theoretical background relevant to this paper is presented. A description of the company that is in the focus of this paper, its position on the market, the scope and level of BPMS adoption is given in section III. The case study findings are presented and analyzed in section IV. Our conclusions are drawn in the final section.

II. RESEARCH METHOD

Lots of research papers address specific aspects of business process management using case study as a research method. Different facets of BPM space from modelling [7] to implementation [8] [9] are covered. One of the reasons for the acceptance of case study as a research method is that they enable researcher to go beyond the quantitative outcomes and understand the

This work has been fully supported by the Croatian Science Foundation under the project PROSPER - Process and Business Intelligence for Business Performance (IP-2014-09-3729).

contextual conditions through the player's perspective [10]. We have used the case study method to collect qualitative but also quantitative data on several BPMS implementations and one of them is in the focus of this paper.

Interviews and questionnaires are the prevailing method in qualitative IS research, and they can be open ended, semi-structured, structured or survey type [11]. We have used a semi-structured questionnaire that was filled out during an interview the member of our research team carried out with participants of the study. The semi structured nature of the questionnaire enabled us to gather both, quantitative data for topics that can be evaluated numerically and qualitative data such as data describing the demographics of the company, background of the interview participant, context of the BPMS project and other environmental information.

Our questionnaire comprises questions from 5 domains or thematic units: (i) Context questions; (ii) Case (BPM project) and BPMS related questions; (iii) Evaluation of BPMS characteristics/features; (iv) Evaluation of BPMS success and (v) Company demographics. The first two and the last two thematic units permit unstructured answers written in natural language while the central part of the questionnaire (Evaluation of BPMS characteristics/ features) assumes numerical grades. Numerical grades are valuable in comparing cases between themselves and also in comparing the opinions of different stakeholders on the same case study.

In the BPM space, three primary stakeholders are recognized: namely the users (companies), the vendors, and the experts are recognized [12]. In this phase of research we primarily wanted to get an insight into the standpoint of (i) the expert and (ii) the practitioner, i.e. end user while the vendors are left aside. We consider experts extremely important because they, to a large extent, possess the knowledge that can align user and vendor agendas and encompasses organizational, technological as well as conceptual challenges. On the other side, end users are crucial for the adoption of BPM solution. For an expert or specialist, it is not necessary to be an employee of a company where the BPM project is implemented while it is implied for the end user (practitioner). Due to the complexity of contemporary BPMSs and relatively weak acceptance in the local environment, it is not uncommon for a specific implementations to be carried out by a business process management consultants - employees of a specialized companies, experts in the field.

An essential element for success in these semi-structured interviews is the interviewers' expertise and preparedness in terms of moderating and clarifying the background of questions. Hence, in our study, interviews were conducted by the most experienced member of our team who, after introduction into research topics, briefly described the structure of the interview to examinee. Introductory questions (such as those depicted in ***Table 1***) from the first thematic unit serve for getting background information on interview participant. Separate sets of questions were prepared for experts and for practitioners.

Table 1 Selection from the introductory questions for the practitioner

Q1.1:	How did you get acquainted with Business Process Management (BPM) concept?
Q1.2:	How would you define your knowledge on BPM?
Q1.3:	What would you consider to be success factors of BPM initiative in your company?
Q1.4:	What are the most important results of BPM in your company?
	…

Answers to questions from the second thematic unit (***Table 2***) provide us with information about BPMS project specifics. This part of the questionnaire, together with the first part, is very much a basis for section III of this paper which describes the specifics about the company and the BPMS implementation for the case study in the focus of this paper.

Table 2 Selection from the questions related with BPM project and BPMS

Q2.1:	Can you describe specific project in which you implemented BPMS?
Q2.2:	Please select one or more phases of the BPM lifecycle related to your project goals: a) Process identification b) Process discovery c) Process analysis d) Process redesign e) Process implementation f) Process monitoring and controlling
Q2.3:	What was the reason for applying BPMS within the project?
Q2.4:	Did you use a specific methodology for BPMS implementation?
	…

The third part of the questionnaire aims to gather data on experts' and practitioners' opinion about BPMS aspects we consider relevant. Prior to preparing this part, we conducted extensive research of scientific and professional literature to identify the features of BPMS relevant for evaluation and selection of business process management software. The partial results of this research is given in our prior work [13]. Evaluation and selection of BPMSs is complicated, costly and time consuming process, while the success of the selection depends on the specific needs of each company. Taking this into account, we have no ambitions in defining universal criteria to generate recommendations for a specific BPMS product currently present on the market. We have limited ourselves to identifying the characteristics of BPMS on which a company should pay attention when it comes to the BPMS choice situation. Our research resulted in establishing 5 categories of BPMS features: BPMS capability, BPMS compatibility, BPMS complexity, vendor's reputation and maturity and implementation costs. Each category incorporates a number of BPMS

features represented with separate question in our questionnaire as can be seen in ***Table 3***.

Table 3 Selection from the questions related with evaluation of BMPS characteristics

BPMS capability	
CAP-1	Process modelling, analysis and design
CAP-2	Business rules
CAP-3	Reporting, analytics, monitoring
CAP-4	Social BPM
CAP-5	Process strategy subsystem
CAP-6	Low-code development
CAP-7	Enactable models and process engine
CAP-8	Mobile & tablet functionalities
CAP-9	Web platform, cloud capabilities
CAP-10	Security and reliability
BPMS compatibility	
COMPA-1	Existence of compatibility
COMPA-2	Simplicity of integration
BPMS complexity	
COMPL-1	BPMS implementation complexity
COMPL-2	BPMS use
COMPL-3	BPMS user interface
Vendor's reputation and maturity	
REP-1	Vendor's maturity
REP-2	Presence on a local market
REP-3	BPMS documentation
REP-4	BPMS installation and maintenance
Implementation costs	
COST-1	BPMS implementation costs

This thematic unit assumes selecting numerical grade or (how we called it) the level of importance on the scale 1 to 5 meaning: 1 = Non Important At All; 2 = Of Little Importance; 3 = Of Average Importance; 4 = Very Important; 5 = Absolutely Essential; X = don't know. The section IV of this paper is based on data from this part of the questionnaire.

The fourth part of our questionnaire (***Table 4***) aims to collect data on experts' and practitioners' impressions and satisfaction with the BPMS implementation.

Table 4 Selection from the questions related with evaluation of BPMS success

Q4.1:	Did implemented BPMS meet your requirements?
Q4.2:	Once the project was finished, would you evaluate the importance of BPMS characteristics/ features differently?
Q2.3:	Please describe the BPMS functionalities you have applied during the project.
Q2.4:	If you could do the project over again, would you apply any other functionality and why?
	…

The participating companies were identified through a judgmental procedure, based on the following factors: (i) the company applies BPM methodology (to some extent) while dealing with business process management and implementation, (ii) there is an ongoing project in the company with the business process (or few of them) implementation using the BPM methodology and one of the established BPMS products. Participants of the interview were asked to evaluate the BPMS characteristics twice – at the beginning and at the end of the BPMS project. Some of them remained at their initial ratings, but some have changed their evaluation grades.

The critical factor was the company's willingness to participate in the research. Given all the above, four companies participated in the study and our research includes four pairs of insights. Each pair of insights depicts one case - from the expert and from the end user standpoint. Unfortunately, one of our case studies had to be rejected so we ended up with three cases. It was excluded from further considerations because of the lack of implementation, monitoring and control phases of the process. In this particular case only phases of process identification, detection, analysis, and redesign were included. For this reason, interviewed participants from this specific case were not able to evaluate the capabilities of BPMS competently.
One of the remaining three cases is in the focus of this paper and more details is presented in the next sections.

III. CASE STUDY CONTEXTUAL DATA

The case study presented in the rest of the paper is focused on a company in transport sector (in the following text Company or Case study) – an airport in Croatia. It is an important airport for summer holiday season offering flights to various European cities.

From an organizational perspective, Company deals with their business processes management activities successfully. Due to geographical limitations (inability to build new runways because of sea/mountains proximity), airports' only way of capacity increase is business process optimization while using the existing runway. Company has established a Business Process Management department, responsible for performing BPM activities including but not limited to process design and analysis, process performance monitoring, data visualization & dashboarding and ARIS platform [14] administration. BPM organizational unit members within the Company have a high level of practical knowledge and experience in BPM, and are attending BPM educations and conferences on a regular basis in order to stay up to date with the latest trends and technology. The BPM approach of this company can be classified as continuous and "by the book". The practitioner who participated in our study recognizes the role and importance of BPM for a company's success. A high level of conceptual but also practical knowledge of BPM makes him a suitable participant in the research and questionnaire. The person from whom we have received an expert insight is an employee of a consulting company that has a long-term cooperation with the Company. Expert from our case study is a senior consultant and BPM projects manager who participated as a team leader on this particular case with six other consultants.

The beginning of BPM at Company dates back to 2002, when business process repository was created. Since the beginning, Company has been using ARIS technological framework and business process management software, and AVE process management methodology. AVE presents a proven ARIS Value Engineering methodology, which contains a combination of a verified consulting approach based on the life cycle of business process management.

Since 2002. until 2018. various BPM projects were implemented at the Company covering all of the phases of BPM lifecycle (listed in ***Table 2*** under question Q2.2). Implemented project activities included:

- *Process identification* – identification and design of process landscape, process owner definition, definition of strategic importance of processes, definition of process goals, BSC (Balanced Scorecard) application.
- *Process discovery* – documenting of passenger service and aircraft ground handling as-is processes, process models quality assurance, implementation of quick wins, definition of process performance goals, expert team formation.
- *Process analysis* – weak point analysis of passenger service and aircraft ground handling as-is processes, time/cost analysis of relevant organizational units, simulation & what-if analysis of flight departures process, identification of performance issues, assigning of process and optimization priorities.
- *Process redesign* – identification of resources for process optimization, evaluation of possible solutions, to-be processes proposals, passenger service and aircraft ground handling to-be process design, preparation of implementation plans.
- *Process implementation* – changes implementation, new IT systems implementation, definition of new tasks for organizational units, change management.
- *Process monitoring and control* – process performance monitoring of improved passenger service and aircraft ground handling process, dashboarding/reporting of flight data and aircraft ground handling process, monitoring of delays and reasons for the delay in ground handling operations (error codes), direct access to the actual processes data with all the necessary information about the flights, the size of aircraft, number of passengers etc., bottlenecks/flaws identification, corrective actions initiation, process metrics application.

Key results of BPM initiatives included mapped business processes within a process repository, process definition starting from the strategy of the Company, analysis of time and cost of certain organizational units, process performance measurement and management, dashboarding as well as reporting. Achieved results of BPM within the Company were measured by predefined key performance indicators such as process time, customer experience scores etc.

BPM initiatives at Company are completely aligned with its strategic goals. Active management support, appropriate technology and support of specialized consultants were recognized as the main success factors of BPM initiatives.

Within Company, BPM is highlighted as a key to process optimization goals achievement since it enables obtaining the whole picture of the Company or "virtual company management" – from strategy and goals definition, process identification and design, process analysis and optimization to performance monitoring, while business process management system developed with a BPMS is used as an enabler.

Process performance monitoring and management is extremely important for this Company, especially due to its seasonal character – which implies a lot of seasonal workers.

Future BPM initiatives are to be adopted to circumstances and changes of the market as well as customers. This implies monitoring and analyzing the processes in order to keep achieving effective as well as continuous optimization.

IV. RESEARCH FINDINGS ON EVALUATION OF BMPS CHARACTERISTICS

In this section we present research findings based on data from the third part of the questionnaire related to evaluation of BPMS characteristics and features. The results are graphically presented in ***Figure 1*** and ***Figure 2***. ***Figure 1*** shows BPMS evaluation in the cluster "Capability" while ***Figure 2*** shows BPMS evaluation on "Compatibility", "Complexity", "Reputation" and "Costs". Green (Company-E) and blue (Company-P) bars on the charts represent evaluation marks given by the BPMS expert and practitioner respectively. Green horizontal marks (AVG Company) show average value of the marks given by both participants from the Company, while yellow horizontal marks (AVG ALL) label the overall average value from all three case studies representatives.

Expert and practitioner from the Company rated all BPMS features equally before and after the implementation, which is not the case with other case studies, so on the charts decimal values can be seen for averages and whole numbers for bars. No question was answered with X = don't know, what is, we believe, related with the interviewer's experience in conducting similar research activities.

From the graphs we can see that there are questions with fully harmonized opinions of the Company's expert and practitioner, as well as questions where that is not the case.

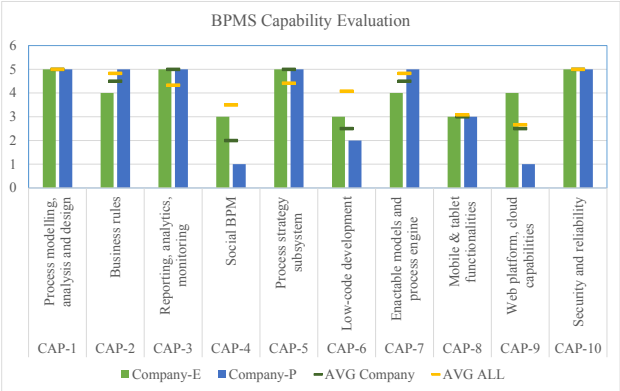

Figure 1 BPMS Capability Evaluation

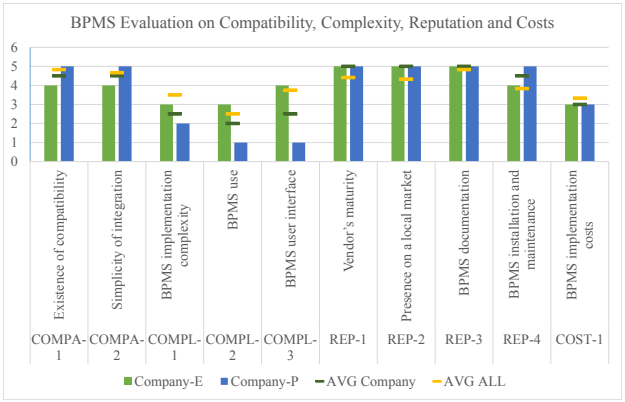

Figure 2 BPMS Evaluation on Compatibility, Complexity, Reputation and Costs

Taking into account BPMS capability attributes (***Figure 1***), marks given by Company's expert and practitioner are fully aligned (green and blue bars are equally high) for half of all questions. Similar applies for other BPMS categories (***Figure 2***). This points out on good understanding between consultants and the Company. It is obvious that users do not expect from BPMS implementation anything more than the experts themselves. There are, of course, differences in ratings that can be explained by taking into account the roles that each one has in the process. For example, Social BPM (CAP-4), Web platform, cloud capabilities (CAP-9) and Low-Code Development (CAP-6) are evaluated as more important by the expert than by the practitioner. The expert's marks on these three categories show understanding of the possibilities of social BPM, mobile information and communication technologies and other IT related business improvements. The lower business user ratings suggest either that in this particular project the effects of these features are not properly presented to them or the implemented process does not need a social networks as a way of connecting with clients neither sophisticated web applications. Possible explanation for the low importance of cloud-based development and deployment is the seasonal character of the airport business related with a large number of seasonal workers who are frequently exchanged. This type of business involves processes not in need of advanced web applications developed on cloud platform. The low importance of low-code development to practitioners is also understandable, because they do not participate in implementation and only use a solution developed by someone else (expert). In contrast, an expert who develops a BPM application appreciates speed software development provided by visual tools as a substitution to hand-coding.

It is also apparent that for some questions the opinion of Company's expert and practitioner coincides with the average opinion (yellow marks) of all the participants in the study. The BPMS functionalities presented with questions having highest marks from all the participants can be considered as the core functionalities of BPMS that should be definitely taken into account when choosing BPMS.

Such functionalities are those related with

- process and business rules modelling, analysis and design,
- security and reliability,
- enabling compatibility of BPMS with the existing IT infrastructure,
- availability of documentation, users' guidelines and manuals.

There are also different attitudes about some issues between Company's examinees and the average opinion of all study participants. Discrepancies are again most evident on questions about social BPM, low-code development, BPMS implementation complexity (COMPL-1) and BPMS user interface (COMPL-3). This can be justified by the differences that exist in the types of processes implemented in different case studies as well as the differences in the phases of implementation of each particular process.

If we look closer at ***Figure 1*** we can see that capabilities related to business rules (CAP-2) and to enactable models and process engine (CAP-7) are rated slightly more important by the practitioner than by the expert. Compared to average opinion (yellow marks) of all study participants Company's participants consider reporting, analytics, monitoring (CAP-3) and process strategy subsystem (CAP-5) somewhat more important. This could be arisen from long-term orientation towards continuous BPM as stated in the questionnaire that between 2002 and 2018 several projects have been carried out covering all phases of BPM life cycle.

BPMS complexity issues are, in line with expectations, of less importance to practitioners than to experts. Also, all complexity related issues are less relevant to Case study representatives than to all participants in general (overall average). This can be explained by the fact that the Company already has a good coverage of business process by existing information subsystems so that BPMS implementation deals rather with their integration than with user interface development.

Within the reputation cluster, all attributes were rated slightly higher by the Case-study representatives than all research participants. Case study expert has given the highest marks to BPMS documentation (REP-3), vendor's maturity (REP-1) and presence on a local market (REP-2) and a second highest mark for BPMS installation and maintenance (REP-4). As these attributes are technically oriented and in this Case study experts deal with

technically related issues high rating of this functionalities is expected. It is interesting to note that Case study practitioner rated the reputation of the BPMS vendor with highest marks in all categories which points out to satisfaction with the existing vendor.

Case study participants rated BPMS implementation Costs (COST-1) as of middle importance, which is to some extent surprising taking into account that finances are always an issue and they are being carefully taken care of. A possible explanation of this attitude is the fact that this airport is state-owned.

Specific business related findings are also recognizable in our Case study. In the Company which is the focus of this case study, nearly no job can be performed well without IT knowledge and experience. Business analysists, IT specialists, process specialists and domain experts need to design, communicate and execute improvement scenarios in a challenging environment while operating 24/7. It is also evident that further possibilities of improvement in segment of customer relationship management based on new paradigms of web based solutions, social BPM and fast process execution still exists.

Considering the fourth part of the questionnaire where Case study participants evaluate the success of BPMS implementation, it is apparent that both sides believe that all of the defined goals are met. It is recognized that BPMS implementation influenced the way employees work in Company, business process transparency is improved, collaboration, continuous performance measurement and reporting is enabled etc. The continuous BPM efforts through the years of implementation have matured to the level of incorporating BPMS into overall Company's information system management.

The findings of this Case study indicate that there is no deep misunderstanding between BPMS practitioner and expert in a sense that user's expectations could not be met.

V. CONCLUSION

The interest in Business Process Management (BPM) is present among practitioners and researchers for quite a long time. Practitioners have been using BPM technologies to model, improve, and enact business processes while researchers have been working on new approaches to support more advanced fashion of BPM. Nowadays, a plenty of BPM software and tools is available on the market and finding the right one for the company is a challenging task.

The aim of our work is to contribute to the project goal related to evaluation of the functionalities of business process management software, and to define basic guidelines for BPMS selection. Our research includes three case studies whose members participated in semi-structured interviews prepared carefully upon previous extensive research. We have chosen this particular approach because qualitative data helped us to understand the contexts of the implemented processes and standpoints of examinees while quantitative data enabled comparing cases between each other and also opinions of different participants on the same case study.

The findings of this study suggest that there are BPMS functionalities that all participants assume to be important. Those are functionalities related with process and business rules modelling, analysis and design, security and reliability, functionalities that enable compatibility of the BPMS with the existing IT infrastructure and also availability of proper documentation. They can be considered as core functionalities and consequently should be taken into account when choosing BPMS. The fact that grades given to some BPMS functionalities diverge a lot has further strengthened our confidence that there is still plenty to explore.

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The Potential and Issues in Data-Driven Development of Web Personas

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***Abstract* - The concept of personas that represent the key audience segments of a service, product, site, or a brand has been widely used in marketing. As of lately, personas are often used in digital services design and development. However, there are some frequent errors and issues that designers and developers come across in the process of developing realistic personas. Namely, personas are sometimes developed based on irrelevant data (e.g. statistically insignificant dataset), or have been developed based on assumptions, inadequate analyses or, most often - intuitively. Another issue is that once created, personas cannot be easily updated. There is great potential in using big data technologies to tackle these issues since it enables analyses of large amounts of data to gain insights into real user behavior patterns that lead to better business decisions. This paper explores the possibilities for developing data-driven web personas based on real user-data with the aim to save time in comparison with current data collection methods and also to enable easier updates. The preliminary study is presented using a dataset from an e-business site. The research results highlight the great potential of developing data-driven web personas based entirely on interactions between real users and a webshop, but also a number of identified issues in the process.**

Keywords - data-driven development; web persona development; big data.

I. INTRODUCTION

Persona is a representative of a group of users who share similar behavioral pattern [1]. In addition to behavior patterns, focus of personas is on common etc. [2]. Marketing professionals use the concept of personas to embody a fictional character that they target with their products, services and advertisement. Even though the most common use of personas is still in marketing and advertising, there has been an increase in using personas in information system design and development [3] where designers and developers use personas as their fictional (future) users.

A common issue that researchers identify is that personas were/are often developed around assumptions about users or customers, based on intuition and not real user data [4]. In that line, new research results highlight the importance of data-based personas, but still focusing on real user data collected via surveys or focus groups [3, 5, 6]. Overall, it is important to note that there is a shift from using qualitative data towards using quantitative data for the purposes of persona development [7].

However, even in cases quantitative data is used to develop personas, there are some common issues, e.g. very often the data set is not a sample size that can be considered statistically significant or it does not contain current user behavioral data, meaning it is not directly linked to real users etc. [1, 8]. The same authors point to another issue – once developed, personas cannot be easily updated. This is especially important since users' habits and interests change and new trends come about fast. Having in mind that user experience (UX) is extremely subjectively, dynamically and contextually dependent [9], designers and developers have to consider a variety of user actions and feedbacks to an organization's offer/system during the overall journey experience [10]. For that to happen, i.e. to continuously track changes in users' behavior as a part of persona development and maintenance in order to inform business decisions, organizations need to dedicate resources, time and money.

Tackling these issues, new concept of data-driven persona development based on real(-time) user data is becoming more popular with scientists and practitioners. Along those lines, the paper presents some possibilities (in section 2) and identified issues related to developing data-driven web personas based on the results of a preliminary study (in section 3). Plans for future work are presented as concluding remarks (in section 4).

II. DATA-DRIVEN WEB PERSONAS

A. Introducing Data-Driven Web Personas

In response to the need for continuous improvement of e-services and systems, the concept of personas evolved. From the one side, (big) data about users is collected and is available and, on the other side, there is a need to create a user-oriented product or a service. Evidently, well known persona technique could be enriched and improved for better results. On top of the straightforward definition of a persona presented previously, data-driven web personas are characterized by an additional feature – automatically collected data, i.e. data collected via digital/web services while users are actually using the service (or in that case – the product) [11, 8]. Figure 1 illustrates the three relevant domains that inform the progress of data-driven development of web personas. These domains are presented hereinafter in brief.

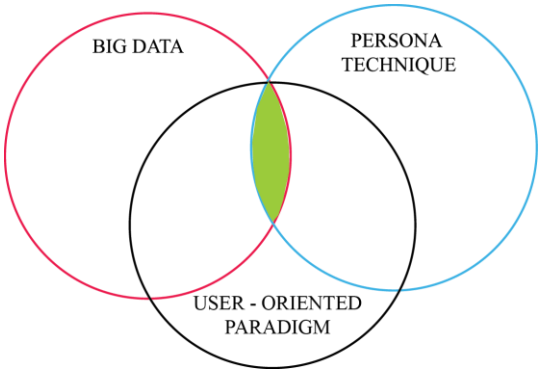

Figure 1. Domains that inform the progress of data-driven development of web personas

B. *The Era of Big Data*

To develop personas based on automatically collected data one must assume there is enough available and usable data. This should not be a problem as a recent report from McKinsey Global Institute (MGI) suggests; we all live in 'The age of analytics' and in a data-driven world, while technologies for data management are amongst the most progressive technology areas at present [12, 13]. Ability to analyze the extremely large amounts of data in order to gain insights into user behavior patterns at the same time presents a great opportunity as well as a great challenge.

The advent of a new paradigm *Business intelligence & analytics 3.0* which takes into consideration mobile and sensor data on top of more 'traditional' data sources, reaffirms the fact that big data efforts nowadays present key assets and business advantage [14, 12]. Nonetheless, most businesses use only a fraction of the total value that is contained in all the data asset, and do not leverage it enough to improve business decisions nor to make better strategic moves [13]. This reluctance to use big data technologies to tackle the data assets is often times due to complexity of the big data solutions and lack of competence to struggle with big data characteristics: velocity, volume, variety and veracity. In terms of persona development and update, these challenges have to be taken into account. A setup where web personas are automatically updated with users' data that is accessible through an analytics tool resolves the velocity and the volume part of challenge.

C. *User-oriented Paradigm and Personas*

For over a decade, organizations have been adopting user-oriented practices for design and development of services with special focus on UX design [15]. Organizations aim to develop and deliver an (e-)service or a solution which is completely user oriented and meets all user requirements. Many studies confirm that direct contact with users is key to achieving that [16]. One could argue that it could not be more direct than using the data that users produce themselves.

In order to reach the satisfaction level where users' needs are met, developers must follow formal records detailing out the requirements, restrictions and other features – i.e. users' specifications (ibid). To understand user requirements, personas are very useful because until the user is precisely defined, a developer can always imagine him/herself as the user or allow the user to become elastic [17]. An elastic user is based on user requirements that meet the needs of developers, designers and all other stakeholders that do not represent real users' needs and requirements [18]. In that sense, defining user personas is key to 'suppressing any tendency for the developer to usurp or distort' the user persona's role [19]. Persona, most simply said, should be used as a tool for translating the world of users in to the world of developers [20]. It should be defined in great and specific detail [19] and the definition should contain characteristics such as users' demographics, behavior patterns, personal interests, motivations, and goals. For a persona to be used in context of design and development, it should contain additional, contextualized behavioral variables [21, 22]. Even though at first it does not seem to be important that a persona should have a name, it is one of the most important elements, because a persona without a name will never be a concrete individual in anyone's mind [19].

D. *State-of-the-art in Persona Development*

Lately, data-driven personas are recognized as a user-oriented concept based on first-hand-data which could be used to develop new (software) products but also for identifying positive and negative aspects of UX. Data-driven requirements as an output of persona development process could be used for agile, frequent and incremental improvements. At the same time, automatically collected data could be used as background for creating personas. Recent research indicates the potential of automatic generation of personas using social media analytics [1]. However, it was not for the purposes of product design and development but for getting insights into competitive marketing and topical interests.

Various methods were used to explore the process of developing data-driven personas. Using static data, factor analysis was used as either an initial step in developing personas [7] or to show relationships between the personas themselves [21]. Hierarchical clustering was also performed to construct personas [1], and on top of hierarchical clustering, statistical approach to detecting sub-populations was implemented [8]. The process of grouping a set of data objects into multiple groups or clusters so that objects within a cluster have high similarity, but are very dissimilar to objects in other clusters [23] is particularly appropriate for developing personas. In addition to commonly used principal component analysis, clustering, factor analysis, latent semantic analysis is sometimes used to develop personas [8].

III. PILOT STUDY

Following the progress in the field of developing data-driven web personas for the purposes of continuous improvement of e-services and systems, we performed a pilot study in order to identify the potential and the issues in the process.

Data set for the purpose of this pilot study has been downloaded from Google Analytics. Google Analytics is a well-known free web tool used for analyzing customer clickstream data logs. As such, it can provide a trail of

users' online activities and reveal users' browsing and purchasing patterns [24].

From Google Analytics, data for a transactional website with more than 19.000 active daily users was used. The website offers timetables and sells bus tickets to an international audience as it is translated to 16 languages. Since this specific Google Analytics account had enabled ClientID dimension, a custom made dimension consisting of a unique ID which is assigned to each device from which users engage with the content – it was possible to obtain data for each user. ClientID field is a unique, randomly generated string that gets stored in browser cookies, so subsequent visits to the same site can be associated with the same user [25].

For the period of seven days, more than 61.000 ClientIDs and related data was recorded and downloaded. With respect to ClientID dimension, the following metrics were recorded: (1) number of users, (2) new users, (3) number of sessions, (4) bounce rate, (5) page/session, (6) average session duration, (7) transaction, (8) revenue, (9) country and (10) device category. Another binary variable 'Transactions made' was created based on 'Transactions' metric. If number of transactions was greater than or equal to 1, 'Transactions made' was set to 1, otherwise it was 0.

The number of available metrics which could be used for persona development presents the first limitation in this pilot study. For example, it was not possible to collect other, additional metrics for each ClientID using this tool. For web personas to be used in design and development, there should be some additional metrics. Pattern of metrics present concise users' behavior, so those patterns can be derived to user behavior [17].

To analyze the data, a classification data mining method was used – decision tree analysis. The state-of-the-art methods for classification of evolving data are classifiers based on decision trees [26]. Also, classification is one of the most widely used data mining techniques which seeks to predict to which group a new instance may belong. Specifically, CHAID method was used. It is a classification method for building decision trees by using chi-square statistics to identify optimal splits. Variable 'Transactions made' was used as dependent variable, while 'Country', 'Device Category', and 'Avg. Session Duration' were used as independent variables. The result is a decision tree containing 11 nodes and 8 terminal nodes with depth of 2. The tree is illustrated in Figure 2.

Only 598 ClientIDs made a transaction using a webshop, so that was used to determine personas in this first step. Since this website is set up with a final goal of performing a transaction(s), vision of owner's design is in accordance with user-oriented paradigm, and their goal is to provide their users the best design – in order to make a transaction. There are 5 nodes that differ statistically based on 'Avg. Session Duration', and there are 3 nodes that differ statistically based on 'Device category'. Therefore, three web personas could be defined. *Persona A* is a user who uses desktop as a device for making a purchase, after spending an average session time of more than 740 seconds. *Persona B* is a user who uses a mobile device for making a purchase, after spending an average session time of more than 740 seconds. *Persona C* is a user who uses a tablet device for making a purchase, after spending an average session time of more than 740 seconds.

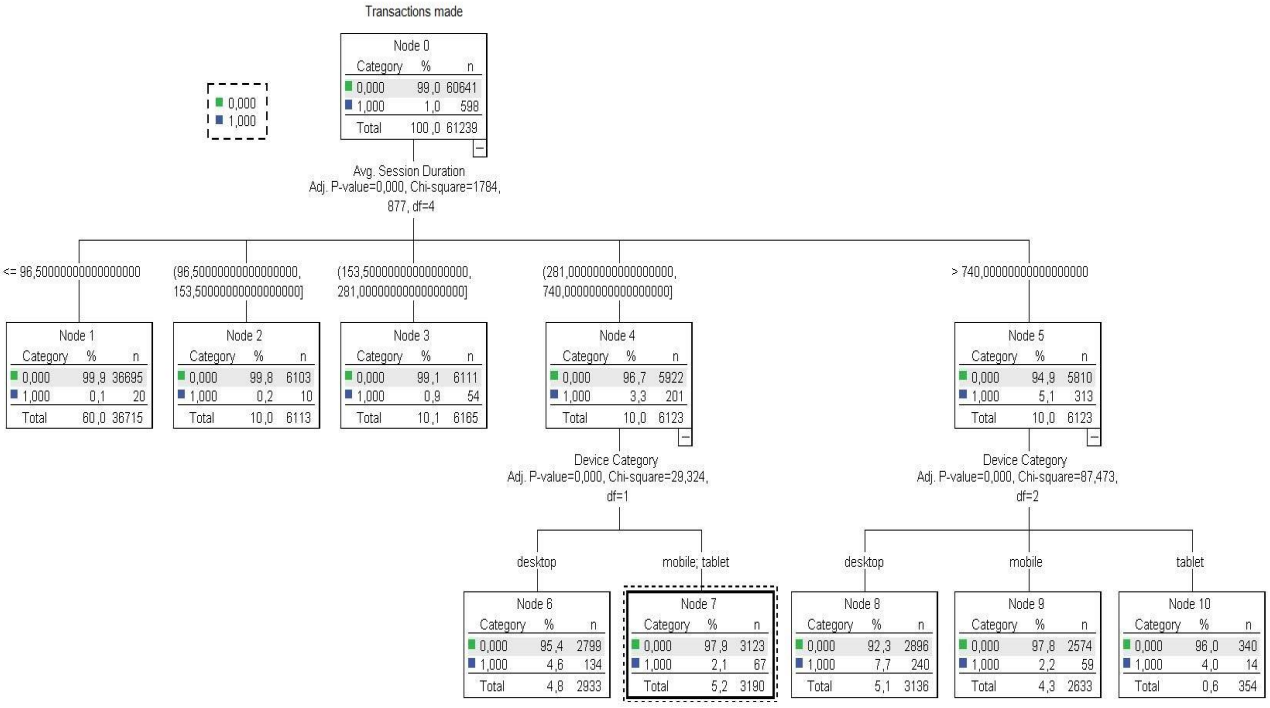

Figure 2. Decision tree

With regards to design and development activities, the focus should be on those users who spend some particular time on the website, but do not make a transaction. Why should this matter? Because there is something common in behavior of those users, and after detecting it, changes in design can be made, and easily tested in a short period of time. That "gap" presents a possibility or an opportunity to redesign the existing solution and to make it more user friendly so there would eventually be more transactions. It would be very useful to provide as much possible characteristics of those persona(s) so that improvements would be relevant.

Therefore, another decision tree was analyzed based on a dataset which excluded users who have a bounce rate equal to 100%. The bounce rate is a percentage of users with a single page session in which there was no interaction with a page. The dataset also excluded users who made a transaction. Growing method CHAID was used again. Variable 'Avg. Session Duration' was used as a dependent variable, and 'Device category' was an independent variable. The result was another decision tree containing 4 nodes and 3 terminal nodes with depth of 1, presented in Figure 3. More than half users (54%) who did not make a transaction are mobile users. That resulted in developing another persona – *Persona D* which uses a mobile device to access the content with an average session duration time of more than 312,144 seconds without making any transactions.

After identifying the four personas (A, B, C and D), they should be enriched with some attributes. Therein lies another limitation of this study - data for age and gender of users is missing. Basic Google Analytics account does not provide gender and age dimension for ClientIDs so aggregated data could be used only. The Google Analytics, however provides statistics on a certain user group, so web personas could be enriched with that data. Table 1 contains data about 'Gender', 'Age', 'Device category' and 'Revenue'. Entire audience was used, thus reflecting skewed gender ratio. Table 2 contains data about 'Gender', 'Age', 'Device category' and 'Bounce rate'. Both tables were used for determining age and gender of developed web personas. After determining gender and age of web personas, crosstabs were used to analyze country frequencies.

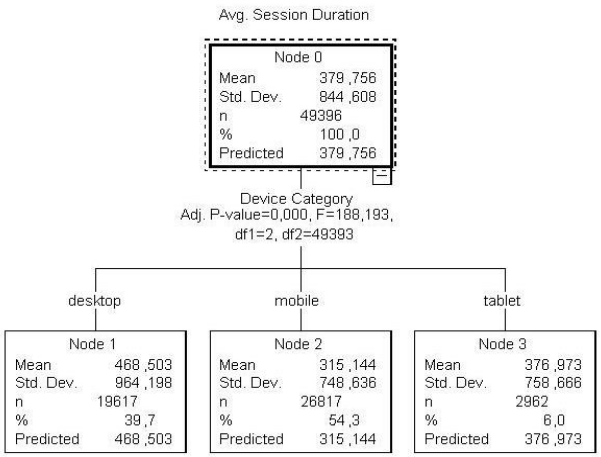

Figure 3. Dession tree for users that did not make a purchase

TABLE I. AGGREGATED REVENUE DATA (IN CROATIAN KUNA)

	Gender	18-24	25-34	35-44	45-54	55-64	65+
desktop	M	8701.68	18917.16	8916.85	5451.27	6930.43	4752.45
	F	13879.76	14193.20	4641.83	7388.26	3302.72	2194.55
mobile	F	2172.06	5518.40	2884.45	2710.21	337.00	0.00
	M	2255.45	5177.72	2742.91	669.80	0.00	0.00
tablet	F	0.00	812.50	0.00	0.00	828.78	116.55
	M	0.00	465.40	601.55	0.00	160.00	506.10

TABLE II. AGGREGATED BOUNCE RATE DATA

	Gender	18-24	25-34	35-44	45-54	55-64	65+
desktop	M	55.21%	56.75%	57.66%	56.36%	55.86%	54.37%
	F	53.57%	56.81%	55.64%	55.94%	54.97%	54.90%
mobile	F	49.89%	49.91%	51.80%	55.00%	54.72%	53.44%
	M	49.33%	48.92%	51.00%	52.47%	53.96%	54.51%
tablet	F	56.83%	53.92%	57.51%	59.79%	59.91%	59.80%
	M	51.65%	54.74%	59.85%	57.11%	56.56%	59.10%

Country was grouped by 'Device category' as well, taking into consideration only users who made transactions. Results are presented in Table 3. Same analysis was performed on the dataset excluding users who had transactions (Table 4).

TABLE III. AGGREGATED COUNTRY DATA (USERS WITH TRANS.)

Country	Device category		
	Desktop	Mobile	Tablet
Croatia	68	29	5
Germany	11	6	3
United Kingdom	12	4	1
South Korea	12	3	1
Spain	10	3	1
…	…	…	…
Total	240	59	14

TABLE IV. AGGREGATED COUNTRY DATA (USERS WITHOUT TRANS.)

Country	Device category		
	Desktop	Mobile	Tablet
Croatia	1116	1799	90
Bosnia & Herzegovina	353	914	35
United Kingdom	538	318	144
Spain	377	463	96
Germany	410	375	80
…	…	…	…
Total	6435	6046	943

Unlike for the results presented in Table 3 where difference per country by device category was not statically significant, for the other group of users, there was a statistically significant difference between country and device category. The most frequent country in each device category is Croatia.

Another important detail as discussed earlier is naming a persona. The most common given names per age group were taken from the National Bureau of Statistics [27] and are presented in Table 5 with other persona characteristics. A quick overview of the characteristics reveals that Persona Marija is the persona whose experience the organization needs to improve significantly. Marija is a representative of an age group that represents 14.10% of all users, almost as the age group from 18-25 representing 15.10% of users. Marija is persona who spends a lot of time on consuming the content but does not make any transactions. Also, Marija access the content using a mobile device.

In general, the results of this pilot study show that the number of mobile users surpasses the number of desktop users, but on the other hand twice as many users make a purchase using a desktop computer than they do using a mobile device. Although these results are consistent with latest studies [28], this also presents an opportunity for designers and developers. An example of an action towards redesigning and improving the service is to create a quick feedback pop-up (e.g. 'Did you use our website just to explore?' or 'What stopped you from buying the ticket?'). One should also consider the aspect of security of mobile payments when analyzing the results [29]. In terms of improvements in that regard, a small change in design could guaranty users that it is safe to pay online using their mobile devices. However, these changes do not have to be big nor sudden, but they do present the potential for improvement.

In this specific situation it would be useful to enrich the persona, Marija, and use more data from other tools such as Hotjar. Hotjar is one of the many tools which can present graphical analysis of users' behavior. For example, it can provide images and videos on how each user interacts with the content. Hotjar can also collect data based on UserID, however, it is not possible to link this with Google Analytics ClientID data. In that sense, this inability to link behavior data is another limitation to this study. Example of the graphic data – website clicks for mobile device users and average scroll activities for mobile and desktop users are illustrated in Figure 4.

TABLE V. CHARACTERISTICS OF THE PERSONAS

	Persona A	Persona B	Persona C	Persona D
Name	Ivan	Ivana	Nada	Marija
Age	25-34	25-34	55-64	45-54
Gender	Male	Female	Female	Female
Device	Desktop	Mobile	Tablet	Mobile
Time spent	Y	Y	Y	y
$	Y	Y	Y	n

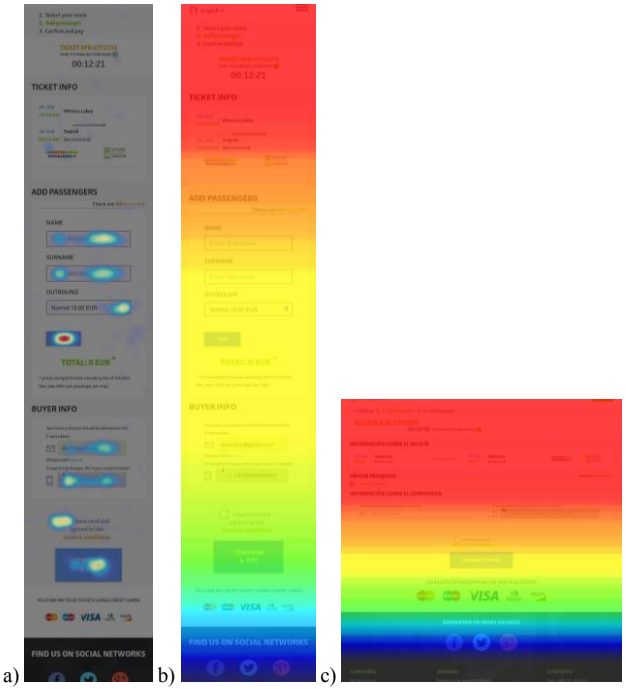

Figure 4. Click (a) & scroll (b) activities of mobile and desktop (c) users

To conclude, this pilot study disclosed that there are four distinct personas each with their specific set of characteristics. Even though the study has identified a number of issues and limitations, mostly related to data availability, the results can be used as inputs for introducing incremental changes in design for this and other similar websites. General idea of the study was to explore the potential for creating data-driven web personas. As it was presented, data from more than 60.000 international users was used for persona development, without conducting interviews or surveys, and without organizing focus groups. In that regard, this is definitely an area where there is a high potential for further improvements and research, as discussed further on.

IV. CONCLUSION

Given the popularity and availability of technologies that enable insight into user behavior patterns and easier understanding of their needs, as well as a much better quality of interaction, the challenge is to explore the potential of these tools in managing the overall user experience. This approach can be useful both for designers and developers. The paper introduced the term of web personas intending to contribute towards popularization of this concept in the field of (re)design and development of web systems. What makes a web persona so different is that its development relies on automatically collected data. In that way, a persona reflects exactly what users do and how they behave in real life scenarios while they interact with the system. If accomplished, automatic update of personas could yield great benefits and enable easy replacement of data with new one to have up-to-date personas. Examples of an automatic update of personas are scarce and even those are not fully implemented but are rather on the level of proof-of-concept. In summation, the potential is huge and the question how to exploit it properly remains.

Shift towards automatically collecting data about users' behavior for the purposes of creating or maintaining web personas is happening. Even though it is enabled and supported by the modern-day technology, there are many issues that need to be addressed (e.g. questions and disagreements about data type, method of collection, method of analysis etc.) [30]. In particular, the implications of data-processing in terms of privacy are an important and imminent issue [31].

Several limitations to this research have already been presented earlier in the paper. First of all, for developing web personas, apart from aggregated user data, only data from Google Analytics was used. There are a number of specific user metrics which could be useful for designers and developers but are not collected 'by default'. Defining the metrics that are crucial for providing user-centric solutions is often times specific, i.e. case related. Merging the data from different sources is a must, and yet due to a lack of opportunity to join data from two different tools, detailed data from Google Analytics was not complemented with detailed behavior data from Hotjar. Given that there is a large amount of data that are not collected using the same tools, there is a huge potential in merging multiple data sources and aligning them with the specific characteristics that are defined in advance and in agreement with organizations' needs. As a continuation of this study, a detailed analysis of the tools will be prepared in order to propose a solution that could provide organizations with an automatic, complete dataset for web persona analysis.

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Predictive models for digital broadcasting recommendation engine

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Abstract – Communication operators are offering to their consumers many services that enable them to consume video content, using different fixed and mobile technologies through different devices, either in their homes or mobile. For operators it is of vital importance to analyze behavior of the consumers in real-time and over longer period of time, to be able to not only maximize revenue and minimize costs, but also to serve consumers better and to reach highest possible level of customer experience. For that reason, operators are using sophisticated recommendation engines to propose to their consumers' content that may be interesting for them. This paper will explain in detail the implementation of such engine in modern content analytics system.

I. INTRODUCTION

Television broadcasting was based on analog signal encoding for long time. Analog television signal was broadcasted over terrestrial antenna systems, over satellite systems and over cable systems. Traditionally, program of TV station was broadcasted through one or more of those distribution channels in real-time. Operators providing transmission services were servicing many different TV stations and programs.

Digital television broadcasting standards started to develop in 1990. In next two decades, they became widely used and now all broadcasting in developed countries is based on digital signal transmission. Existing terrestrial, cable and satellite operators have migrated to digital transmission systems.

Digital broadcasting allows many advantages, including higher quality of transmitted signal and support for higher resolution (HDTV and 4K Ultra HD), less requirements for bandwidth and opportunity to include additional services or functionality, like additional languages or subtitles or more audio channels. Television sets have also changed with digital tuners replacing analog tuners. Also, LED technology and flat screens have replaced traditional Cathode ray tube (CRT) TV, with large wide screens that support higher picture resolution and refresh frequency.

Those changes have enabled consumers to have completely new and enhanced user experience for watching television programs and video content with multi-channel audio that is easily comparable with experience in Movie Theater. Video content, including TV programs, can be consumed in different ways, including use of mobile devices and on the go, not necessarily related to television set and living room.

In parallel, new types of content delivery services and channels for content consumption have emerged, enabled by development of Internet and continuous growth of available bandwidth for data transmission in fixed and mobile communication networks.

That development created opportunity for many new players in the market who are providing different services. One group of providers are communication service providers (CSP) who are offering broadcasting services over their communication networks.

Other group of providers are providers of "over the top" (OTT) services for broadcasting, also known as streaming video services, like Netflix or YouTube. Such services can broadcast television channels but they can also stream video content that is not related to particular channel or schedule.

Each player in the market is trying to attract as much as possible customers to use their services, trying to provide best possible customer experience. Main leverage in that process is analysis of consumer data and behavior that enable service provider creation of relevant recommendations for content consumer.

The main goal was to design and implement a content analytics system with two main features: capability of fast processing of semi-structured and unstructured heterogeneous data originating from digital content delivery services, and a recommendation engine that continuously gathers data and generates the recommendation list. Biggest challenges were the choice of streaming engine, due to the large volumes of various data generated in real time, choice of data storage layer that can match the data volume and the choice of a recommendation algorithm that is capable of building recommendations for each user independently from the beginning.

In chapter II the different types of digital content delivery services are described. Chapter III observes the customer experience in the content delivery services and provides the requests for the content analytical system. In chapter IV main approaches for implementation of recommendation engine for content delivery are described. Chapter V describes the functionality and the architecture

of a modern content analytics system. In chapter VI the architecture of implemented recommendation engine is explained.

II. CONTENT DELIVERY SERVICES

In this chapter we will describe different types of digital content delivery services that can be offered in the market by various service providers. There are two main types of services – broadcasting and streaming (Internet) services.

Broadcasting services enable consumers to watch only broadcasts in real-time and they include following types of services:

- Digital Terrestrial TV
- Digital Satellite TV
- Digital Cable TV

Streaming services are using Internet and IP protocol for distribution of the content. Consumers can watch real-time broadcasts, but they also can watch historical broadcasts that are stored on providers' infrastructure. Streaming services include:

- Internet Protocol television (IPTV)
- Over the Top content services (OTT)
- Mobile TV (TV on the go)

Digital Terrestrial TV is traditional broadcast distribution that is broadcasted through the air and require standard antenna for reception and TV tuner to tune the programs. Broadcasting company does not know who and how many people are watching which program, due to the fact that signal is aired and there is no feedback loop from consumer to provider. Data about ratings is collected by marketing agencies such as Nielsen Media Research in USA. No detailed analysis of the complete dataset is possible.

Digital Satellite TV broadcasting is similar to terrestrial broadcasting, having in mind that signal is transmitted through the air. Signal is at consumer side collected by satellite antenna (dish) and decoded by satellite broadcasting specific set-top box.

Digital Cable TV service is provided through proprietary digital network owned by digital TV service provider. Historically, cable TV broadcasting was analog and using coaxial cable for distribution but since 1990's all providers have migrated to fiber networks and digital signal, which has allowed to have more channels and also additional services, that include time-shifted transmission, Video of Demand (VOD), use of broadband Internet and voice services. Today, main difference between cable TV and IPTV is that cable TV is provided through dedicated infrastructure and IPTV through Internet. Cable TV require specific set-top box to decode the channels.

IPTV is multimedia streaming service delivered over IP based communication networks managed to provide the required level of quality of service and experience, security, interactivity and reliability. Service is provided by CSP, over dedicated network and using proprietary terminal equipment (another type of set-top box). IPTV service is usually including combination of live and recorded broadcasts:

- Live television transmission
- Time-shifted transmission that include replays of a TV shows that were broadcast some time ago (usually up to 48 hours), replays the current TV show from the start and fast forward and rewind of time-shifted transmission
- VOD - browse and view items in a stored media catalogue, i.e. digital video store with free or paid content, usually movies

CSP's are usually offering IPTV services to their existing customers who use fixed voice lines and / or broadband Internet access, and for new customers CSP's are offering packages with all services.

Over the Top (OTT) content streaming services are provided by third-party provider over public Internet. Provider create content and / or acquire content from media companies, but the content is delivered via the same cable infrastructure as data. Usually, OTT providers such as Netflix are charging monthly fee for their services that define which content and through which devices can be consumed. There is also many content streaming services that are offering free content, such as *Youtube*. There are also many illegal providers such as *Kodi*, who are streaming content free for consumers but without paying for the rights.

In following table are compared main differences between IPTV and (OTT):

	IPTV	**Over-the-top technology**
Content provider	Local telecom	Studio, channel, or independent service
Transmission network	Local telecom - dedicated network	Public Internet + local telecom
Receiver	Local telecom provides (set-top box)	Purchased by consumer (TV, computer or mobile)
Display device	Screen provided by consumer	Screen provided by consumer

Table 1: Comparison between IPTV and OTT [1]

Mobile TV service enable consumers to watch streamed content over broadband mobile network and on mobile device. Services include paid packages delivered by CSP's or by OTT providers, free packages by terrestrial television stations or free packages by content providers

such as HBO. For each service, consumer will require mobile application from service provider.

III. Customer Experience for content delivery services

In previous chapter we have described various types of broadcasting and delivery services delivered by different service providers. As almost every household is watching television and terrestrial television is usually limited to small number of local programs available, there is big potential for all types of broadcasts and streams.

CSP's are very active in this area and their typical activities include:

- Providing IPTV services bundled with fixed voice and broadband Internet
- Providing Mobile TV services over mobile broadband network
- Providing Satellite TV services
- Acquisition of smaller cable TV providers with existing Digital cable TV network
- Selling subscriptions for OTT services with their broadband Internet and IPTV packages
- Packaging of services together, i.e. if customer is using IPTV he can use free Mobile TV on one device

This situation can generate quite complex business scenario, where one customer can consume content using different services, different delivery channels and different devices. For instance, at the same time members one household can watch:

- Father is watching Champions League using IPTV
- Mother is watching Discovery Channel on Mobile TV
- Daughter is watching OTT content on tablet

Each of described system is using different system and application architecture for service delivery and create and capture different information. Each action of the consumer who navigate his set-top box with remote control or navigate application at mobile device is logged in CSP's applications.

CSP's are trying to get as much customers possible, providing best possible service and assuring best possible customer experience. Analytical systems for content delivery services shall enable CSP to:

- Understand consumers' behavior, which content they consume, through which channel at what time and on what device
- Analyze the performance of offered service packages and package options
- Use rating information to negotiate content with content providers
- Segment consumers based on their behavior
- Approach consumers with appropriate offers and recommendations

Many CSP's are using simple recommendation engines that are not personalized. Good example is situation where the same message is distributed to entire IPTV consumer base when new blockbuster is available in VOD service. Such approach is not only very ineffective, but it also can be very annoying for the customer.

Complex recommendation engines should be implemented by CSP's that will combine historical analytics of consumer behavior with real-team feed of consumer actions and create personalized recommendations that will be fed back to content delivery systems through open APIs in real time.

IV. Recommender Systems for content delivery

In this chapter we will describe main approaches for implementation of recommendation engine for content delivery.

There are two basic types of information that recommender systems can use [2]:

- Information from customer profile (age, gender, education, interests) and information about the content itself and its various attributes (i.e. for movies that will be the genre, director, starring actors). Recommender systems that use profile information filtering are known as content-based recommender systems
- Explicit user ratings or user interactions with content delivery platform that are recorded in usage logs. Recommender systems that use interaction information are known as collaborative filtering recommender systems. Collaborative filtering method usually produce better results, but has one important disadvantage – it cannot make prediction for new users, because there is no historical data on his behavior and ratings. This problem is known as cold start problem [2]

Some sources [3] are dividing content-based recommender systems in two groups – demographic filtering if it relies on customer profile attributes and content-based filtering if it relies on item attributes.

If recommender system is using both profile and interaction information in combined approach, it is considered to be hybrid recommender system. Some hybrid recommender systems are used not only for broadcasted content, but also for other types of broadband data. [5], [7]

Recommender systems are used for many years in e-commerce. *Amazon* is famous for its recommender system, and leaders in field of recommendations for content delivery are *Netflix* and *Youtube*. Big impact in

recommender systems for content delivery was done by Netflix Prize contest [4] in 2006. Netflix has released set of 10 million ratings made by 50.000 anonymized customers for 17.000 items, promising 1 million USD reward for the team that can improve their recommendation algorithm for more than 10%. More than 48.000 teams have downloaded the dataset and many provided their solutions, which resulted in many advances in algorithms used for recommender systems.

Beside Mobile TV services, mobile devices are massively used to consume short video content, including short music videos, news clips and video blogs [6]. Collection and analysis of data about customer behavior related to consummation of this type of content can add a lot of value to recommender system.

Modern analytics systems are capable of holding terabytes of various data that holds valuable information. Usually, the data is stored in distributed environment with parallel data processing capabilities. By that, analytics system can be enhanced with data mining capabilities that enable the broader information gathering from the data. Recommender systems are one of the typical usages, since they apply the prediction algorithms on the collected data during the low loading periods, which allows the system both to consume data faster and optimize the resources usage. Results of the algorithms give valuable information to CSP's and give the users a possibility of using the resources that are more suited to their daily usage. Recommender system enhances the results by every new stream of data and by that optimizes the results for every entity for which they are calculated.

There are two main issues that affect the results of real-life implementations of recommender systems for content delivery – absence of rating results from users for delivered content items and the fact that same user account is used by one or more people in the same household, thus resulting in a user behavior that's the union of the behaviors of all household members. [7]

For rating results, unfortunately it is usually not possible to have ratings of the movies or shows that user has posted at some external source such as *IMDB*. In such cases, rating results can be supplemented with approximation that if user has consumed the whole show or major part of it, he like it and he will rate it good. If he watched only small part, we can assume that the rate will not be good. [5], [7]

Other important requirements for recommender system for content delivery are:

- Available items for recommendations are constantly changing
- Prices for content change over time
- Some additional rules shall be applied for particular users (i.e. filtering of adult only content)
- Recommendations must be created very often to be able to have current recommendations for large number of users

V. CONTENT ANALYTICS SYSTEM

In this chapter, we will describe functionality of modern content analytics system developed by Poslovna inteligencija, including big data and fast data (streaming) architecture, Vertica MPP database and Vertica ML modules.

The content analytics system is divided into three layers: the data integration layer which is based on Apache Kafka [8], data storage layer based on Vertica [9] multi parallel processing (MPP) database and analytics layer, consisting of multiple tools.

Poslovna inteligencija content analytics system is shown in Figure 1:

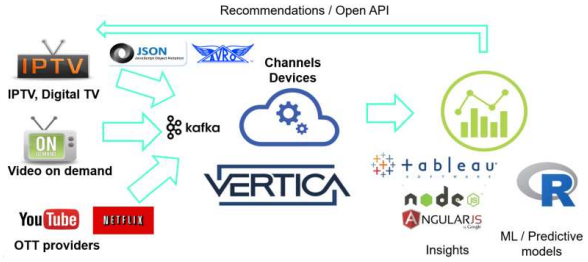

Figure 1. Architecture of Poslovna inteligencija content analytics system

The Data integration layer provides the functionality of real time streaming data pipeline between various source systems and the data storage layer. Its basis is Apache Kafka, a distributed streaming platform with real-time capabilities for stream storing and processing. Apart from that, due to its capability of holding stream data, Apache Kafka provides a single source of data for the data storage layer loading, thus being the system's data staging area.

Data consumed by Kafka varies by the source. For example, the data sent by the IPTV set-top box is an unstructured log which can be parsed into a structure during the streams or stored in the data storage layer in order to be transformed prior to its usage. Also the JSON data, popular in the modern real-time systems [10] and in the terms of digital broadcasting OTT providers is used in the similar manner.

Data storage layer is the analytics platform Vertica, a massively parallel processing product chosen both for its performance and native integration with Apache Kafka and Apache Spark [12]. The platform gives the system a possibility of performance scaling and data warehouse-like querying capabilities, which in the case where few source systems generate large volumes of data constantly has advantage over similar Big Data solutions. As Vertica is column oriented, retrieving data through analytical queries is significantly faster and the data compression can be performed easier compared to row-oriented database systems typically used for data warehousing. Initially, the similar approach for storing the data was taken by using Cassandra DB [11], which is also a column-oriented, but the usage of NoSQL database had drawbacks in terms of stability and performance.

The data analytics layer should be viewed as two separate parts due to their usage. The one is the user interface developed as a custom web application and Tableau visualization software that allows real-time analysis of recommendation data stored in Vertica. The other is a key component of the recommendation engine, Apache Spark, which creates the recommendations set for each user based on its data through the recommendation generating algorithms. Communication with the data storage layer is bi-directional, as both user interface and Apache Spark consume the data in Vertica, but the later also stores the results of its algorithms into the database. The data flow in the system is shown on the diagram in Figure 1.

Due to the intensive system usage during recommendations generation, its running is schedules in the periods of low usage on a daily basis, similar to the processes in the traditional data warehousing. The data generated by the users' actions in the systems is collected, transformed and stored in the Vertica platform as soon as it is delivered, providing the system with parallel ETL streaming solution. Apache Spark, as a part of the data analytics layer, retrieves the stored data through stored ETL procedures and uses the cluster for running the recommendation algorithm in a parallel manner.

The choice of streaming oriented layers is important on several levels: integration should have parallel transforming capabilities in order to allow the data to be processed into the storage layer without significant delay. The analytics of high volumes of data should be connected by computational pipelines. Due to the fact that Apache Spark has push-down capabilities, the data volume in the pipeline can be reduced by running pre-processing operations in Vertica. The pipelines between layers are usually the communication bottlenecks, so it is essential to both allow the layer to process the data faster and to reduce the network load.

Finally, recommendation results are exposed, they can be accessed through API and integrated back to content delivery system.

VI. IMPLEMENTATION OF RECOMMENDATION ENGINE AS A PART OF CONTENT ANALYTICS SYSTEM

In this chapter, we will explain the architecture of implemented recommendation engine, with emphasis on:

- Approach used for design and implementation
- Integration with source systems used for digital broadcasting
- Recommendation algorithms used

A. Input data

Source data for the recommendations engine is stored in the Vertica platform. Detailed historical data about customer activities on content delivery platform are used to prepare the tables that will be used as input data for the recommender system. The input data required for the whole recommender system consists of two tables – one that will be used as the user-item matrix and the other for items metadata:

i) user-item table

ii) content item table

User-item table describes customer activities, i.e. which shows did the user watch, when, for how long, etc. The data is aggregated on the level of subscriber id and item id. It is automatically refreshed and maintained on daily basis.

User-item table is loaded using defined rules for filtering records that are not related to actual content consummation. One example of filtered records is if the time between changes of the channels is less than 30 seconds' record is filtered because user is just browsing through the channels. Other example is if the channel is not changed for more than several hours - that means that most likely set-top box is turned on and TV is turned off during the night and nobody is watching the content.

Content item table contains items metadata, i.e. information about TV shows, such as the title, type, length, genre, description, director, year, etc.

B. Algorithm implementation

For the time being, we focused on implementing a recommendations engine for video-on-demand type of content on the IPTV platform. Recent studies suggested that model based collaborative filtering algorithms usually outperform other techniques [4]. In this chapter, we describe our implementation of a matrix factorization model for a recommender system of an IPTV platform.

The algorithm that gave the best results in our case is model-based collaborative filtering, where users and items are both represented by a set of latent factors. These factors, or features, are inferred from the ratings patterns and represent their characteristics that do not necessarily have to be human-interpretable (like e.g. movie genre); they are implicitly present computer-calculated dimensions used as characterizations of users/items in the calculations. Matrix factorization techniques are used to learn these factors. Spark's implementation uses alternating least squares (ALS) to find latent factors [12], and then uses them to predict the missing values in the user-item association matrix – ratings matrix is approximated as a product of two low-rank matrices.

Alternating least squares is one of the methods used in matrix factorization models to minimize the squared error on the set of known ratings in order to learn the latent factors. Since there are two unknowns in the optimization process – item features vector and user features vector – ALS works by rotating between fixing one side and solving a least squares problem on the other, and vice-versa. These steps are performed iteratively until convergence [12]. Spark uses ALS in favor of e.g. stochastic gradient descent because ALS can leverage parallelization. User and item factors are computed independently of other user/item factors, and since Spark is a parallel data processing engine,

it can leverage ALS technique for better performance on large datasets, which is important for IPTV recommender systems that generally do have large amounts of data to process.

The IPTV platform does not provide explicit user preferences; users are not asked to give ratings to the shows they watch. Therefore, we only have usage data available. Since we cannot explicitly know the user's opinion about the shows he watched, we used the usage data to estimate users' preferences, i.e. to assign implicit ratings (minimum rating is one, maximum is five) based on the percentage of the duration of the show they actually watched. More precisely, if the user watched the entire show (once or even multiple times), his rating will be the highest – five. Otherwise, the rating is determined depending on the percentage watched, by the following formula:

$$\hat{r}_u(i) = \begin{cases} 5\,, & pct_u(i) \geq 1 \\ 2 + 3 * pct_u(i)\,, & 0 < pct_u(i) < 1 \end{cases} \quad (1)$$

$\hat{r}_u(i)$ is an estimated rating of user u to item i, and $pct_u(i)$ represents the percentage of the show i the user u watched (0.8 means he watched 80% of the show duration). The logic behind it is that, if the user at least started to watch the show, that means he showed interest for it, and his rating will be at least two. The more he watches, the greater the level of confidence in his preference estimation.

Implicit ratings are inferred from the users' activities. Therefore, the recommendations are based only on the users' past behavior. Although implicit ratings are less reliable and less accurate, it is very common that explicit ratings are unavailable, since their retrieval would be more complicated and sometimes inconvenient or cumbersome from the users' perspective.

C. Storing results and generating recommendations

The recommender engine processing is scheduled and performed on daily basis, in the time when users are less active. The output of the processing is 10 recommendations for every user, i.e. 10 items that the algorithm predicted the user will most likely want to watch. The results are stored in a Vertica table and fetched to display to the user as his top 10 recommendations while he is looking for something to watch. For implementation for real-time broadcasts, recommendation table shall be extended with show start timestamp, to be able to propose to the user the show that has not started yet and will start soonest.

Although collaborative filtering algorithms are generally more accurate, their disadvantage in comparison to content-based techniques is that they suffer from the cold start problem. As a new user arrives, he has no activities yet and since CL algorithms are completely based on past behavior, they cannot give predictions for him. In that case, his list of recommendations will be a list of the most popular items, until the user has some usage data that the CL algorithms can base his predictions on. The list of most popular items is also kept in a table and regularly refreshed.

VII. CONCLUSION

Recommender systems are playing critical role in many digital industries and one of the most important applications is for content delivery.

Creation and implementation of a good recommender system is not an easy task and the field is continuously advancing with each new implementation.

In this article we have tried to summarize common problems that CSP's are facing when implementing recommender systems for content delivery.

Recommender systems that we have developed and implemented as a part of our content analytics system is based on model-based collaborative filtering, using alternating least squares (ALS) to find latent factors. System is constantly enhanced and further developed based on the results of real-life implementations.

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A Methodology for Product Segmentation Using Sale Transactions

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***Abstract* - This paper presents a novel methodology for product segmentation using customers' transactions on products. The proposed methodology introduces FMC model, and utilizes this model's features and clustering algorithms to group products into segments. The applicability of the proposed approach has been demonstrated on data collected by a supermarket chain. The results show that the pro-posed methodology provides an efficient tool that can be used to identify different product segments and to gain valuable insights about these distinct groups. The resulting product segments can help managers in the inventory management and developing marketing strategies.**

Keywords - Product taxonomy; segmentation; clustering; supermarket; RFM; KDD

I. INTRODUCTION

Recent advances in information technology and continuously decreasing costs in data storage and processing have given today's companies the ability to collect and store massive amount of transactional data in databases. All these data holds intrinsically valuable information about shopping trends and patterns. In this context, knowledge discovery in database (KDD) has become highly important for enterprises to expose the hidden value of transactional data [1]. The core part of KDD process is the application of data mining techniques with which the knowledge is inferred from the data and is transformed it into a human-understandable form for further use [2]. Clustering which forms meaningful groups by accumulating data objects sharing similar characteristics is one of the most commonly used data mining techniques to extract useful knowledge from large databases.

Among the application areas of clustering, customer segmentation is the popular one for discovering useful commercial knowledge in today's competitive environment. Customer segmentation divides entire customers into homogeneous groups based on their behaviors and characteristics utilizing companies' transactional data. Due to its ability to improve decision-making, it has been successfully applied in a variety of industries, e.g., health and beauty [3], textile [4], healthcare [5], hairdressing [6], banking [7], tourism [8] and grocery retail [9]. Customer segmentation enables enterprises to identify different groups of customers, such as loyal, profitable, new, lost, and to understand the needs and characteristics of these customer groups separately. With this knowledge, it is possible to develop unique customer relationships and marketing strategies for each customer segment [10]. Hence, companies can improve the quality of the service, retain loyal customers, and increase their profits.

Despite the benefits of customer segmentation and its wide applicability, there has been no study attempted to segment products using transactional data. Nowadays, most retail companies present a tremendous diversity of products to customers, and so product categorization plays a vital role for these enterprises to reduce the complexity in many organizational tasks. In many shopping domains, product taxonomy is widely used by retailers, and products are categorized according to their individual characteristics by domain experts. For instance, some categories from grocery shopping include fruit/vegetable, beverage, breakfast food, and detergent/cleaning. Such a taxonomy can help the company in managing products, but the products under the same category may not show a similar pattern in terms of sale transactions. In this manner, product segmentation based on sale transactions can be helpful for managers to discover various product groups with different characteristics. Therefore, such a solution allows supermarkets to obtain more meaningful and homogenous product segments, which can provide more efficient development of marketing and inventory strategies.

Based on the above motivation, this study aims to propose a methodology for product segmentation, which utilizes customers' transactions on products. For this purpose, this study adapts the two features of well-known RFM model for customer segmentation, and introduces a new feature in order to characterize products more meaningfully and to identify product groups more efficiently. Based on these features, both hierarchical (K-means) and partitional (Ward's method) clustering techniques are tested to divide products into groups. The proposed approach is applied to grocery retail domain by conducting a case study on a supermarket chain. The resulting product groups are investigated in terms of their characteristics.

The rest of this paper is organized as follows. In Section 2, related work is provided. Section 3 describes proposed methodology. In Section 4, a case study carried out in a grocery retailing company and the results are presented. Finally, Section 5 concludes the study and points out directions for future work.

II. Related Work

Segmenting products is a crucial task for retailers. It gives a clear view of product lines for customers and eases to manage product space, which may consist of millions of products. Such a product taxonomy represents hierarchical relationships between products and enables to handle them in the reduced dimensional space [11]. The product taxonomy also plays an important role in the knowledge discovery process of data mining and for this purpose, many previous studies utilized product taxonomy. In [11], [12], product taxonomy is used to improve the recommendation quality of current recommender systems. Further, in [13], [14], more personalized recommendations are made through employing product taxonomy. In [15], product taxonomy is applied to focus more on customers' category specific behaviors.

Aforementioned studies in the literature show that product taxonomy can lead to an improvement of the results of prediction and recommendation techniques, and thereby the discovery of more specific and concrete knowledge in data mining. However, in these studies, product groups are mostly arranged based on their intrinsic characteristics and domain experts' experience. Different from these studies, in [16], a clustering analysis based on customers' spending records is performed and the most distinguishing products of each cluster is identified to generate recommendations for a customer in a particular segment. In [17], products are grouped into segments based on products' description to identify products that are similar to the one selected by customer. In [18], product groups are formed based on products' buying associations for a new store layout by calculating the spatial representation of these relationships through the multidimensional scaling technique.

III. Proposed Methodology

This study uses sales transaction data and unsupervised learning method to identify different product segments and to obtain valuable insights about these distinct groups. In order to perform product segmentation, the first task is to decide which features are to be used for clustering. The RFM model constituents, which are recency, frequency and monetary, are well known and the most widely used features for customer segmentation [19], [20]. Moreover, such features can easily be extracted from the transactional data of companies. Due to its simplicity, several researchers and practitioners have applied different versions of RFM models for clustering customers, and have achieved useful results.

Based on the aforementioned efficiency of RFM model in customer segmentation, this study incorporates the features of RFM model into product segmentation. In typical RFM model, recency is the time interval since the customer's last purchase (e.g., days or months) and reflects buying or visiting potential of the customer. In customer segmentation, customers' relationship with the company is investigated, and this one-to-one relationship. However, in product segmentation, the product's characteristics is examined in an aggregated manner by considering whole customers' transactions on that product. Hence, this feature is mostly stable, and generally takes zero for products. Because of these, recency feature is not proper for product segmentation based on transactional data. Therefore, this research introduces a new model called FMC for product segmentation by incorporating customer variety (C) feature into traditional RFM model instead of recency (R).

In our FMC model, frequency (F) is the total number of times the product has been purchased by the whole customers in a certain period of time. A product with a high frequency score indicates that it is one of the best-selling products of the company. Monetary (M) is defined as the total amount of money spent for that product by the customers in a certain period of time. The products having high monetary score contribute higher revenue to the business. Finally, customer variety (C) denotes the total number of unique customers who have been purchased the product in a certain period of time. A product with a high customer variety score means that it is one of the products that is demanded by many customers. In summary, the products having higher scores in terms of these three features are the high value products for enterprises.

In companies' databases, such features like the ones in FMC model are hidden in the transactional data. Based on these transactional data, the FMC scores of each product were computed. After this process, each product has its own frequency, monetary, and customer variety values to identify its selling characteristic. Since the features vary in range, they were standardized by using min-max normalization (standardization) between 0 and 1 prior to clustering. Two well-known and commonly used clustering techniques namely K-means and Ward's method were applied and intraclass inertia was used to determine the most appropriate one of these clustering algorithms. This measure is the average squared Euclidean distance between each observation and its cluster mean, and it shows the compactness of clusters [21]. Note that smaller value of this measure indicates a better clustering solution.

After identifying the best clustering algorithm for product segmentation, it is needed to determine the suitable number of clusters (k). For this purpose, we adopted the elbow method [22]. In this method, clustering algorithm is executed for different number of clusters (k), and for each k, total WSS (within-cluster sum of squares) is calculated. Then, a curve between WSS and the number of clusters is drawn, and the appropriate number of clusters is determined using the location of a knee in the plot. After the proper number of clusters is decided, the results of clustering with the determined number of clusters are analysed. Then, FMC scores are computed for each resulting product group and based on FMC characteristics, product segments are then profiled.

IV. Case Study

To show the applicability of the proposed methodology, we have conducted a case study on supermarket shopping domain using a real-world dataset obtained from a grocery retailing company. All the details related to this case study will presented in the following sub-sections.

A. Sample and Data Description

The data used in this study was extracted from the loyalty card system of a grocery chain and contains purchase transactions between October 1, 2012 and August

31, 2014. In the dataset, products are categorized according to a four-level hierarchy. The lowest level includes information about the product brand, amount and etc. For ketchup, for example the third level category is “ketchup”, and one of the examples of fourth level category for this product is “Nestle Chocolate, 80 Grams”. “Nestle” is the brand of product, whereas “80 Grams” is the amount of it. Since the fourth level is highly specific, we considered third-level categories in this study. Thus, there are unique 414 third-level product categories in the dataset.

In the dataset, each transaction record contains customer’s membership id number, purchase date, purchased item, quantity purchased, item category, a set of item sub-categories, unit price. The features of FMC model were generated for each product category and the descriptive statistics regarding the maximum, minimum and average values of these attributes are presented in Table I.

TABLE I. THE DESCRIPTIVE STATISTICS OF FMC VARIABLES

	Maximum	***Minimum***	***Average***	***Std.Dev.***
Frequency	38051	2	1166.48	3404.56
Monetary	316114.77	7.29	7419.55	27809.76
Customer Variety	1433	1	128.72	225.93

B. Performance Comparison of Clustering Techniques

The results of intraclass inertia for each clustering algorithm against varied k values are presented in Figure 1.

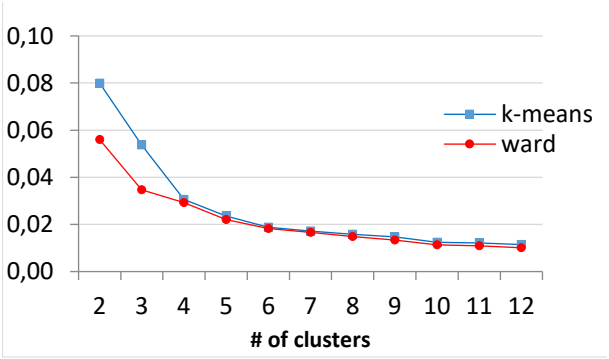

Figure 1. The intraclass inertia for both clustering techniques

Note that lower values of this measure indicate better clustering performance. As shown in Figure 1, Ward’s clustering method leads to slightly better results in terms of intraclass inertia than the K-means algorithm for this dataset. Therefore, we utilized the Ward’s method to characterize product groups.

C. Determination of Number of Clusters

Figure 2 shows WSS (within-cluster sum of squares) results of Ward’s method against different number of clusters (k)

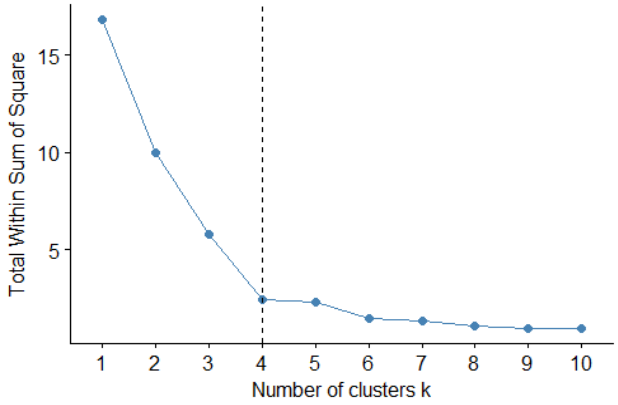

Figure 2. WSS values of the Ward's clustering method

When the number of clusters increases, WSS decreases. As seen in Figure 2, there are significant decreases in WSS value, as increasing the value of k from 2 to 4. For the number of clusters bigger than four, there is a very slow change in the value of WSS, and its value becomes constant for the higher number of clusters. Therefore, four is the elbow point, and we take the results of clustering with k=4 to characterize product groups.

D. Characteristics of Product Segments

We have 4 groups of products with different characteristics and the dendrogram obtained by Ward’s method is shown in Figure 3.

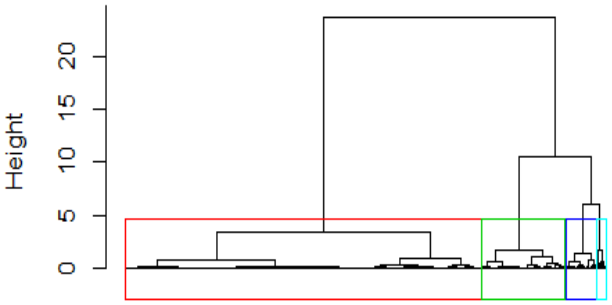

Figure 3. Dendrogram for Ward's method

We can also see from Figure 3 that the best choice for total number of clusters is 4. Table II shows all the details for each segment such as the sample size, the average values of FMC attributes and FMC scores. In forming the last column, FMC scores, we implemented the technique as suggested by [23]. This technique puts the up symbol (↑), if average F, M, or C value of the segment is greater than the aggregate average; otherwise uses the down symbol (↓).

TABLE II. RESULTS OF PRODUCT SEGMENTATION BASED ON FMC FEATURES

Segment	*Sample Size*	*Average F*	*Average M*	*Average C*	*FMC Scores*
1	8	21753.5	165814.94	1123.87	F↑ M↑ C↑
2	72	1895.87	12945.64	236.73	F↑ M↑ C↑
3	307	184.08	1296.1	30.88	F↓ M↓ C↓
4	27	4291.77	15377.26	658.33	F↑ M↑ C↑
Average		1166.48	7419.55	128.72	

Moreover, Table III shows sample products from each segment.

TABLE III. SAMPLE PRODUCTS IN EACH SEGMENT

Segment	*Samples*
1	Bread, yogurt, milk, egg, chicken, beef, chocolate
2	Biscuits, liquid oil, butter, meat delicatessen, coffee, tea, sugar, flour, rice, shampoo, paper products (toilet paper, tissue, etc.), etc.
3	Legumes, salt, detergents, cleaning products, personal and baby care products, etc.
4	Non-seasonal vegetables and fruits (e.g. tomato, pepper, potato, onion, apple, banana, etc.), white cheese, pasta, beverages, etc.

As shown in Table II, cluster 3 has lower F, M and C values compared to average F, M and C values, whereas for segments 1, 2 and 4, values of F, M and C are above average F, M and C values. However, clusters 1, 2 and 4 have identical FMC scores, the magnitude of these features are different for each cluster. In this manner, the values of F, M, C features are the highest for segment 1 and it is followed by segment 2 and 4. Products in segment 1 which are bread, yogurt, milk, egg, chicken, beef, and chocolate are basic daily necessities of the general population regardless of gender, age, marital status, etc. As a result, they are the best-selling products of the company and make the most contribution to company's revenue at the same time. Thus, for these products, there is no need to provide any promotions or campaigns. However, it is important to effectively manage the inventory for this product group since the consumption rate of products in this segment is considerably high.

On the other hand, products in segment 3 which are nearly 75% of all products are least sold and least contributing products to the company's revenue in terms of F, M, and C values. Legumes, salt, detergents, cleaning products, personal and baby care products are some of the products placed in this segment. Such type of products has a lower consumption rate, and a long shelf life. Customers usually pursuit promotions or campaigns to buy such products, especially the expensive ones, such as detergents, cleaning products, etc. In that manner, the effect of marketing strategies to these products might become potentially greater than the effect to others.

As seen in Table III, products may place in different groups, different from their categories formed according to their intrinsic characteristics by domain experts. As an example, "dairy products" is a well-known product category in the supermarket shopping and includes basically the following products: milk, cheese, yogurt, butter, etc. With our proposed methodology for product segmentation, these products are classified into different clusters. According to our clustering results, milk and yogurt are in cluster 1, butter places in cluster 2, and cheese is in cluster 4. Therefore, we can conclude that although products are similar to each other in terms of their intrinsic characteristics, they may have different sale characteristics, so they may be grouped into different segments.

V. CONCLUSION

In this paper, a novel product segmentation methodology is presented. The proposed approach takes customers' transactions on products as input and employs clustering algorithms to segment products. Additionally, this study revises the RFM model used in customer segmentation to be the FMC model for product segmentation. The proposed approach was applied to a supermarket chain. For our case study, the results indicated that K-means perform better than Ward's method in segmenting products. Further, the obtained product groups showed that products placing in the same category in terms of their intrinsic characteristics may be grouped into different segments according to their sale characteristics.

This study shows the importance of sales transactions on the product segmentation. In this manner, retail companies can utilize the transactional data in their databases to group their products into meaningful segments. By using our proposed methodology, managers can gain useful insights about products' sale characteristics and identify different product groups. Further, obtained product segments through this methodology can be used by enterprises in streamlining both their marketing and supply chain efforts. Such a product segmentation can also be effectively used with an approach or a technique in the domains of data mining and KDD. In addition to these, the results of this study give a clear view of products' sale characteristics in the grocery retail domain, especially Turkish market.

As a further study, it is worthy applying the proposed approach to other retail domains. Another possible direction for future research might be to employ different clustering techniques to compare their performances with ones used in this study. In addition to these, we have not utilized the resulting product groups in the development of any marketing or inventory strategy. In this context, a valuable advancement to this study would be the inclusion of research measuring the impact of resulting product groups on the marketing and inventory strategies.

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Navigating Pre-recorded Off-road Routes Using a Mobile Device

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***Abstract* - Most navigation systems, during calculation of user's route, use a directed graph whose edges represent streets and roads. Using shortest path algorithms they find an adequate route. But as most bicycle paths, macadam roads and forgotten old paths are not digitally mapped, these algorithms become useless. In this paper we present a solution for tracking user's route while driving through the unmarked area as well as navigating the user through one of the recorded routes from the repository of a stored routes. During tracking, user can mark the route by adding navigational cues. Upon completion of the tracking, previously marked route can be modified and shared with others by uploading and publishing in a shared repository. To successfully navigate user through the selected route, we developed a position determination algorithm and user-friendly interface for mobile devices. Navigation part of the solution is responsible for visual and voice instructions about the upcoming navigational cues at the right time.**

The software is intended primarily to cyclists but can be used, for example, by hikers and mountaineers for safe exploration of nature.

Keywords; navigation; tracking; route; mobile application;

I. INTRODUCTION

As an object moves through space, a path of its movement represents its past and present positions and its attributes. For a long time, question of (i) presenting position of an object on Earth's surface, and (ii) determining the attributes of that position were one of the top challenges for the future of humanity. Global Positioning System (GPS) is one of few positioning systems used by receivers to determine its location on the Earth's surface. GPS refers to a network of 24 satellites that the United States is committed to maintain available 95% of the time [1]. The GPS consists of three components: (i) a space component, (ii) control component and (iii) user component. The space component consists of satellite constellations that transmit, by the atomic clocks generated, time signals, used to calculate GPS receiver position [2].

Constellation, consisting of a minimum of 24 satellites, is organized so that at any time, at any place on Earth, at least four satellites are visible. This is necessary to properly determine the location of the receiver [3]. In order for the GPS system to function successfully it is necessary to monitor the work and the path of GPS satellites. The task of the control component, consisting of global network facilities, is the management, maintenance and development of the entire GPS system. The user component consists of all those who use the GPS system and their receivers.

Signals transmitted by satellites make it possible to estimate position (latitude, longitude and altitude), time and speed to varying degrees of accuracy. Those data can be used to calculate moving object's speed without measuring how fast e.g. car or bicycle wheels are turning; or to measure the distance an object has passed, or to record a sequence of GPS locations so the route of an object can be viewed on a map after or during the drive. Together with a map with accurate data about roads and crossings, a GPS receiver also helps in navigation, and this is a function that truly promotes the spread of GPS devices.

The ambition of embedding GPS units in other products has driven the miniaturization trend in building a GPS receiver. Low production costs and GPS receiver getting smaller and smaller made it possible to embed it into mobile devices, resulting in widespread availability and popularization of GPS technology. Mobile devices are lightweight, easily portable, an inseparable companion to most of us, and that makes mobile devices excellent assistant for any type of travel.

Most navigation systems used by mobile devices, when determining a route, converts the streets, roads, and tracks into a directed graph. Then, using the algorithms to find the shortest path, finds a route. In order for the navigation system to navigate the user, all roads and tracks must be mapped to digital maps. But as most bicycle paths, macadam roads and roadways are not mapped to digital maps, these algorithms cannot be used.

One of the possible solutions is presented in this paper. This paper describes the implementation of tracking user's path, marking the route with the navigational cues, and navigating user through pre-recorded route using an application for mobile devices running the operating system Android.

The structure of the paper is as follows. After the introduction and related work, fundamental concepts in development navigational application for mobile devices are presented in section III. A description of the

navigational algorithm, we have developed and implemented, is given in section IV. Our conclusions are drawn in the final section.

II. RELATED WORKS

A number of companies (e.g. [4][5]) offer devices that integrate hardware for collecting GPS locations and software solutions for displaying and navigating object on a single screen. Built-in navigation systems are often included in standard equipment of many modern cars. There are also products targeted to cyclists and pedestrians with integrated hardware and software (e.g., [6][7]) for route planning and navigational cues via pre-downloaded maps and online GPS tracking service.

Despite the fact that the prices of the GPS receivers are rapidly decreased in relation to the beginning ones, a specialized navigation devices are still expensive to some groups of interested users. The possibility of integration of a GPS receiver in mobile devices, creates the ability for cheaper solutions, for development of navigational applications for mobile devices.

According to [8] almost two-thirds of new vehicle owners with a built-in navigation reported using their smartphone or a portable navigation device to find their way at least some of the time. We believe that majority of bikers and pedestrians would also prefer to use a free software on a mobile device instead of a professional navigation device. The other motivation for developing solution presented in this paper is the possibility of tracking and sharing own routes with others. Such functionality is rarely possible with professional navigational devices.

In this paper we are solving the problem known as Bicycle Route Planning in a specific way. Bicycle Route Planners are a very popular and efficient tools promoting cycling in urban and rural environment. The number of papers published by researchers within this field is modest. In [9] the authors describe a web-based tool that helps cyclists to determine safe and efficient routes while in [10] authors describe developed comprehensive bicycle planning method that uses GIS, MCE, and ESDA.

Our solution includes a system where users store their own recorded routes in a common repository and share them with others. We are aware that similar software solutions already exists on the market (e.g. [11][12]), but to the best of our knowledge the functionality of setting navigational cues during and after tracking the route, implemented in our solution, is not present in any of them.

III. FUNDAMENTALS OF NAVIGATIONAL APPLICATION FOR MOBILE DEVICES

Development of a navigational mobile application implies the use of a framework with rather advanced capabilities such as the ability to obtain the exact location of an object or the ability to detect user's activity (e.g. are they walking, running or cycling). According to number of sources Android and iOS are the most widely-used mobile operating systems. Having this in mind we developed navigational application for mobile devices using Android OS. In the rest of this section we explain fundamental concepts in development of navigational application for mobile devices with an emphasis on those using the Android OS.

A. Determining object location

The key of successful navigation is in determining a user's location. An accuracy and frequency of an information about new GPS location, determined by its latitude and longitude, greatly influences the efficiency of different navigation methods. For example, due to an inaccuracy of the current location received, the navigation system may mistakenly conclude the moment of the user passing by the navigational cue or current distance between the user and the route that the user needs to be navigated on. Further, in case of the excessive time interval between arrivals of successive location information, the navigation system cannot promptly notify the user on the necessary actions to take (e.g. 'turn left'). To overcome issues like mentioned ones, for development of mobile navigational applications, a frameworks that automate tasks such as providing current location of an object and detecting user's activity are on disposal. Currently, the most advanced framework for operating system Android is *Google Location Services API* [13].

Google Location Services is an application programming interface that enables developers to embed location awareness to mobile applications. The framework automatically handles location providers and user's movement and offers the ability to control different parameters to efficiently manage location accuracy. With the ability to define the desired level of precision and time interval of the location update, it is also possible to set the minimum distance (expressed in meters) between two consecutive location information. The specified minimum distance determines whether the received location will be forwarded to the application. Depending on the parameters, the mobile device automatically adjusts settings and selects the appropriate location access source.

These parameters significantly affect the performance of a battery in a mobile device. By requiring the location of the highest possible precision, applications will most likely use GPS as a location source and will thus have the highest energy consumption. Also, the frequent retrieval of the current location increases the mobile device battery consumption. In order not to compromise the user's navigation ability and to minimize battery consumption the optimum value of the location parameters should be set.

B. Tracking a user's route and setting navigational cues

In order for the user's location information to be received frequently enough, and in order to determine the location of the user as accurately as possible, it is necessary to set the configuration parameters so that the *Location Service API* [14] returns the new user's location in the highest possible precision, as frequent as possible (e.g. every second). When tracking a user, the user's previous and current location must be known at any time. To minimize mobile device energy consumption specific situations (e.g. the user does not move) should be recognized. This can be done (as stated in previous

section) by determining (and setting) the minimum distance between consecutive locations required to receive new location information.

In order to draw different shapes (for example, the current location tag or navigational cue) on the map segment showing the area where the user moves, we need to know their geographic locations. APIs for navigational applications development, such as *Google Maps Android API* or *osmdroid* [15], incorporate functions that serve to display the map on the screen and desired shapes on the map. Also, they contain functions for calculating the distance between different shapes that are plotted on the map, and the interfaces that listen and respond to touches of the screen.

Once the tracking begins, we store all the incoming locations in a suitable data structure. Collection containing a sequence of geographic locations allows the reconstruction of a user's movement route. The passed route can be plotted on a map by linking geo-locations with a suitable geometric shape (e.g. polyline, a common geospatial data type). Besides the preview of the user's movement route, it is convenient to show the distance he has passed as can be seen on Figure 1. At the beginning it amounts to zero, and whenever a new location arrives, the total distance is increased with the distance between the current and the previous location. Since Earth is not a flat panel, it is necessary to consider its curvature when calculating the distance between two geographic locations.

In the mobile app we have developed, there are two ways to create a route with navigational cues: (i) user adds a navigational cue to the current location on the spot, during the route recording and (ii) user adds navigational cues to a previously stored route.

Pressing the segment of the passed route opens a window with the option of selecting a suitable navigational cue (Figure 2). Creating a route relies on the ordered collection of a geo-locations presenting the movement path. When adding a navigational cue, we store its navigation instruction (e.g. make a U-turn), its geo-location, and the index of geo-location that precedes the cue.

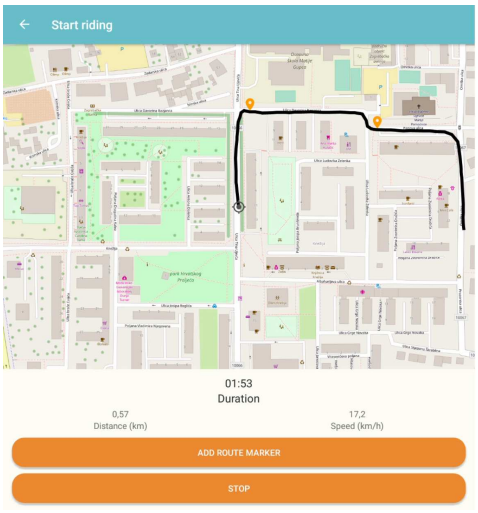

Figure 1. Tracking user's movement

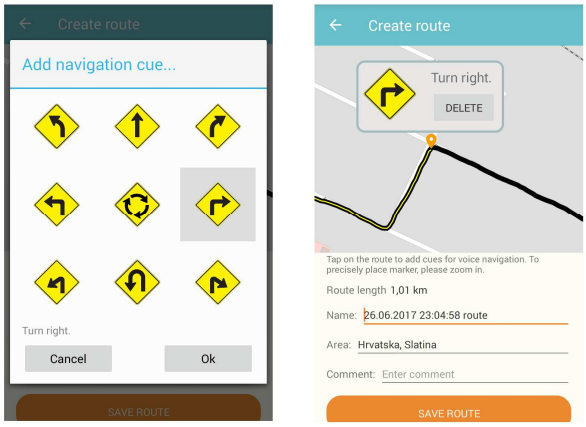

Figure 2. Placing a navigational cue to a previously stored route

Storing the index of geo-location that precedes the cue is motivated with situations where it is not trivial to determine the part of movement route the navigation tag refers to. Such situations are those where the route sections overlap like the one shown on Figure 3. The red X represents the navigational cue, and the black circles represent the geo-locations of the movement route. The geo-location of the navigational cue in this case does not indicate which part of the route the cue refers to. It may refer to the direction west-east or south-north. By linking the navigation cue with the index of preceding geo-location from the passed path, we can precisely define to which part of the route the navigation tag belongs.

Thus, the navigation cue for the west-east direction is determined by its navigation instruction, its geo-location and index number 4. If a navigation cue is added during tracking user's movement, determining its geo-location and previous geo-location index is pretty simple. Its geo-location is the user's location at the moment of adding a cue, and the index of preceding location is equal to the number of elements in the collection minus one.

Adding navigational cues to existing user's movement route is somewhat different. It is done by pressing a *polyline* that symbolizes the path the user has passed. The interface defined for the *polyline* is listening to the events of pressing the screen, and returns the geo-location at the pressed point. As the interface responds to the pressure of the drawn geometric shape, in order to get the most accurate results, it is necessary to zoom in sufficiently. Like with adding a navigational cue during tracking user's movement, it is necessary to determine the index that defines it.

The first step in finding the appropriate index is to create a *polyline*, representing the segment of the passed route. At the beginning the polyline connects the first two geo-locations in collection. Then we need to check whether this segment is close enough to the geo-location of the navigational cue. If the segment is not close enough, the next segment of the route is created and checked. In case where the segment is close enough, the index of starting point of segment is linked to navigation mark. The process is repeated until a segment close enough to the geographic location is found or until the end of the collection is reached. If the segment was not found, the user must re-select (press) the location on the *polyline*.

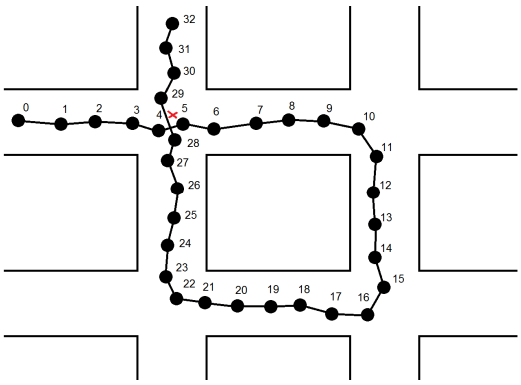

Figure 3 Placing a navigational cue in overlapping parts of the route

The boundary value for the distance that determines whether the route segment is sufficiently close to the navigational cue is arbitrary and should be chosen carefully. When the distance is too long, it can cause an incorrect linkage of the navigational cue with the geo-location from the route.

Figure 4 illustrates the procedure of determining the index for the navigational cue. In the first step, the geo-location for the navigational cue is selected by pressing the polyline. In the second step, the distance of the segment (marked in yellow) is checked against the navigational cue. As the distance is greater than the defined boundary, further search continues. In the sixth step, a segment close enough to the observed location was found. The number four becomes the index that determines the navigational cue. When storing data for the route, the navigational cue locations (along with the navigational cue identifier) are stored after the geo-location that determines them.

IV. NAVIGATION OF A USER

To navigate the user through the route, at least one route must be created and saved. As already described, the route is defined with an ordered collection of geo-locations. The navigational cues, defined for the route, are stored in an additional collection. In addition to the data described in previous section, such as the text and image of navigational cue, and the index pointing to its position within the geo-point collection, information indicating whether the user has already passed that navigational cue or not is also stored. When navigating a user, the navigational software must be able to determine user's position in relation to the route at any time. Our navigational algorithm includes functions that describe the relationship between the current geo-location of the user and the segment of the route. The route segment is the smallest unit on which the route can be divided and has two neighbouring geo-locations as its borders. The functions we have implemented to determine user positions are:

- The function that calculates the shortest distance between the point *p* and line defined by *start* and *end* points.

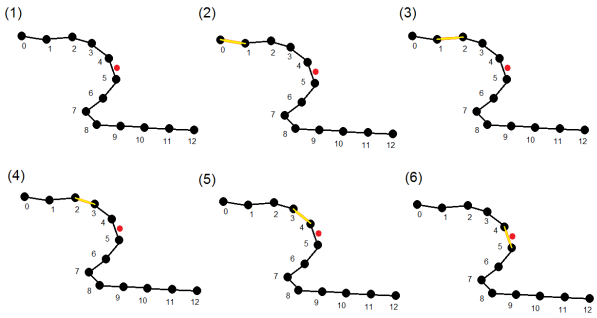

Figure 4 Determining the segment closest to a geo-location

- The function that finds the point on the line, defined by the *start* and *end* points, representing the intersection of that line and the shortest distance path passing through the point *p*.
- Function that verifies whether the line representing the shortest distance path is orthogonal to the line specified by *start* and end *points*.

In relation to the segment of the route, the point can be in three different positions as shown in Figure 5. In the first (1) and third (3) case the shortest distance is not at the intersection of two orthogonal lines. In such cases, the length of the shortest distance is equal to the distance between the point *p* and the *start* or *end* point (whichever distance is shorter). Then, the function for finding the intersection returns the *start* or *end* point. In the second (2) case the shortest distance is the length of the line connecting the point and the intersection of two orthogonal lines.

A. *Algorithm used for navigation*

After the user starts navigation, navigation algorithm (Algorithm 1) is executed each time a new user's location (`usersGeoLocation`) is received. At each algorithm iteration it is necessary to note the user's location in relation to the route. A variable called `previousSnappedToRouteIndex` is used for storing the index of the location the user last passed by during navigation.

If the navigation is started for the first time, it is necessary to check whether the user is near the route (lines 6 to 12) or not. The algorithm iterate through the route segments, trying to find a segment close enough to the current user's location. What is close enough is defined with the parameter (`closeEnoughDistU-S`). Defined parameter value determines the maximal allowed distance between the user's current location and the observed segment that will trigger the navigation. In case that such segment is found, the navigation begins.

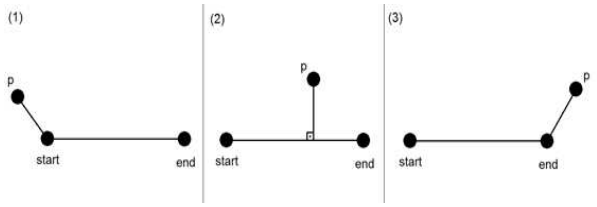

Figure 5 Three possible cases when determining the shortest distance between the point and the line

Otherwise, it is assumed that the user is far away from the route and the navigation is stoped (line 9 - `NavigationStopped_FarAwayFromRoute`). If the user is near the route, it is necessary to determine `previousSnappedToRouteIndex`.

If the function for finding intersection between that segment and the current location returns an end point of a segment, it means that the user has already passed that segment. The `previousSnappedToRouteIndex` stores the index of geo-location representing the end of the observed segment. In two other cases, index of geo-location representing the start point of the segment is stored.

Then the algorithm goes through the collection of navigational cues and checks whether the user has already passed any cue (line 11). If it is passed, it should be marked as passed. This situation may, for example, occur if the user starts navigation from the middle of the route. Part of the algorithm between lines 13 and 36 is executed always – regardless the fact the navigation is initiated for the first time or not. The `previousSnappedToRouteIndex` is set and the first navigational cue that the user did not pass (line 13) should be find. If the user has passed all the navigational cues (including the target one), the user navigation ends (lines 14 and 15).

Then the algorithm (lines 16 to 24) tries to find a segment whose distance to the current user's location (`currentDistU-S`) is the smallest (`smallestFoundDistU-S`). The search begins with the route point whose index is stored in the `previousSnappedToRouteIndex`, that is, from the last point of the route the user has passed. Due to the possibility of user to leave the route, it is necessary to check whether the user is close enough to the observed segment (line 18). When the first segment, in line with the conditions, is found, the position of the user in relation to that segment is also found (line 19).

As already explained, according to Figure 5 there are three possibilities. The algorithm then checks whether the `previousSnappedToRouteIndex` should be binded to the start point or to the end point of the segment. Accordingly, its value is updated and the segment search is finished.

Algorithm 1: Navigation of the user

```
1  Input: usersGeoLocation;
2  Output: navigational instruction;
3  closeEnoughDistU-S   ← parameterValue;
4  farAwayDistU-S       ← parameterValue;
5  almostFarAwayDistU-S ← parameterValue;
   Begin
6     if (navigation started for the first time) {
7        find first segment with usersGeoLocation < closeEnoughDistU-S;
8        if (segment not found)
9           turn navigation OFF and send notification NavigationStopped_FarAwayFromRoute;
10       determine value of previousSnappedToRoute;
11       mark all passed navigational cues;
12    }
13    find the first navigational cue the user did not pass;
14    if (user has passed all the navigational cues)
15       turn navigation OFF and send notification RouteCompletedSucesfully;
16    for (segment defined by  previousSnappedToRouteIndex; end of the route; next segment) {
17       currentDistU-S ← distance between the usersGeoLocation and the segment;
18       if (currentDistU-S < closeEnoughDistU-S) {
19          determine value of previousSnappedToRoute;
20          smallestFoundDistU-S ← currentDistU-S;
21          break;
22       }
23       determine whether the currentDistU-S is the smallestFoundDistU-S;
24    }
25    if (smallestFoundDistU-S > farAwayDistU-S)
26       turn navigation OFF and send notification NavigationStopped_UserWandering;
27    if (smallestFoundDistU-S > almostFarAwayDistU-S) {
28       Send notification makeU-turn;
29       return;
30    }
31    mark all passed navigational cues;
32    find the first navigational cue that the user did not pass;
33    if (user has passed all the navigational cues)
34       turn navigation OFF and send notification RouteCompletedSucesfully;
35    currentDistU-C ← distance to the next navigational cue;
36    given the distance, provide the user with appropriate visual and vocal instruction;
   End
```

While searching for the appropriate segment, smallest distance between the user and all iterated segments (`smallestFoundDistU-S`) has to be found and saved (lines 20 and 23). If the smallest distance between the user and the segment is larger than some pre-defined value (`farAwayDistU-S`), navigation is turned off and user is notified accordingly (lines 25 and 26 - `NavigationStopped_UserWandering`). Warning about user leaving the route and instruction about performing a U-turn is issued when the smallest distance is less than the

value required to terminate the navigation (`farAwayDistU-S`), but is large enough (`almostFarAwayDistU-S`) to alert the user (lines 27 and 28). User can return to the route as long as the smallest distance does not exceed the value of parameter (`farAwayDistU-S`) indicating that the user is far away from the route. If none of this is the case, the algorithm checks whether the user has skipped some navigational cues in the meantime (line 31). Iterating through the list of navigational cues and comparing its attached index with the value stored in the `previousSnappedToRouteIndex`, the algorithm determines cues that have been passed. In case that the user has passed all the cues, navigation is turned off (lines 32 to 34).

Next step (line 35) is finding the distance between the user and next navigational cue (`currentDistU-C`). It can be easily calculated knowing the user's geo-location, value of `previousSnappedToRouteIndex` and geo-location of the next navigational cue by calculating and summing the lengths of individual route segments. Voice and visual instructions consist of the distance between the user and next navigational cue and the instruction telling which action user has to take. Visual instructions are updated at each iteration of the algorithm, while voice instructions are activated in relation to the user's distance to the navigational cue (line 36). The voice instruction will be activated when the user is close enough to the navigational cue. That is just one of the software's parameters. When the user's distance to the navigational cue is within the specified interval, the voice instruction will be activated. Once the voice instruction is activated, it shouldn't activate within that same interval again. When a user is close enough to the navigational cue, the vocal and visual instruction should omit the information about distance from the cue so that the user can respond in a timely manner. Figure 6 shows the layout of the screen during navigation when the user has passed the first navigational cue.

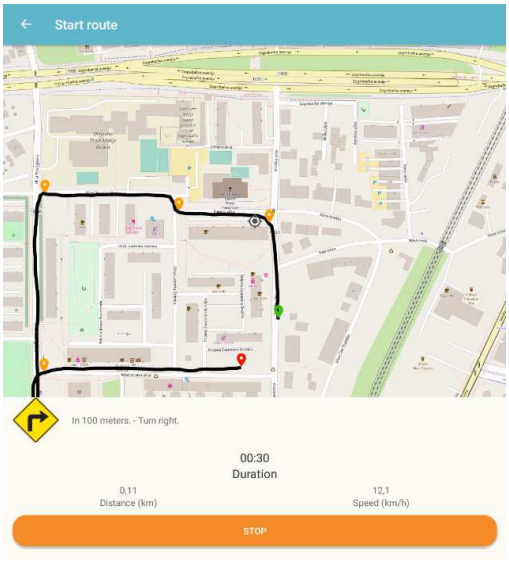

Figure 6. Display of a navigational cue

Also, along the navigational icon and instruction, application displays the distance to the next navigational cue.

V. Conclusion

This paper has investigated and described the basic concepts existing in GPS navigation space. We explained the motive for development of mobile navigational application as well as the reason we opted for operational system Android. The fundamental concepts of navigational applications such as: determining object location and principles of tracking the user's route are described. The algorithm for navigating the user along the route is explained in detail. To successfully navigate the user through the selected route, we developed a position determination algorithm and user-friendly interface. Navigational part of the software provides the user with visual and voice instructions about the upcoming navigational cues at the right time. Possibility of setting up navigational cues while recording the route and later, after the route is saved is the main advantage of our solution compared to similar.

We believe that this solution can be useful to cyclists but also to pedestrians, hikers and mountaineers for safe exploration of urban and rural environment.

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On Adaptive Prediction of Nonstationary and Inconsistent Large Time Series Data

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***Abstract* - The use of time series prediction results in benefits for an organization. Forecasting efficiency relies on applied prediction formula and quality of data received from technical devices and manually inputted. They are often of low quality, with inconsistencies. However, high data quality is crucial for efficient forecasting/prediction purposes (also event detection from time series and pattern recognition), in particular during large data sets processing (often heterogeneous, including data obtained from IoT devices). Such processing should cover inconsistency analysis, interpolation of missing/lacking data, as well as the use of data pre-transformations.**

The paper presents problems of inconsistent, nonstationary data prediction on the example of stock level daily forecasting. Selected methods of time series interpolation are outlined. Results of implementation of algorithms for short-term time series prediction are illustrated and discussed. Prediction quality measured based on errors values calculated both in total and in a moving window is discussed. A concept of an adaptive algorithm based on a change in the prognostic formula depending on short-term characteristics of time series is outlined.

Keywords - time series analysis, prediction, forecasting, interpolation, adaptive prediction algorithms, Big Data, IoT

I. INTRODUCTION

The use of effective predictors of time series datasets is valuable for organizations. It relies on data quality received from technical devices (often heterogeneous processed in distributed systems) and manually inputted data, typically of low quality, with inconsistencies. Time-delays, outliers, redundancy and finally changes in time-series stationarity can be observed.

High data quality, in particular processed time series and diagnostic signals [8], is very important for the prediction purposes, event detection [9], [6] and pattern recognition tasks. A limited set of short-term prediction algorithms is typically implemented for original data or data slightly transformed. In addition, short-time statistical and frequency properties of processed data are not considered during calculations. It results in decreasing of the probability of obtaining reliable prediction results.

Computer processing of large data sets, including data obtained from Internet of Things devices (IoT), in the first processing step requires an application of methods for inconsistency analysis and then interpolation of missing/lacking data. The use of pre-transformations is often recommended (e.g. for time series data sharpening, smoothing etc.). In the next processing step, consistent and informative datasets can be analyzed both in time domain (exploiting statistical methods [3]) and frequency domain [6] (i.a. with Fast Fourier Transform (FFT)). Thus, based on identification of the series a selection of suitable prediction algorithm(s) can be applied.

For many companies an estimation of inventory level is particularly important [2], [7], [11]. It influences the change in profits and storage costs of products. Such estimation is typically based on time series processing describing i.a. a number of items of a product in a time unit. Inconsistencies and unreliable values negatively affect the decision-making process [5].

Efficient time series prediction needs an application of adaptive algorithms dedicated to processed time series properties. Such algorithms are presented and described in [9] and [10]. In addition, processing of components of the series should be considered (see [6] and 10]).

The paper presents remarks on effective short-term prediction of non-stationary, inconsistent time series. Such a task is typical for large heterogeneous datasets (Big Data) processing. Requirements of efficient time series prediction are outlined. Data inconsistency problems are discussed, interpolation methods are described. Short-term prediction algorithms of non-stationary time series data (zero-order-hold [4], first-order hold, polynomial extrapolation, adaptive Holt's model [1], [9]) are presented and used for one-day ahead forecasts of 5 input time series (real data: stock levels). Prediction results calculated with prediction algorithms and interpolation methods are illustrated and discussed. A concept of an adaptive prediction algorithm based on a change in the prognostic formula depending on short-term characteristics of the processed time series is outlined.

II. INVENTORY LEVEL PREDICTION

A. Remarks on inventory level prediction problems

Estimation of the optimal stock level of a product is not a trivial task. The inventory level is correlated with the demand, related time and cause-and-effect dependencies between changes in stocks. It also relies on profiles of contractors (customers, providers, suppliers), life-cycle phase and the product quality [6], [11], [2].

Low stock level of a product is related to low storage costs while high level potentially increases the quality of

customer service. To estimate quasi-optimal inventory level expert-knowledge supported by time series prediction can be exploited [2]. Short- and medium-term characteristics of the demand/inventory level can be described as time series or advanced profiles (averaged, classified and attributed short-term characteristics in time and/or frequency domain). Time series can represent i.a. a number of items in a time unit (sampling rate: time/date). Time series prediction quality (efficiency) directly implies the validity of decisions made. It may result in changes in benefits and also costs of lost profits due to out of stocks.

For the purpose of effective decision making in the area of inventory level/stocks estimation, the use of advanced predictive models is recommended. Predictive models are understood as sets of formulas for computer time series forecasting for a fixed horizon (short, medium, long). The forecasting process can be divided into processing stages. Typically, it may consist the following:

- a preliminary analysis of original time series (the goal is to obtain data of good quality, consistent, after identifying not available data or time series interpolation); an interpolation method affects the results of further calculations (i.a. correlation or similarity analysis);
- an application of preprocessing algorithm(s) (for example, to retrieve valuable information, to noise reduction, to extract specific components from processed time series);
- an application of selected forecasting algorithm(s) for a fixed time period and horizon;
- an analysis of quality of prediction results with dedicated error measures (for example, root mean square errors, RMSEs).

B. Input time series and data interpolation

Input set of time series used for analyses and prediction as sample non-stationary data represents daily stock level in a company (floor covering sector). 500 inconsistent time series (real data) illustrate a number of items (products) recorder for consecutive working days (time-period covered: one year). Due to low level of consistency, a subset of 5 time series was used for further processing. Selection was based on exceeding the threshold set to 90%. Sample series is shown in Fig. 1.

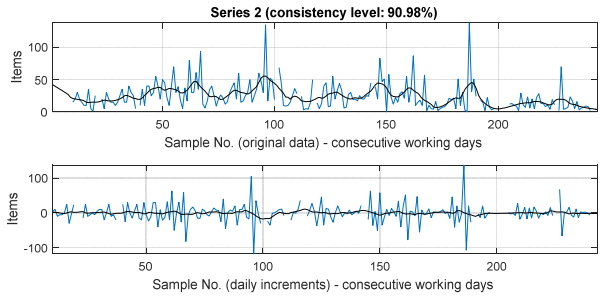

Figure 1. Sample input time series: original data – daily stock level of a product traded (floor coverings sector, upper subfigure) and its one-sample daily increments (lower subfigure); on the background smoothed time series are depicted (solid black lines).

Fig.1. reveals exemplary inconsistencies of the series in neighborhood of the sample 100 and 200.

In the next processing step, interpolations were applied to obtain data to be used for further calculations. Selection of an interpolation formula influences the efficiency of data processing algorithms, in particular aimed at prediction purposes. Properties (quality) of interpolation are very significant in the case where there are long series of inconsistencies in processed time series data.

A number of methods of time series interpolation have been analyzed. Finally, the following ones were selected: (a) arithmetic mean hold (AMH) in a moving window fixed to 10 (2 working weeks) and (b) polynomial approximation (PA) of the degree 1 in a moving window fixed to 22 (one working month).

Then, interpolated time series were used as an input data for further calculations aimed at time series short-term (one-day-ahead) prediction.

C. Prediction models for inventory level forecasting

Univariate prediction models (one-dimensional ones) are proposed for the forecasting purposes. In this case, one-sample-ahead prediction can be delineated based on the series dynamics (ARMA signal models [4]) or with extrapolation models. A function of a trend is assumed arbitrarily (a polynomial, for example linear trend, can be assumed) which parameters are usually calculated with the Least Squares (LS) method by a series approximation in a fixed window, or by expected value and the series increments exponential smoothing method (Holt's forecasting model [1]) [9], [1].

In the case of the Wiener process (random walk) where daily increments are treated as stationary sequences of independent random numbers, the optimal predictor, especially for short-time prediction horizons, is the last value of the processed series. For this purpose, the zero-order-hold (ZOH) and the first-order-hold (FOH) methods can be used [4].

The Holt's model [1], [9] is used for smoothing and prediction of time series containing a trend and a random component. The first-order polynomial is used to describe the linear trend in the series $\{y_n\}$. The variable level and its increments are exponentially smoothed. The adaptive Holt's model can be applied by the parameters (weights) adaptation in a moving window. *p*-step prediction of time series *y* at the time *n* is calculated as:

$$\hat{y}_{n+p} = \tilde{y}_n + g_{Yn} \cdot p + c_{Yn} \cdot p^2 \tag{1}$$

where $\tilde{y}_n$, g_{Yn}, c_{Yn} denote exponentially averaged values *y*, one-step and two-step increments:

$$g_{Yn} = g_{Yn-1} \cdot \beta + (1-\beta) \cdot \Delta y_n \tag{2}$$

$$c_{Yn} = c_{Yn-1} \cdot \gamma + (1-\gamma) \cdot \frac{\Delta^2 y_n}{2} \tag{3}$$

$$\tilde{y}_n = (\tilde{y}_{n-1} + g_{Yn} + c_{Yn}) \cdot \alpha + (1-\alpha) \cdot y_n \tag{4}$$

The parameters α, β, γ (ranged between 0 and 1) can be adjusted in an arbitrary way. They directly influence the contribution of a component of time series y in the process of forecasting.

For prediction purposes presented in the paper, adaptive Holt's model is exploited. For each time-instant n (iteration) a set of the parameters α, β, γ is randomly generated (with pseudorandom number generator built in Matlab). For each set of parameters (of size S) one-step-ahead forecasts are calculated in a window containing W retrospective data (samples), ranged between $n - i + 1$ and $n - 1$ sample. Then, forecast errors (RMSEs, see (5)) are calculated. Finally, the best set of parameters (with the smallest prediction error calculated for retrospective samples) is selected to perform forecast at the time n.

$$RMSE_n = \sqrt{\sum_{n=1}^{k} \left(y_n - \tilde{y}_n\right)^2} \tag{5}$$

D. Selection of prediction models for analysis

To compare an applicability of interpolation methods used for original series and to analyze efficiency of the inventory level prediction performed for the series with different long-term statistical properties, the following prediction models were used: zero-order-hold; first-order-hold; polynomial (linear trend) extrapolation (window width fixed to 22 samples – one work month); adaptive Holt's forecasting model (windows width: 22 samples/working days) – see (1)-(4).

Due to short length of time series used as a sample data, prediction algorithms dedicated for processing of time series containing cyclic component were not applied.

III. Results and Discussion

A. Real time series data prediction results

Four prediction models were used to calculate one-day-ahead forecasts (see section II.D) of 5 input time series (interpolated datasets, see II.B) and corresponding errors: total ones and errors calculated in a moving window. Results get with two representative interpolations (arithmetic average hold, AMH, and polynomial approximation of degree one, PA) are shown. However, analyses focused on an application of various number of interpolation methods, different moving window widths and parameters of prediction models were performed.

Calculation results are depicted in figures 2-9. Figures 2–4, 6 and 8–9 show interpolated original time series data (solid black lines) and the predicted series (red lines) with total RMSEs (see captions of figures). Figs. 2–7 illustrate predictions obtained for the series interpolated with the AMH. Figs. 8, 9 depict prediction results for time series interpolation with the PA. Note, that one-sample-ahead point predictions (and corresponding errors) are calculated also for interpolated values of the series. It affects the quality of predictions.

Figures 5 and 7 illustrate prediction errors calculated in a moving window containing 22 values (working days). Error values allows to highlight time intervals of efficient forecasts with a given predictor (RMSE values near to 0), time intervals covering abrupt changes of an error (thus changes in prediction quality) and periods where relatively constant one-step-ahead daily prediction efficiency is observed. The window width (22 time instants) was fixed arbitrarily. Nevertheless, it can be adjusted in relation to an equivalent of a work week/month/quarter/year.

A significant increase in a RMSE value at the time n reveals a deterioration of used predictor. They can be an effect of changes in short-term time series statistical properties (for example, changes of mean value or variance). However, changes of errors can be further used as an useful diagnostic signal to detect untypical data, outliers, undefined patterns etc. In many cases identification of short-term changes of statistical properties of the processed series can trigger a need of switching the forecasting formula or adjusting the predictor parameters. As a result, ongoing suitability of prediction model to processed short-term characteristics of the series thus a possibility of calculating of efficient predictions can be achieved.

The best prediction results are obtained with the polynomial extrapolation method and the adaptive Holt's model. In both cases, the most accurate predictions are calculated for the Series 1 and the Series 4 (these time series don't reveal abrupt changes of short-term mean value and dispersion related to other ones; in addition, they have the lowest variance). For the other ones, significant changes of the errors computed in a moving window are visible.

Figures 4, 6, 8 and 9 show that results get with the polynomial extrapolation visualized as a series of point predictions have less dispersions (smoother predicted series plots) than prediction calculated with Holt's model. It is visible that forecasts calculated with Holt's model are more sensitive to changes in original (historical) data.

In general, results obtained with two proposed interpolation methods are comparable, thus one may say that both the AMH and PA are suitable for inconsistent time series processing. Interpolation methods (AMH, PA) can be used for predictions purposes due to relatively constant values of prediction errors in the neighborhood of the interpolated data points (for example, see the second subfigure in Fig.7).

In the case of high dispersion of consecutive prediction results (point predictions, RMSEs) error values differ in amplitude and the length of time period where the RMSE's properties are relatively constant.

Thus, it is recommended to apply different forecasting models in relation to processed time series data short-term characteristics (statistical properties, components etc.).

Both the ZOH and the FOH methods produce worse results (in total) than Holt's and polynomial extrapolation. Inadequate prediction quality arising from nonstationarity of input series (regardless of performing calculations for daily increments series, more stationary than original data). It's possible to obtain negative values of predicted stock level (see Fig. 2). Considering RMSEs in a moving window, the ZOH and the FOH can be used as indicators of changes in the time series stationarity.

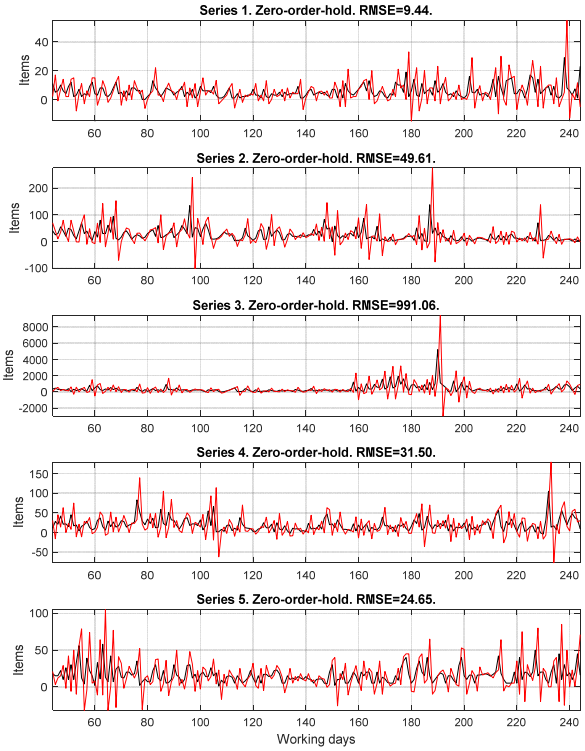

Figure 2. One-sample-ahead prediction results obtained with the zero-order-hold (ZOH) and the total RMSEs (AMH interpolation).

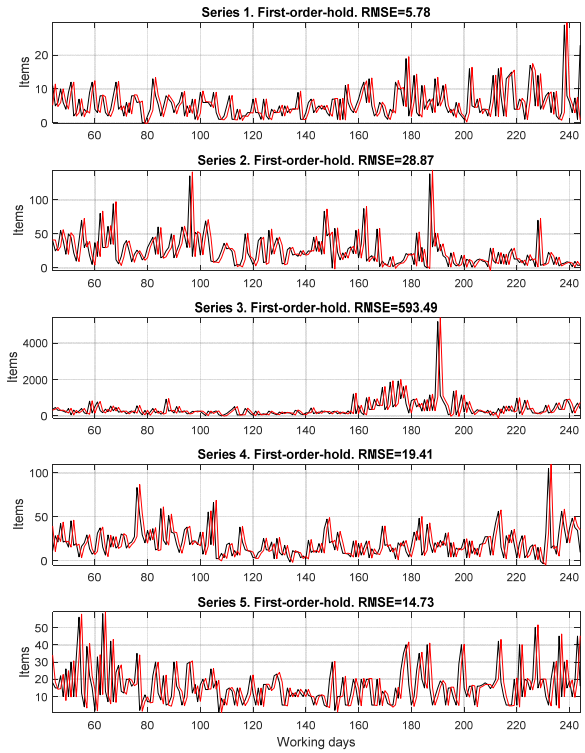

Figure 3. One-sample-ahead prediction results obtained with the first-order-hold (FOH) and the total RMSEs (AMH interpolation).

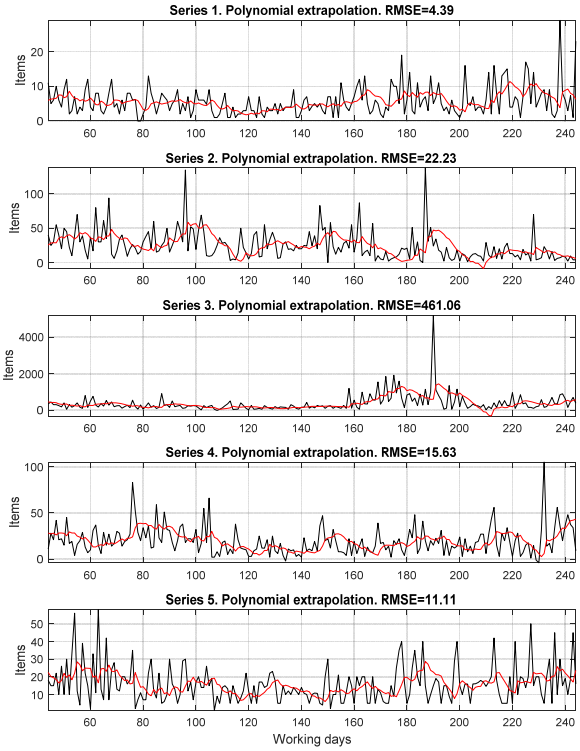

Figure 4. One-sample-ahead prediction results obtained with the polynomial extrapolation and the total RMSEs (AMH interpolation).

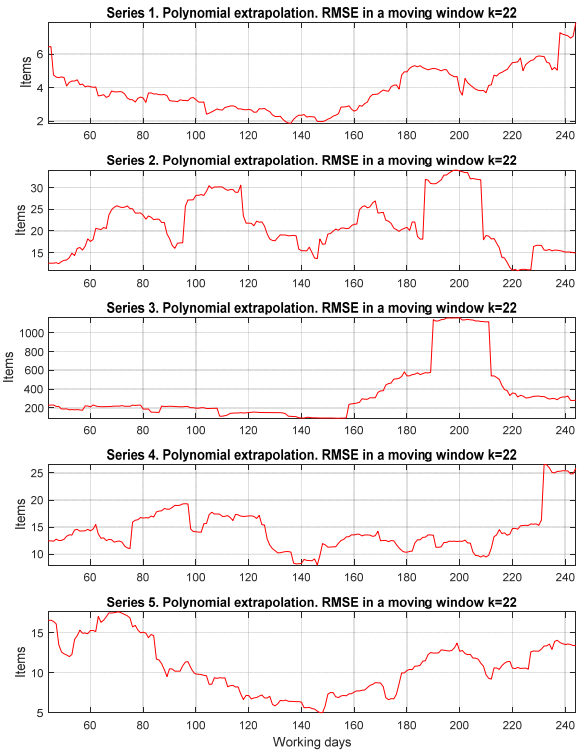

Figure 5. Errors of one-sample-ahead prediction with the polynomial extrapolation; moving window $k = 22$ (AMH interpolation).

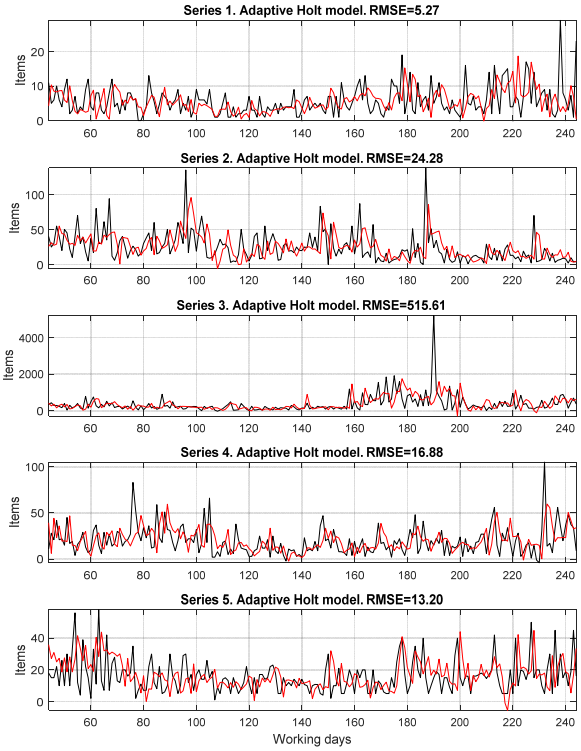

Figure 6. One-sample-ahead prediction results obtained with the adaptive Holt's model and the total RMSEs (AMH interpolation).

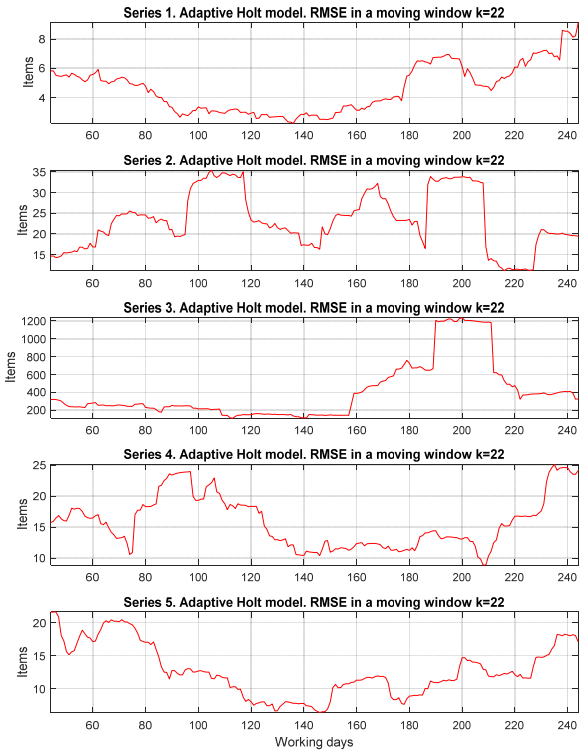

Figure 7. Errors of one-sample-ahead prediction with the adaptive Holt's model; moving window $k = 22$ (AMH interpolation).

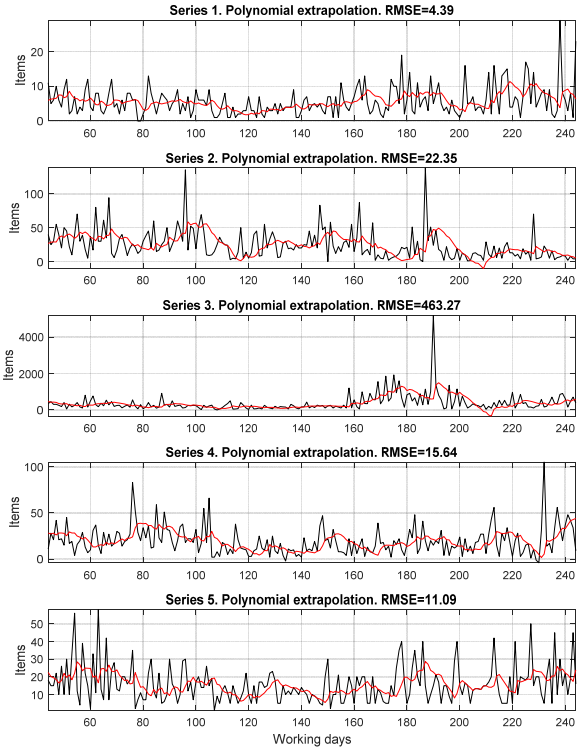

Figure 8. One-sample-ahead prediction results obtained with the polynomial extrapolation and the total RMSEs (PA interpolation).

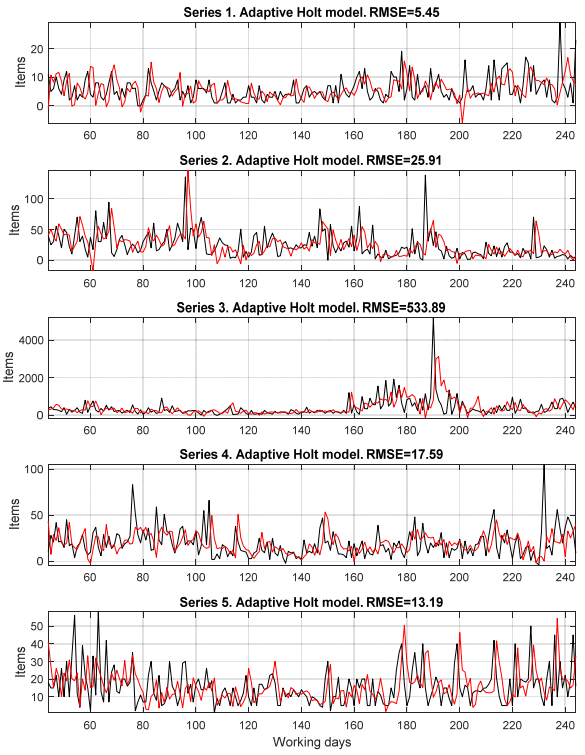

Figure 9. One-sample-ahead prediction results obtained with the adaptive Holt's model and the total RMSE (PAs interpolation).

B. *An idea of prediction improvement: dedicated adaptive prediction algorithm*

As discussed in the section III.A, depending on short-term statistical properties of processed time series, predictor parameter adjusting [10], prediction formula on-line switching and application of a pre-processing method (i.a. interpolation, smoothing) are recommended to perform. They reduce a probability of decreasing of short-term predictions accuracy thus inefficient decision making. It is valuable to analyze available data toward identification of symptoms of a change in short-term statistical and/or frequency properties.

Accuracy of forecasting can be improved by application of an adaptive prediction algorithm [9] aimed at switching prediction formula depending on current time series behavior. It may be done in the following steps:

1. At the time *t*, input data is analyzed and, if necessary, interpolated.
2. Short-term statistical properties are calculated (in a moving window of fixed width).
3. Forecasts are computed (with the polynomial extrapolation and adaptive Holt's model), errors are calculated.
4. Distance coefficients between the analyzed data and time-shifted data are calculated (to this aim, correlation analysis can be also used).
5. Adequate predictor is selected based on a comparison of prediction efficiency calculated for retrospective data related to a similarity of the processed subseries and time-shifted series in earlier time intervals at the time *t*.

An implementation of the algorithm presented above will be the aim of further research.

Considering large datasets (and high computational complexity problems) comparison of time-series properties at the time *t* and historical ones is difficult and can be impossible to perform in acceptable time.

Thus, it's reasonable to employ an idea inspired by biology to overcome problems of exploring large data sets in real time. In particular, an immune paradigm can be exploited [9], [10]. In this case, the goal is to (a) represent short-term data as lymphocytes, (b) create adaptive knowledge base containing information concerning temporary data characteristics and related prediction efficiency, (c) to establish the rules of adaptation of the knowledge base and (d) selection of information on predictors (algorithms, parameters, processing steps) suitable for the processed subseries at the time *t*.

IV. CONLUSION

In the paper, problems of prediction of inconsistent data are outlined. Results get with four prediction methods (for data interpolated with two methods) are illustrated and discussed. They show a necessity of a predictor adaptation during data on-line processing based on short-term statistical characteristics analysis and prediction errors. Calculation results show that efficiency of a predictor cannot be only relied on the total error value. More valuable is to analyze errors calculated in a moving window. The idea of adaptive prediction algorithm dedicated to on-line switching the prediction formula based on change in the data properties is outlined.

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Simulation Based Business Processes Analysis in Higher Education Institutions

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***Abstract* – Business process management (BPM) based on the usage of simulation modelling allows organizations to sustain and improve their operational performance. Discrete event simulation (DES) can help identify resource's bottlenecks, such as staffing, estimate process execution or delay times, test improvement suggestions in the process design phase, and overall assist in understanding how processes might impact performance in various scenarios. While many research papers report on the industry applications of BPM and DES, we focus to higher educational institutions (HEIS). Goals of the paper are: (1) to review the research of BPM and DES in HEIs, and (2) to discuss the impact of BPM and DES to process performance in one Croatian HEI. The case study methodology has been used in order to shed some light on the issue of applying discrete event simulation in BPM in the HEIs, especially for the purpose of collaboration improvement and impact assessment.**

Keywords – business process management; higher education institutions; discrete event simulation; case study, Croatia

I. Introduction

Discrete event simulations (DES) have an important role in BPM since their usage better support the development of processes and evaluation of their impact to business performance, allowing experiments under different scenarios. While previous researches indicated that the usage of DES in the most often present in industries, such as manufacturing, transportation and storage [1], other authors suggest that DES could have a relevant impact also to HEIs [2]. Besides, Damij et al. and [3] and Máchal [4] noticed that HEIs have been challenged by internal and external factors to become more efficient in performing their processes. Due to their need to renew and reshape their organizational structures and management practices, DES has been proved as a valuable method in BPM at HEIs [5].

Business process management (BPM) is applied in different ways in higher educational institutions (HEIs), but these various applications can be systemized in two main categories.

First, BPM is taught at HEIs as part of the curriculum, as a sole course, but also integrated as part of other supporting courses. BPM courses are taught in a variety of levels: from introducing students to BPM fundamentals, [6], [7] to applying BPM through problem-based learning and role play simulation [8], [9], [10], and using simulation games as a teaching tool in the classroom [6], [11], [12]. In addition, BPM is an important research topic in business and management. Research in BPM field focuses to the development of case studies [13] as well as the development of prototypes based on these case studies, and/or commercials toolkits [14], [15].

Second, BPM can be used for the improvement of HEIs processes. According to Hrabala, Opletalova and Tučekc [16] process architecture of a university consists of 5 main groups of processes: five value chains (management processes, coursework processes, research processes, processes related to creating and applying knowledge and environment engagement processes) and support processes. Therefore, BPM is used for the improvement of numerous external processes of higher education institutions, such as: customer relationship management process and HEIs external services that are provided to third parties, such as business projects [3], [4]. In addition, BPM is used for the improvement of internal processes performance in HEIs, related to students, such as enrolment and grading, as well as to academics, such as academic performance and career advancement [5].

Mattila and Mattila [17] identify several requirements that can be achieved by using DES in HEIs BPM projects, such as: goals set on an operational level and in relation to operations, usage of performance indicators, and measurement and evaluation of actions and activities. In our work, we focus to the improvement of internal and external HEIs processes by the BPM and DES implementation within this university process architecture [16].

Taking into account the research gap in the usage of DES as a supporting tool for BPM in HEIs, we develop the following research goals: (i) to provide bibliometric analysis of the usage of BPM and DES concepts for both internal and external business process improvement of HEIs, and (ii) to investigate the usefulness of their application in HEIs at one case study of Croatian HEI.

To achieve these goals, the literature review is conducted (Section II) by searching Scopus and Web of Science databases, and the analysis of the results about the usability of BPM and process simulation in the HEIs is presented (Section III). The usage of DES in the BPM research project is presented in Section IV. Next, the

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implications of the results for the improvement of HEI process performance are demonstrated (Section V). Finally, the conclusions are given and the suggestions for the future research are indicated.

II. Selection of Papers on Usability of Process Simulation in HEI

Literature review was conducted in order to find the articles of the interest for our research. Two scientific data bases (Web of Science and Scopus) were searched in January 2018 based on a combination of keywords (Table I). The search was focused on peer-reviewed articles in journals and in conference proceedings regardless the diversity of HEI covering areas. The additional analysis was performed after the articles were collected. Search of Web of Science (WoS) resulted in 16 papers, while search of Scopus resulted in 48 papers. Larger number of papers in Scopus is likely the result of its broader coverage of journals and conferences and its stronger focus to the field of management information systems, which is the 'umbrella 'field for BPM.

Table I: Search strategy (1995-2018)

WoS search strategy	WoS Hits
TOPIC: ("BPM" and "simulation" and "higher education") OR TOPIC: ("BPM" and "simulation" and "university") OR TOPIC: ("Business Process Management" and "simulation" and "higher education") OR TOPIC: ("Business Process Management" and "simulation" and "university")	16
Scopus search strategy	**Scopus Hits**
TITLE-ABS-KEY ("BPM" AND "simulation" AND "higher education") OR TITLE-ABS-KEY ("BPM" AND "simulation" AND "university") OR TITLE-ABS-KEY ("Business Process Management" AND "simulation" AND "higher education") OR TITLE-ABS-KEY ("Business Process Management" AND "simulation" AND "university") and (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp"))	48

Source: Authors

After merging of results from Scopus and WoS, we excluded duplicated entries i.e. 12 publications which were found in both databases. Therefore, 52 articles remained for the qualitative analysis.

Since we focus to the improvement of HEIs internal and external processes by the implementation of BPM and DES within the University process architecture model, we developed the following criteria for the selection of papers: (1) an article is considered relevant, if it specifically covers the application of DES for the purpose of HEIs processes improvement, and (2) HEIs processes must be comprised within the university process architecture model which was proposed by Hrabala, Opletalova and Tučekc [16].

After applying these criteria, only 7 publications that were published from 2008-2017 (APPENDIX I) remained for the further analysis. The small number of publications about implementation of DES in HEIs allows us to analyse the content only using qualitative methods and confirms our assumption about the need for further insights into this field.

III. Results of Literature Analysis on Usability of Process Simulation in HEIs

A. Analysis framework

Tuček and Basl [18] present the list of principles of the corporate sector that can be applied to an academic environment. According to them the most important principles are: "(1) *the customer-oriented principle* – a customer (internal or external) evaluates the quality of products and services, (2) *internal service-oriented principle* – throughout a process the attention must be focused on the quality of service output because only the final outcome stands for customer's benefit"; (3) *the efficient usage of resources* because of its' limited capacity and costs that are related to its' utilization and (4) *the establishment of the high-quality interface* that enables efficient communication of the participants within the processes.

In our work we focus to the following aspects of found papers: (i) methods, techniques or frameworks applied in BPM initiative; (ii) tools used; (iii) research results; (iv) name of one or more HEIs' processes that were in the focus of BPM initiative; and (v) applied principles of the corporate sector according to Tuček and Basl [18]. These aspects are presented in Table II, in which the first column presents the number of the paper in Appendix.

B. Analysis of the papers

BPM initiatives identified in the examined papers focus to various methods, techniques or frameworks, such as Business Process Model and Notation (BPMN), Identification, Simulation, Evaluation, Amelioration (ISEA) method, Serious Game-based Method for BPM, Event Driven Process Chains; Event Driven Simulation Modeling, Educational Process Management (EPM) framework, Rapid analysis & Design (RAD), Social Network Analysis (SNA); Agent-based simulation, and TOGAF framework (The Open Group Architecture Framework). Among them, only BPMN was present in four papers, while others were present in only one paper. This result indicate that the field of BPM and DES in HEIs is emerging, with the tendency to experiment with the various approaches. Tools used for the research are also various, such as newly developed soultions (e.g. Prototype of a role playing simulation game), and mature solutions (e.g. IBM Websphere Business Modeler).

Various processes were the focus of the investigated papers. Most of the processes were internal, such as travel expense reimbursement, the overtime pay, university library processes, and schedule optimization. Only two procesess were external: graduate financial aid management process and the application and admission process.

Based on this result it is not suprising that the most often present principle identified by Tuček and Basl [18] is internal service-oriented principle, which is present in five papers. Additionally, three papers focus to the customer-oriented principle, two papers to the efficient usage of resources, and two papers to the establishment of the high-quality interface.

TABLE II: LITERATURE ANALYSIS REPORT ON USABILITY OF PROCESS SIMULATION IN HE INSTITUTIONS

APP. I No.	Methods, techniques, frameworks applied	Tool(s) used	HEI process/processes in the focus of BPM initiative	Research results	Applied principles according to Tuček and Basl [18]
1	Identification, Simulation, Evaluation, Amelioration (ISEA) method; Serious Game-based Method for BPM; BPMN	Prototype of a role playing simulation game tool (3D)	The travel expense reimbursement process of the Grenoble Informatics Laboratory (LIG); the overtime pay process at ENSIMAG School of engineering Grenoble-INP; the application and admission process in MIAGE at Joseph Fourier University.	The usage of role-playing simulation game for BPM initiative in HEIs is proposed as a particularly useful approach for process mapping establishment and for the continuous improvement of existing business processes. The importance of social BPM is stressed. The results show that BPM may profit from social techniques.	(2) and (4)
2	Event Driven Process Chains; Event Driven Simulation Modelling	EP-Simulator; EPC Analyser; Bflow (Eclipse plugin); DesmoJ (Java based)	Process in the University Library: Print Catalog, Catalog Request Process, Book Labeling	DES is successfully used to identify and analyse business process inefficiencies (e.g. process gaps, waiting times) and to manage human resources in processes (e.g. to enable the staff substitutions in a transparent, flexible and efficient way in a case of unexpected situations, like illness).	(2) and (3)
3	Educational Process Management (EPM) framework; BPMN	IBM Websphere Business Modeler 7.0.	Graduate financial aid management process (assistantship)	A framework for management of educational process is developed. Process simulation (DES) and analysis function of IBM Websphere tool is proposed to be used for process optimization. The authors claim that the process quality and efficiency are evaluated by students.	(1)
4	BPM: Rapid analysis & Design (RAD); BPMN	Bizagi Studio	University processes dealing with the Management of Pre-professional Practices	Research activities were directed towards testing how BPM can be applied in redefining a process that includes cross-sectional interaction of different vertical areas of the HE institution. Authors conclude that the use of the BPMS and simulations can help HEIs to substantially improve the degree of compliance with functional objectives in the management of academic processes.	(2) and (4)
5	Social Network Analysis (SNA); Agent-based simulation	Social power cluster network generators	University admission processes of 9 universities	Agent-based simulation and Social Network Analysis are used successfully to explore the collaboration capacities and platforms in form of blogs, wikis, emails, shared documents and other innovative social collaboration options. The results show that these tools can be used to provide efficient interaction between performers along the execution of business processes.	(1)
6	BPMN	Software as a Service (SaaS) like platform prototype developed a an extreme Collaboration environment	Negotiation process in which the professors declare their availability and approve/ refuse the first draft of the schedule and the optimization of the Scheduling problem	Authors have developed a SaaS prototype composed of a web application for editing and managing BPMN workflows and an engine for workflow orchestration and task execution. The prototype enables the simulation of various implementation scenarios, reusability by building block combinations, information sharing and knowledge dissemination.	(2) and (3)
7	TOGAF (The Open Group Architecture Framework)	Bonita Soft	Managing activities involved in the grading student activities in various modalities	Bonita Soft simulation function (DES) is used to improve tracking of the process, to reduce response times and to improve the efficiency indicators for all process performers. Process quality can be evaluated by both teachers and students.	(1) and (2)

Source: Authors

IV. CASE STUDY OF CROATIAN HIGHER EDUCATION BPM RESEARCH PROJECT

A. *Case study description*

For the purpose of this study, results of a previous project conducted in 2012 and 2013 under the name University Process of the University of Zagreb, funded by the University Development Fund were used. The case study was adjusted to the new regulation regarding the process of performing academic and educational ranking of the University of Zagreb. The objectives of the previous project were the following: (i) Identify core business processes that are common to all constituents of the University of Zagreb; (ii) Analyse and document existing business processes using the appropriate software tools as well as propose models of improved business processes. The purpose was to increase the effectiveness of the University's processes from the perspective of internal and external users, using process-oriented organizational restructuring.

On the performance of the project, 12 researchers were employed (two authors of this paper) from three constitutive faculties of the University of Zagreb. As part of the project, the project team has developed a complete methodology and proven its validity on the most targeted types of business processes. The methodology also included the application of simulations based on which the expected impact can be assessed for different variants of the process improvements.

B. Case study simulation results

For some of the selected processes a simulation based improvement assessment was performed and the illustrative criteria for deciding on the selection of improvement scenarios that will be practically implemented with or without the use of ICT have been demonstrated. One of the analysed processes was related to the Business Area of Human Resource Management "Perform academic and educational ranking". This process is modelled in accordance with BPMN 2.0 and a simulation of the execution of the process was carried out.

The simulation results of the process showed that the process lasts an average of 173 days with an average deviation of 63 days, and the utilization of resources at the home institution is responsible for the execution of the process only for an average of 27 hours and 29 minutes (half of that time is spent by the Commission for Evaluation of Candidate Works), while the remaining time to the overall average duration of the entire process can be disregarded to a relatively small amount of time spent outside the institution and a considerable waiting time (e.g. time for receiving applications to the competition, time of the regular sessions of the constituent boards and councils who are deciding on process instances and similar formal time-related influences factors).

Given the results of the simulation, several enhancement options are suggested, which can be practically implemented individually or together, with results of simulation testing of various combinations of process improvement. The proposed improvement of the process did not relate to estimating the expected effects of a) intensive utilization of ICT in order to support observed process or b) changing the ranking rules or ways of equating the often different interpretations of the particular regarding the valid Rulebooks and the formal conditions.

Since in the meantime there has been a change of the Rulebook and the formal conditions for the "Performing academic and educational ranking", a new model of the observed process has been given in this work. The model shown in Figure 1, illustrates one of the most common process execution scenarios – the evaluation of academic and educational ranking for HEI teaching employees. The reason why all possible scenarios of performance are not shown on the model is a) the complexity of the process b) the need to identify the problems associated with the collaboration participants.

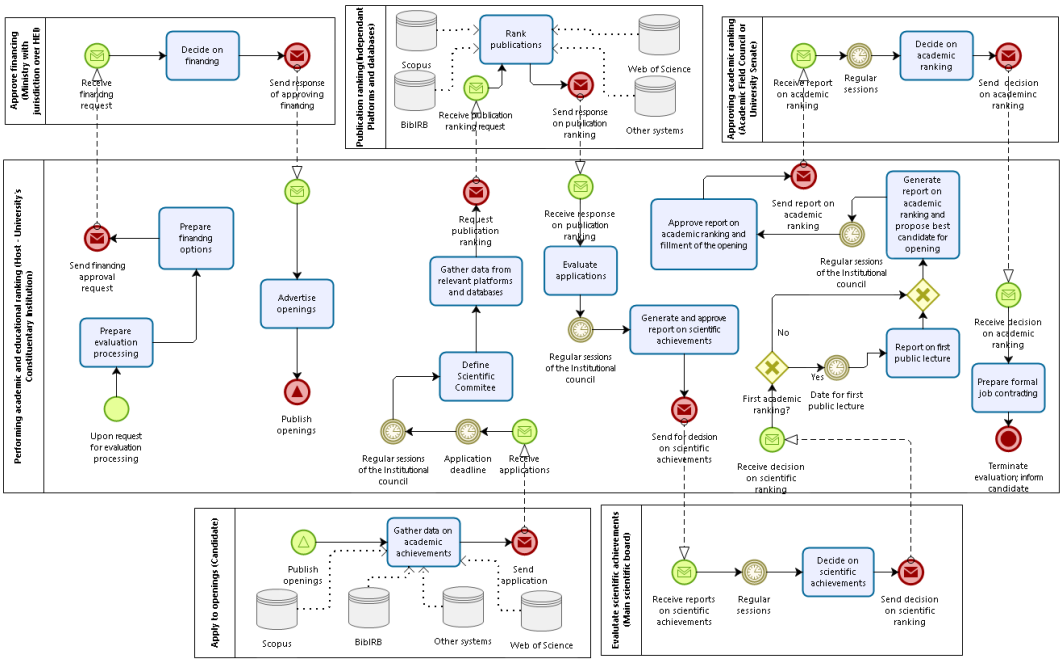

Figure 1. "Performing academic and educational ranking" business process model; Source: Authors' work

After modelling, simulation of the model was carried out. The simulation results show that there are no significant improvements from the previous version of the model regarding the duration of the process at the host institution, which is one of the key parameters of the model's estimation of quality (26 hours 33 minutes). Shortening the time interval between the two sessions of the decision-making body remains a valid option to shorten the overall length of the process, but it does not reduce the time spent on human resources that perform the process activities.

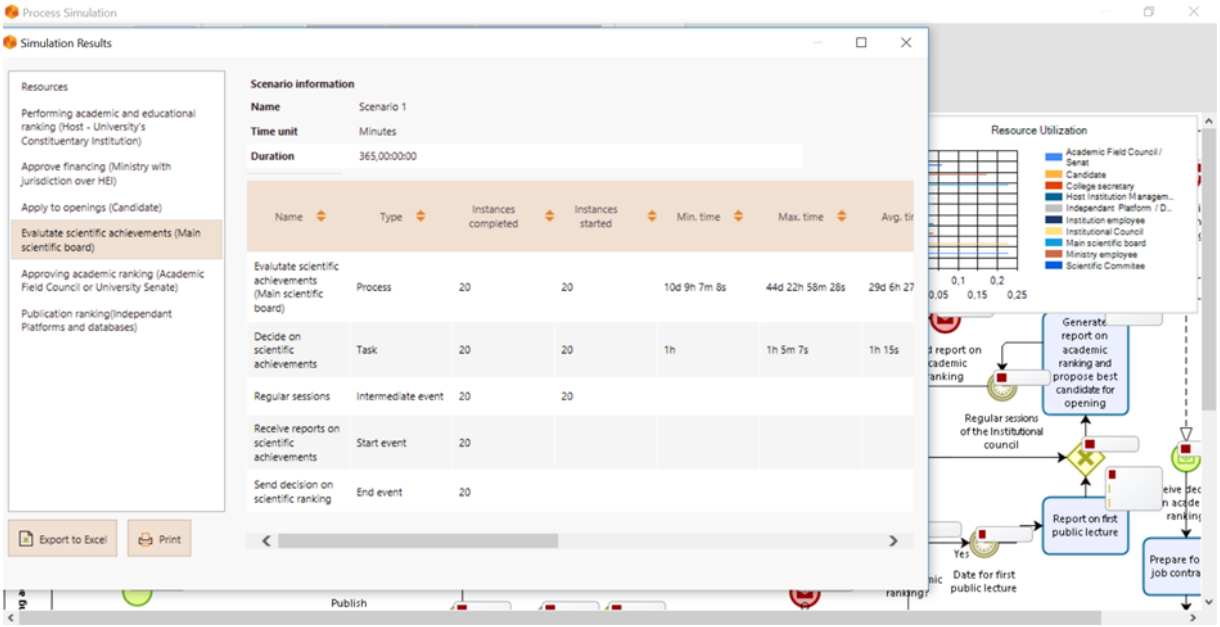

Figure 2. "Performing academic and educational ranking" business process model simulation; Source: Authors' work

The model shows that some key activities of the process take place outside the institution responsible for the implementation of the ranking, whereby the host institution has no impact on the duration of the activity for the collaboration participants. Any interruption or disturbance in the performance of a process activity within the jurisdiction of these institutions affects the duration of the entire process. Examples of such disruptions are changes in human resources (e.g. personnel changes in the relevant ministry, constitution of main boards and councils) or changes in the terms of licensed use of independent platforms and ranking databases.

C. *Impact assessment of simulation*

After simulation-based testing of what process scenarios could bring to managing HEIs an impact assessment should be performed in order to evaluate the feasibility of implementing new BPM initiatives. The process improvement suggestions should, based on the conclusions from process analysis stage, be attempted to find ICT application that would result in achieving better performance of the process operational key factors. Due to the results of our analysis the action on two key issues is relevant: shortening the overall duration of the process and more effectively evaluation of the candidate's scientific productivity. The use of ICT should be implemented on the activities of communication and collaboration between the collaborators in order to shorten the time of physical documentation exchange between the participants. This suggested improvement could thereby enable dynamic planning and organization of the work of the participants, ensure more effective monitoring of the activities of the process and build a repository of digital materials to which all authorized process participants have access. Technologies related to Social BPM show promising effects in this area.

More effective evaluation of scientific productivity can also be supported by using ICT, by supporting the activities of the Scientific Committee at the host institution which have relatively long duration. One of the solutions that exists in the similar institutions internationally is the introduction of a unique national classification of publications, whereby it is planned to connect this new system with already existing similar systems and subsystems that are currently being developed. This support for the process of "Performing academic and educational ranking" could shorten the duration of following activities regarding collecting scientific productivity data, evaluating applications and reporting. Appropriate technologies related to this area are in the Content/Document Managing systems with cloud-based solutions. In the transition period the duration is expected to decrease gradually, due to the fact that the evaluation data will be available or entered in reverse and in real time (therefore some publications written by multiple authors from the same scientific field could be evaluated in the equated interpretations of the valid Rulebooks and formal conditions).

V. CONCLUSION

In our work we focused to the process improvement of HEIs, with the two goals in mind: (1) to review the research literature about BPM and process simulations in HEIs and to discuss the findings; and (2) to investigate how BPM and DES can help HEIs to better manage and to improve the performance of their processes on the example of Croatian HEI BPM research project. First, we tracked 7 papers dealing with BPM and DES in HEIs, which focused mainly to the internal university processes, but applying various methods and frameworks, as well as tools. Although we searched the period from 1995 to 2018, identified papers are not older from 2011, and are mostly published in 2016, indicating that this is a growing research field.

The results of our case study support the premise that usage of BPM and simulation modelling allows higher

education institutions to apply important principles of the corporate sector to an academic environment in order to better manage their operational performance. Therefore, we concluded that BPM based simulations can assist in understanding how various processes scenarios might perform in term of collaboration improvement, improving customer-oriented relationships, boost internal service-oriented processes or test process as service implementation. Based on our results, we identify the following future research directions. First, an extensive quantitative validation of HEI BPM initiatives is needed that should be done on a broad scale. Also in-depth studies are needed to determine the impact of new developing technologies applicable in the HE sector.

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APPENDIX I LIST OF SELECTED ARTICLES PROCESS SIMULATION IN HEI

No		Database
1	M. Santorum, "A serious game based method for business process management", in Proceedings - International Conference on Research Challenges in Information Science, art. no. 6006843, 2011.	Scopus
2	C. Müller and C., Krüger, "A tool for a flexible posterior analysis of simulation experiments" in Proceedings - 29th European Conference on Modelling and Simulation, ECMS 2015, pp. 406-411, 2015.	Scopus
3	J. Liang, X. Han and Y. Liu, "An operation framework of educational process management enhanced by information technology -take graduate financial aid management as an example", in ACM International Conference Proceeding Series, pp. 204-208, 2012.	Scopus
4	A.E.C.,Aushay and V.J. Garcia, "Processes modeling, simulation and automatization in the management of university academic services", 3C TECNOLOGIA, Vol. 6, Issue 2, pp. 32-51 DOI: 10.17993/3ctecno.2017.v6n2e22.32-51, 2017.	WoS
5	A.Sonntag and P. Fettke, "Efficiency of generated performer networks in collaborative business process models", in *Proceedings - CBI 2016: 18th IEEE Conference on Business Informatics*, 1, art. no. 7780297, pp. 26-34, 2017.	Scopus and WoS
6	D. Campagna, S. Costanzo, C. Kavka and A. Turco, "Exploiting web technologies to connect business process management and engineering", in *ICSOFT 2016 - Proceedings of the 11th International Joint Conference on Software Technologies*, 1, pp. 186-193, 2016.	Scopus and WoS
7	C.L.P. Ruiz, F.A.H., Carreno and J.V., Vega, "Modeling of the process in the thesis subject of the Systems Engineering degree program [Modelamiento del proceso de la asignatura trabajo de grado del programa de ingeniería de sistemas]", in *Proceedings of 8th Euro American Conference on Telematics and Information Systems, EATIS 2016*, pp. 95-115, 2016.	Scopus and WoS

Discrete Simulation Modeling of Intelligent Passenger Boarding

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***Abstract* – The aim of this paper is to explore the potential of intelligent passenger boarding systems for airports. To investigate the implications of smart systems implementation, specifically in the context of internal business processes and organizational unit optimization, discrete simulation modeling was performed. The simulation model of the passenger boarding process at Split Airport was developed integrating two different variants: i) validated *as-is* process simulation and ii) *to-be* process simulation of the process supported by intelligent passenger boarding technology. Special attention was given to model validation. Significant degree of optimization was achieved in the intelligent passenger boarding simulation experiment, thus supporting future decisions regarding self-boarding solutions. This research demonstrates the potential of discrete simulation for exploring benefits of using smart technologies in airport operations as a part of ongoing smart transport and smart mobility initiatives and solutions.**

Keywords – business process management; discrete simulation modeling; intelligent passenger boarding; self boarding; smart technology.

I. INTRODUCTION – INTELLIGENT PASSENGER BOARDING

As air transport becomes more popular and air traffic grows, airports have to become more innovative and adaptive to changing aviation dynamics. The need for industry-specific solutions such as intelligence products providing supported decision-making for unique and enhanced passenger experience, and automated process management resulting in optimized operational efficiency is apparent.

As an organization, airport is different from majority of other types of businesses as it is normally open 24/7. Still, as any other organization, it has to be resilient to changing customer demands while remaining cost effective. The real challenge is to make airports' systems integrated, simple to access, digitally aware and intelligent. In order to initiate this transformation, new concepts and technologies such as sensor technologies, connectivity, mobility and analytics are crucial.

When exploring the concept of mapping customer journeys in air transport, researchers have found that air passengers undergo a high level of stress from arriving to the terminal, until boarding the plane [1] therefore it is important to challenge and redesign the whole process. On the other hand, from the organizational point of view, Vasuki and Rawat have recognized some key challenges that airport operators face [2]:

- capacity shortfalls,
- dissatisfied passengers,
- declining aeronautical revenues,
- increased competition, and
- outdate and unreliable IT infrastructure.

Furthermore, they have recognized the context of self-service for aircraft boarding as one of the key use cases to overcome those challenges, especially capacity shortfalls. In that regard, the use of technology for self-service is quite important. A Self-Service Technology (SST) is an object which allows customers to interact with Self-Service Software (SSS) [3]. Similarly, SST encompasses all devices that have technological interfaces that enable customers to produce a service independent of direct service employee involvement [4].

Self-service in general is most definitely a concept that is *en vogue* - from supermarket checkout to airline check-in kiosks, self-service is proven to be a very large benefit to business, and even more importantly to their customers [3, 5]. From the customer perspective, such services imply increased efficiency and effectiveness during tasks performed during their customer journey, time and cost savings, more flexibility as well as "feeling of fun" [6]. Furthermore, benefits to organizations could include reduced costs of labor as well as increased efficiency and revenue.

However, some potential disadvantages of using SST have been identified as well [7, 8, 9]:

- losing a great deal of interpersonal contact with customers,
- lack of comfort with the technology on the customer side,
- fear of possible loss of personal information,
- fear of the unknown, and
- difficulty of interaction for visually impaired or customers with disabilities.

The automation of passenger processing began long time ago with self-check in, but it is now closing the circle by enabling the passengers to board the aircraft by self-scanning the same boarding pass generated by self-check on their own.

When it comes to intelligent self-boarding solutions, DIY boarding was one of the most technology advanced ones at the time, and was tested at Heathrow airport, as well as some other airports in Europe [10]. Before boarding, passengers go through an electronic barrier that scans their faces. The scan is then compared to an earlier face scan carried out during check-in or security. If the biometric data matches, the passenger can board the plane [10]. In such scenarios, airport staff can use their time to add real value to the journey of the passenger, instead of performing their usual activities like scanning travel identification documents and boarding passes.

To explore the potential of smart technologies for customer self-service in an airport, the authors opted for simulation modeling. A process simulation model is a representation of a real system and its behavior, as well as an instrument to perform different analyses [11]. Discrete simulation enables re-engineering, optimizing and analyzing processes, as well as resource planning. Problems at operational and tactical level in particular are suited for modelling and analyzing [12] since the simulation provides a proper understanding of the environment and its multiple potential scenarios [13]. By using process models and simulation, it is possible to experiment with multiple scenarios (what-if analysis) in order to opt for an optimal variant [14]. Thus, it is possible to avoid experimentation in real life systems which are in production as experimenting with these systems can be very costly, but sometimes impossible to perform as well [15].

This paper investigates the implication of intelligent passenger boarding system implementation for airports by using ARIS simulation - specifically in the context of internal business processes and organizational unit optimization. The simulation model of the passenger boarding process at Split Airport was developed integrating two different variants: i) validated as-is process simulation and ii) to-be process simulation of the process supported by intelligent passenger boarding technology. This research demonstrates the potential of discrete simulation for exploring benefits of using smart technologies in airport operations as a part of ongoing smart transport and smart mobility initiatives and solutions.

II. MODEL DEVELOPMENT

In order to further explore the implications of self-service, intelligent boarding system implementation on airport's internal organization and process performance, a pilot research study at Split Airport was performed. Split airport is the international airport serving the city of Split, Croatia. It is located in the town of Kaštela, less than 30 km from Split. In 2017, it was the second busiest airport in Croatia after Zagreb Airport handling around 2.8 million passengers per year [16].

The study started with collecting the primary data so as to understand the process as well as to develop and validate the simulation model. The model was developed based on the information obtained from relevant airports' information systems, discussions with managers, operators and staff in general, as well as by process monitoring and measuring/timing.

A. *Process flowchart of passenger boarding*

The process flowchart of passenger boarding is illustrated in figure 1. It is a segment of a larger model that illustrates the whole process of passenger departures. For this paper, a segment focusing on passenger boarding was selected and presented hereinafter. After completing the check-in and baggage drop off procedure, as well as clearing the security and customs (in case of international flights) passengers arrive to the boarding zone and start their boarding at a certain time. This is where our simulation model starts. Depending on a flight, two to four ground operators check customer IDs and scan boarding passes during the boarding process at the gate. After that, passengers are directed to board the plane – by directly walking to the plane if it is right outside the gate, or by boarding the bus first, which takes them in front of the plane.

The process flowchart (and thus the selected and illustrated, simple segment) was verified by process observation during 10 days on-site, and is considered valid. It is used further in the construction, verification and validation of the simulation model.

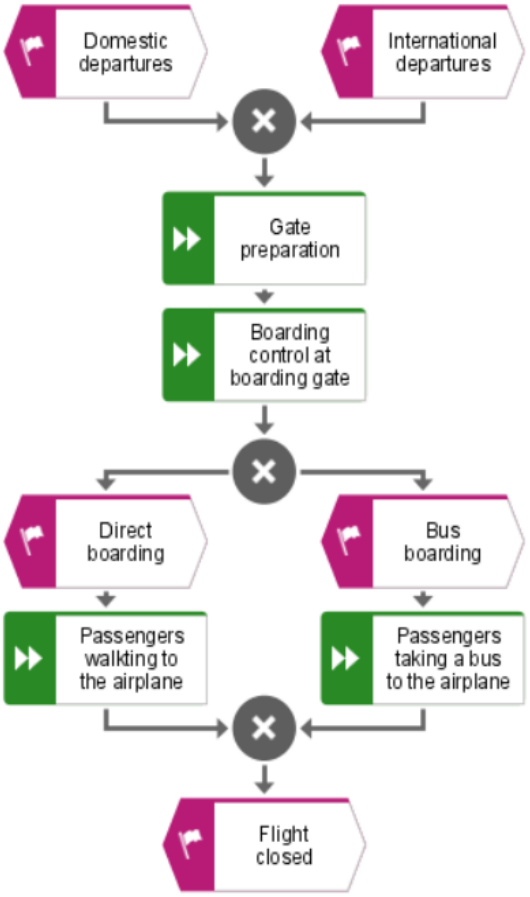

Figure 1. Process flowchart of passenger boarding

B. *Simulation model of passenger boarding*

The objective of simulation modelling was to assess the impact of intelligent boarding system on resource

allocation and process performance using a computer simulation model. The simulation model was designed by using ARIS Architect software, with an activated extension pack titled Simulation. ARIS (Architecture of integrated information Systems) is a leading enterprise business process management framework. As an extension to "standard" ARIS environment, ARIS Simulation enables performing realistic business process simulation and dynamical analysis of business processes. It helps its users identify optimal strategies in order to improve business processes and organizational units. ARIS Simulation user interface is illustrated in Figure 2.

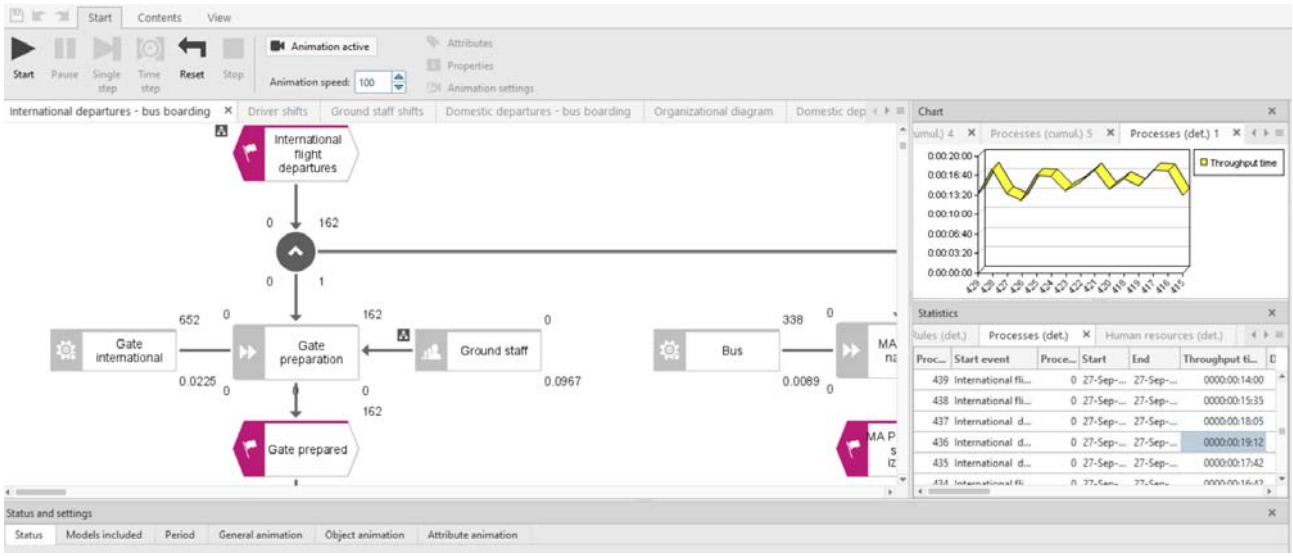

Figure 2. ARIS simulation interface with a part of the simulation model

First of all, simulation period was selected and defined through ARIS tool. Next, ground service personnel and bus drivers were defined as resources required for the process. Objects for their representation in the simulation model were created, and were allocated a number of workers as well as working hours within the tool, exactly as in real life. Besides organizational resources mentioned, technical resources were allocated to the simulation model as well: domestic and international gates as well as the busses, all three with capacity defined as in real life.

After that, for the time period selected, all departure flights were defined in the tool, with appropriate departure times as well as average delays, if any.

Finally, process models were defined. Organizational and technical resources with the assigned properties were allocated to the process activities. All of the departure flights that were defined in the tool were assigned as initiating events for each new process instance. Times and appropriate statistical distributions were allocated to each process activity.

C. Input analysis and data validation

As already indicated, input data for the simulation time period was collected from relevant sources. More specifically, complete organizational diagram, number of employees for each working position relevant to the simulation, along with working shifts and hours, were provided by the airport personnel. These resources included ground service operators and bus drivers. Number of technical resources was provided as well: international and domestic gates with their computer terminals, and transport busses.

Data about the flight departure times was collected from the publicly available flights schedule [16]. Furthermore, information about the average delays of each flight was received from the airport authorities.

Regarding the process activities and their duration – these were collected by tracking and measuring on-site, at the airport, as well as from the data provided by the airport – where these data were available. Duration of process activities was required for the following activities: gate preparation, boarding control at the boarding gate, passengers walking to the airplane, and passengers taking a bus to the airplane.

The authors of this paper acknowledge the importance of simulation model validation. There are studies that point to frequent faults in simulation model designs caused by the lack of the formalization process needed to understand, verify and validate the models before any implementation [17]. In line with the theory, validation of the simulation model was performed to determine if the model is an accurate enough representation of the system [14]. The validation was performed in line with the guidelines proposed by Leal et al. [18] and Kotachi et al. [19].

In order to validate the simulation model, data about the process flowchart was used and statistical calculations were made. Flows of entry and exit, activities, but also entities, organizational and technical resources were observed. The use of conceptual model assisted validation by using animation of the simulation as well.

Statistical techniques were used in order to prove that the simulation model behaves with satisfactory accuracy and consistency in relation to the real-life object of the study. An important thing to note is that a model can

never be 100% validated – there can always be errors and it is never possible to provide guarantee that the model would work as intended in every possible situation.

Four days of historical data from the summer season period were analyzed in detail, following the recommendations to organize information from the simulation model and the real system into two sets. In order to validate the data, only the data for two days was used to fit the distribution and input analysis, while the data for the other two days was used to validate the simulation model and compare its outcome. Days with nearly identical flight schedules were selected in order to avoid biases.

To test the adherence to a normal distribution, Arena Input Analyzer tool was used. Figure 3 illustrates fitting the average time of the boarding control at boarding gates based on data from two days from the simulation. Best fit is a normal distribution with a mean of 11.7 and standard deviation of 2.49. After fitting the data, Chi Square and Kolmogorov-Smirnov tests were used to analyze the goodness of fit. *P* values for both tests are higher than 0.05, indicating the fit is acceptable.

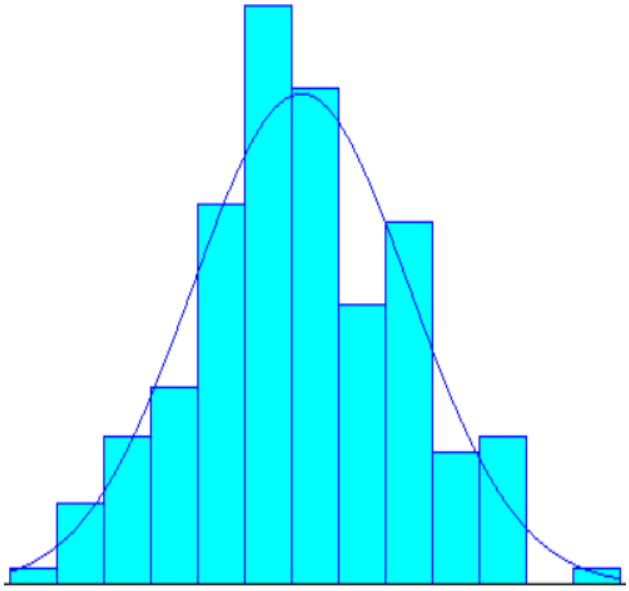

Figure 3. Time for boarding control for days 1 and 2 (simulation data)

Output from Arena Input Analyzer tool is presented in the following:

Distribution data:

Distribution: Normal
Expression: NORM(11.7, 2.49)
Square Error: 0.005

Chi Square Test
Number of intervals = 8
Degrees of freedom = 5
Test Statistic = 6.75
Corresponding p-value = 0.243

Kolmogorov-Smirnov Test
Test Statistic = 0.0385
Corresponding p-value > 0.15

Data Summary
Number of Data Points = 172
Min Data Value = 5.32
Max Data Value = 18.9
Sample Mean = 11.7
Sample Std Dev = 2.49

In the same manner, real data from the remaining two days was fitted in a distribution. That distribution is illustrated in figure 4. Best fit for this data set is normal distribution, with mean 11.6 and standard deviation 2.88. As a result, data from both tests could be represented by a normal distribution.

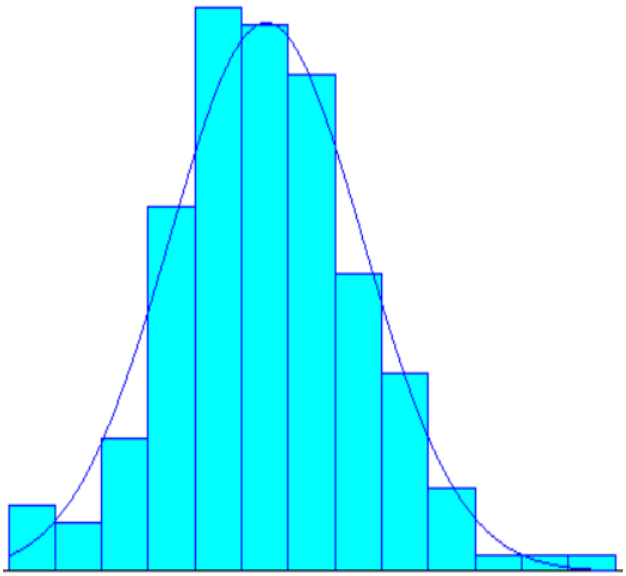

Figure 4. Time for boarding control for days 3 and 4 (observed data)

Distribution data:

Distribution: Normal
Expression: NORM(11.6, 2.87)
Square Error: 0.001

Chi Square Test
Number of intervals = 7
Degrees of freedom = 4
Test Statistic = 2.03
Corresponding p-value = 0.731

Kolmogorov-Smirnov Test
Test Statistic = 0.0466
Corresponding p-value > 0.15

Data Summary
Number of Data Points = 172
Min Data Value = 4.53
Max Data Value = 21.1
Sample Mean = 11.6
Sample Std Dev = 2.88

To test the hypothesis that both data sets (real and simulated) have equal variances, F-test was performed. The results of Levene's test for equality of variances (F=2.018, *p*-value of 0.156) point that both data sets have

equal variances. Also, *t* test for two independent samples (t=-0.158, *p*-value is 0.874) confirms that there is no statistical difference between the two sets of data analyzed (real and simulated). Therefore, the model is statistically valid.

III. RESULTS – WHAT-IF ANALYSIS

The most rewarding part of business process simulation is performing simulation experiments, or what-if analysis. It enables the identification of best strategies to improve business processes before actually implementing the changes in real life – and before making the costly changes to implement them.

For the purpose of this research, two what-if scenarios were explored where the "standard" boarding control at boarding gate activity was replaced with "intelligent boarding", i.e. smart self-boarding solutions. Although some sources point to reduction of boarding control time by 33% using smart self-boarding solutions [20], and some even by 50% [21], we have decided to analyze and experiment with 20% reduced boarding control time. In addition to expert opinion, we believe this reduction is realistic since the average boarding control time in the above-mentioned studies were longer than our average 11.6 minutes.

The first scenario completely eliminates the ground services airport staff required to operate the gate terminals and perform ID and boarding passes check-in. The results of the analysis are as follows: the average boarding time is reduced from 11.7 minutes in *as-is* to 9.1 minutes in the *to-be* variant of the process, while the utilization of ground services airport staff for the process is reduced by 56%. The justification of this scenario and the results is that unlike for the "standard" boarding control, intelligent boarding requires no airport personnel. However, as there might be issues with using self-boarding solutions, the reality is that there should be someone from ground services airport staff, an operator assisting the users should they need any help with using the implemented technology. In order to support this, we have included 1 FTE for ground services airport staff in the second scenario. In that second scenario, the utilization of ground services airport staff for the overall process is reduced by 26%. Both scenarios point to reduced process time and quicker turn-around time, but also to significantly more time for airport personnel to use for some other value-added activities.

	Average boarding time (minutes)	Utilization Reduction (%)
As-is scenario	11.7	-
To-be scenario 1	9.1	56
To-be scenario 2	9.1	26

Figure 5. Simulation results

IV. CONCLUSION

Airports will have to implement various automation and digital technologies in order to become truly "intelligent". This will enable them to improve operational efficiency and customer experience, while acting as a foundation for future growth. The literature provides various evidence regarding possible effects of cost savings due to an increase in productivity or reduction in turn-around time in processes related to innovations in passenger boarding (e.g. systematically cited and reported in [22]).

With an increasing number of airports using intelligent or smart technologies, an effective digital strategy of the airport becomes an important aspect of airport management. As airports become more customer oriented, they are adapting various technologies (a list of number of solutions is available from [21]) within touchpoints with a customer, but also within their entire customer journeys.

The simulation model presented in this paper encompasses only a segment of the flight departures process at Split Airport. The model simulates activities of the flight boarding process for domestic and international flights, along with the relevant human and technical resources. Working shifts, capacities, and real flight schedules were recorded in the simulation model.

The focus of this paper was on validating the *as-is* model simulation data and performing experimental what-if analysis. Data was collected for four days of airport operations, however two days data were used for simulation model, while the remaining two days data were used as real, observed data for *as-is* model validation purposes.

After the *as-is* model was validated, we tested the results of potential implementation of intelligent boarding system that would replace the existing boarding method. The results of two what-if scenarios indicated that with this smart technology implementation, the average boarding time could be reduced while at the same time the utilization of ground operators could be reduced significantly.

In addition to demonstrating the potential of discrete simulation, the paper explored the steps and recommendations for proper simulation data and model validation. Also, the paper discusses the potential of intelligent, or smart technology implementation that could lead to multiple benefits for the entire airport organization.

To continue our research, we plan to develop a simulation model that would cover the whole processes of flight departures and arrivals integrating other smart technology solutions. Also, we would expand our what-if analysis by experimenting with other parameters in order to detect additional bottlenecks. In addition to implications of the potential implementation of intelligent systems for internal business processes and organizational units, we plan to evaluate the effects on the customer experience external to the organization as well.

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Sales configuration creation for complex telecommunication solutions

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Abstract **- The increasing complexity of telecommunication configuration solutions has driven a rising interest in effective object-oriented modeling of solutions with linear complexity scaling. In order to accomplish this, the decision was to implement and develop new configuration engine for the official Ericsson Product Catalog used by sales and marketing personnel of Ericsson. Telecommunication sales requirements are to achieve simple and fast orders for solutions based on different complexity levels. This paper gives an overview of the whole advanced system for assembly and sales process developed to support all specific requirements.**

I. INTRODUCTION

Telecommunication industry is under the pace of change with growing demands for mobile services and mobile data. Ericsson forecasts there will be 1 billion 5G subscriptions for enhanced mobile broadband by 2023[1]. Mobile data traffic continues to grow, meaning that the mobile infrastructure is critical for innovation.

Apart from having an unlimited commitment to innovate, it is required to ensure that there is actively reduced time to market in a way that would not affect customer experience. In order to successfully do so, it is required to have a quality and evolving solution configurator [20], providing future-proof solutions and enabling customers to enjoy new products and services more quickly and efficiently.

The purpose of this document is to describe specific business problems faced by using previous solution, SAP Variant Configurator (VC) [2] and how the new solution SAP Configure, Price, and Quote (CPQ) for solution sales configuration [3] managed to solve them. The document also provides a comparison of a previously used solution and a new one. Furthermore, the document described all specialized interfaces and tools which are, together with SAP CPQ for solution sales configuration, presenting a process required to handle product release flow. The developed configuration engine is presented in Section II. The following section is guiding the user over modeling environment interface. Handling of models which can interact one to another is handled using knowledge base orchestration, described in Section IV. Product pricing and supply, implementation, and connection to SAP ONE [4] are described in Sections V. and Section VI. Following two sections are presented product structure handling and presenting that structure connected with implementing models as a part of web interface named Ericsson Configuration Portfolio. The Ericsson proposal tool is presented in Section IX, while Section X. describes document generation and graphical drawing tool which is taking all required data from created model configuration. The new solution implementation process is described in Section XI. Section XII. is presenting the solution quality assurance description handled by different types of test.

II. CONFIGURATION ENGINE

The configuration solution that was used, SAP VC, reached its limits when it came to supporting Ericsson's new increasingly flexible and modular products. This was especially true for the newest products. Product complexity has ever scaled as fast as latest Ericsson products. There was a requirement for a solution in accordance with well-established standards.

A study was made to select and evaluate through a proof of concept, a configuration engine that will in turn modernize the development environment at Ericsson and support implementation of new products. After finishing evaluations and a proof of concept, SAP Configure, Price, and Quote (CPQ) for solution sales configuration was selected as the most suitable configurator and soon after that, SAP CPQ was included in the system landscape.

SAP CPQ for solution sales configuration is a system that helps customers to configure and sell solutions made of complex product combinations. For example, many technology companies sell solutions that include combinations of highly complex hardware, software, and services, and each of these can have options or features that must be specified by a customer during the ordering process. [3]

From a modeling perspective, each individual product can be split into many different instances, and there are many possible relationships and dependencies between the product instances. SAP CPQ for solution sales configuration provides a flexible modeling environment, which in turn simplifies the ordering and configuration process for the customer.

SAP CPQ for solution sales configuration is integrated with the SAP Customer Relationship Management (CRM) and includes a configuration engine that provides the ability to perform bottom-up configuration as well as the normal top-down approach. The system is designed to provide efficient configuration execution performance and advanced integration capabilities. [5]

Engine is running models created in solution modeling environments [6] and it runs on Java instead of ABAP [7].

Pros compared to old Internet Pricing Configurator (IPC) engine:

- SAP CPQ gives the possibility to work modular with large models,
- It provides more effective object-oriented modeling with linear complexity scaling,
- More efficient development environment with integrated Java development,
- More powerful modeling options,
- Version control possibilities enabling possibility to more agile and parallel development,
- SAP CPQ also approaches the configuration complexity in a more declarative way which scales linearly and makes engine suitable for handling the increased complexity of future Ericsson models.

Cons compared to old IPC engine:

- New competence requirements (Java, architectural knowledge),
- Simple procedures not possible to create outside Java e.g. dynamic hiding of options and functional pricing.

III. SOLUTION MODELING ENVIRONMENT

The solution modeling environment is a part of SAP CPQ for solution sales configuration and it can be installed locally on personal computers as a plugin for Eclipse environments with integrated Java development possibilities. It is integrated with SAP Customer Relationship Management (SAP CRM) and SAP ERP Central Component (SAP ECC) [8]. Integration with CRM and ECC is allowing solution modeling environment to exchange configuration master data. The solution modeling environment has a file-based structure and there is no need to create any transactions. The solution modeling has support for version control via EGIT [9] supporting collaborative modeling.

Within the modeling environment, there is no longer predefined class structure as it was in the previous environment. The user is defining model elements such as classes and characteristics and then defining dependencies between model elements using only constraints and rules.

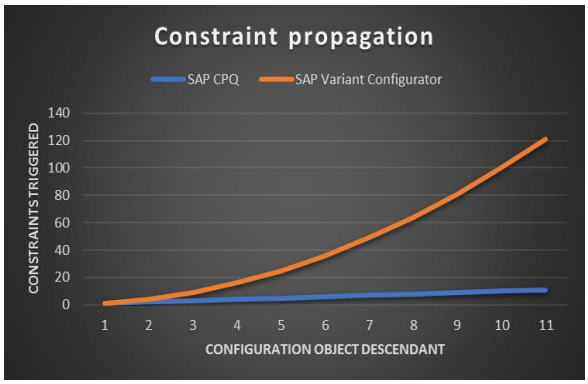


Figure 1. Configuration constraint propagation

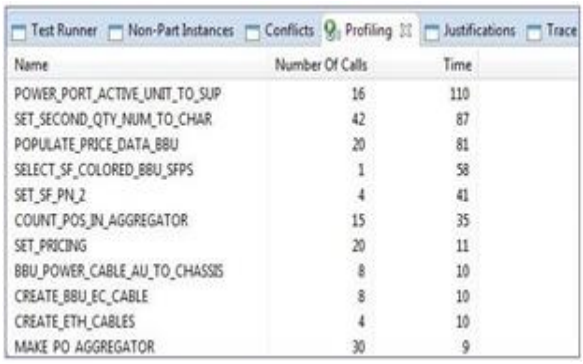
There is independent creation of modeling objects available, meaning that instances are created dynamically when specific creation conditions are valid.

The solution modeling environment has object-oriented configuration possibilities included, such as abstract Data Type (ADT) characteristics and the use of Java functions which are being used by calling model rules named pfunctions. Pfunctions completely replaced procedures which were used in SAP Variant configurator.

The main advantage of SAP CPQ of solution sales configuration is the use of ADT characteristics that point to other object instances. Simple example of that advantage can be explained by modeling solution which should express connection between two objects, each of them is a descendant of a different parent. In the VC hierarchical structure should be created and it would be required to propagate data of parent object up to its child. Symbolic mapping to identify the child object should be done, meaning that it would be required to check every child object in the whole configuration, map and calculate unique identity for that object which should be connected to some other object identity. All of that should be done with procedural code and at least quadratic constraint propagation. For that in SAP CPQ for solution sales configuration are used ADT characteristics which are a shortcut to required objects and can be run instantly and with linear complexity, meaning by far more efficient. Each triggered constraint takes time to execute and it is prolonging the time required to create a solution. Figure 1. is showing constraint propagation of this simple example based on two parent objects and their descendants. All triggered constraints required to express connection between two object descendants are counted as propagated constraints. Horizontal axis present descendants of parent objects, while the vertical axis present quantity of minimal constraints required to be triggered to manage the connection between first parent object descendent and second parent object descendent. It is important to state that the graph is presenting a comparison based on same descendent of both parent objects (4th descendent of first parent object and 4th descendent of second parent object etc.). The SAP CPQ line shows that constraints triggered to connect to descendent are in a linear relationship with descendent, due to ADT usage. The SAP Variant Configurator line shows that constraints triggered to connect to descendent are in quadratic relationship with descendent due to required symbolic mapping.

Aggregating characteristics and specific generic object implementations are handling aggregation of objects or calculations can be handled using specialization of objects.

A part of solution modeling environment is model explorer, containing lists of all objects and dependencies. Implementation of solution modeling environment includes a test user interface and a configuration engine, which allows the user to test and optimize the model before transporting it to the target sales system. Test user interface allows users to save test scripts, identify the constraints and rules applied during a configuration session, and test the performance of constraints and rules.



Test Runner | Non-Part Instances | Conflicts | Profiling | Justifications | Trace

Name	Number Of Calls	Time
POWER_PORT_ACTIVE_UNIT_TO_SUP	16	110
SET_SECOND_QTY_NUM_TO_CHAR	42	87
POPULATE_PRICE_DATA_BBU	20	81
SELECT_SF_COLORED_BBU_SFPS	1	58
SET_SF_PN_2	4	41
COUNT_POS_IN_AGGREGATOR	15	35
SET_PRICING	20	11
BBU_POWER_CABLE_AU_TO_CHASSIS	8	10
CREATE_BBU_EC_CABLE	8	10
CREATE_ETH_CABLES	4	10
MAKE PO AGGREGATOR	30	9

Figure 2. Profiling of executed calls

Figure 2. shows the user interface of the Profiling tab which helps to test the performance of the model. Profiling is a part of the solution modeling environment (SME) and it contains "Name", "Number of calls" and "Time" tab. "Name" tab is presenting a name of triggered constraint or a rule per modeled solution. "Number of calls" tab is a quantity of triggered constraint or rule per modeled solution. "Time" tab is presenting total execution time of specific rules or constraint measured in milliseconds. Performance of the SME developed model depends on the number of calls and time required for execution of each rule or constraint. It is important that that there are minimal calls needed per each solution. Optimization of Java pfunctions is crucial to shorten the time required for execution of rules.

IV. KNOWLEDGE BASE ORCHESTRATION

Knowledge base orchestration (KBO) is a process that enables multiple knowledge bases to handle Coupled product packages which are shown to end users as a single large solution. KBO possibility enables separation and maintenance in a more agile way than in classic VC model, because Coupled product package contains smaller, more manageable individual configurable objects handled by their specific knowledge bases. Configurable objects can also be launched separately, as stand alone configurations. [10]

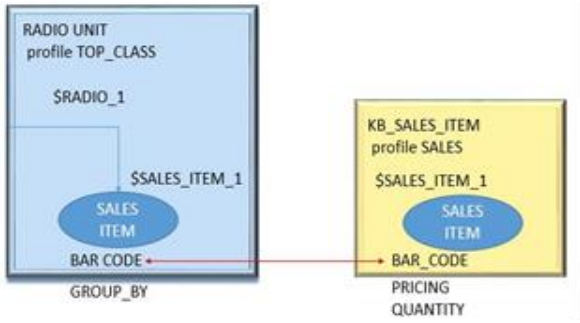


Figure 3. Knowledge Base Orchestration implementation example

Coupled product package with orchestrated configuration is shown in Figure 3. where are two knowledge bases available, "RADIO UNIT" with a configuration profile "TOP_CLASS" and "KB_SALES_ITEM" with configuration profile "SALES". As a part of RADIO UNIT" knowledge base, instance "$RADIO_1" is a creation condition for new instance named "$SALES_ITEM_1" with class type "SALES ITEM". Since there is a same class type object implemented as a part of "KB_SALES_ITEM" knowledge base, "SALES ITEM" logic that's a part of that knowledge base should also be valid. It can be seen that as soon as there's a reference for orchestrated class available, SSC engine will recognize it during configuration runtime and call the latest run time version of the KBO model. In this case, an instance named "SALES ITEM" is a reference, since there is a same class type object in both knowledge bases. Characteristic named "BAR_CODE" is used by both object implementations, meaning its value is orchestrated over both packages. For example, if the user would enter some value under "BAR_CODE" characteristic which is a part of "SALES ITEM" instance in "RADIO UNIT" knowledge base solution and then saved the solution, he would also be able to load configuration with only "SALES ITEM" instance as a part of "KB_SALES_ITEM" knowledge base solution with populated "BAR_CODE" characteristic of other knowledge base.

V. PRICING STRUCTURE

A configurable product is priced by price objects. The price object is used to denote functionality and enables "value-based selling". Normally it is not a physical product and is not delivered to the customer. It enables value-based selling and is used to communicate the price model to the customer. Price objects refer to documents that give details of the prices associated with a product and its functionality.

The price structure of the configurable product model is shown on Figure 4. where price object is named "PO", price object aggregator is named "AGGR" and price object container is named "CONTAINER". "ID" parameter on "PO" and "AGGR" are presenting product number, while "QTY" parameter presents many objects which should be taken in count and stated on the receipt at the end. Implementation of pricing, as a part of a model is handled by the price object aggregator which collects all objects with same product number. After aggregator creation, the price object container must be created and collects all pricing aggregators. The price object container is handling aggregators of price objects because it has a possibility to handle item packages which have different price than items that are being sold as single ones.

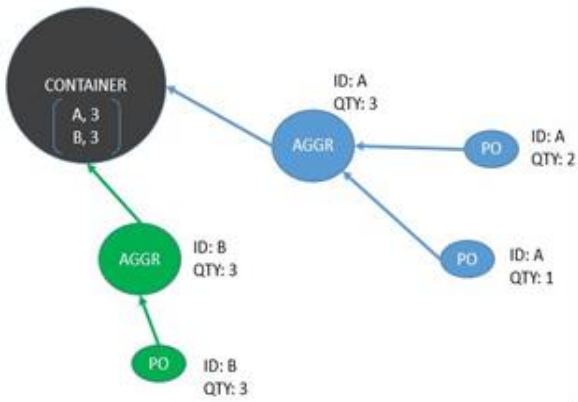


Figure 4. Implementation of pricing object handling

VI. SUPPLY STRUCTURE

Each product package has existing supply structure, which is also called the bill of material (BOM). The supply structure consists of orderable products, AGOs and SMs. An AGO (Assembly Grouping Object) consists of one or more SMs (Standard Modules) that are ordered from one specific order office in SAP ONE. The Delivery Object in the Product Package is only there for informational purpose. The Product Package is ordered by specifying options and priced by its price objects. Material types in SAP ONE are presented as orderable or delivered objects.

VII. PRODUCT PACKAGE DESIGNER

Product Package Designer (PP Designer) is a windows client. The product owners use the PP Designer tool for the following:

- Maintain Product Catalog, Price Lists, and Price Guides,
- Connect configurable products to catalog,
- Update non-configurable products,
- Handle product and catalog lifecycle. [11]

The root catalog for PP Designer is called the Catalog Structure or the Global Structure. This structure contains the Product Catalog and its product packages, as it is shown on Figure 5. The products created here by the product owners will be available in the ECP web interface for configuration by the product users.

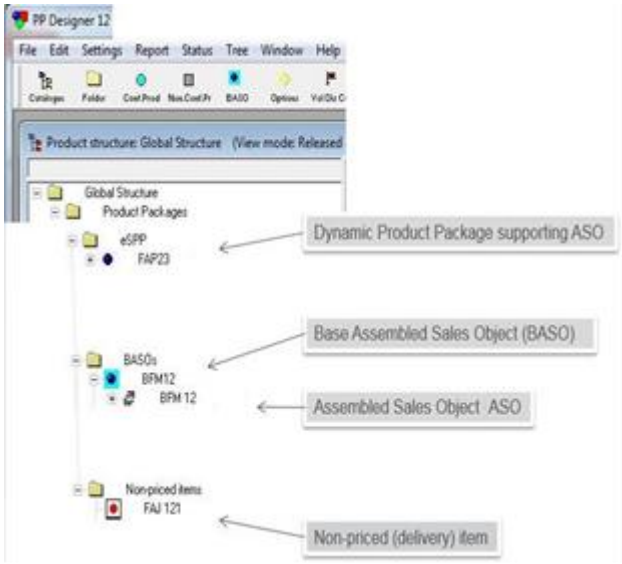


Figure 5. PP designer basic structure

Product package terminology:

- FAP: Class for product package (ECP runnable);
- AGO: Assembled Grouping Object. Containing all material that can be mounted in a cabinet;
- BASO: Basic Assembled Sales Object. Containing all material that can be mounted in a cabinet;
- ASO: Assembled Sales Object. A specific configuration created from BASO;
- SMuPP: Standard Module under Product Package – Material type in SAP ONE.

VIII. ECP

Ericsson Configuration Portfolio (ECP) [12] is a part of the official Ericsson Product Catalog and the corporate Ericsson IS/IT Landscape. Implementation of ECP is done in Sybase [18] ASE (Adaptive Server Enterprise) DB 15, which is also relational database management system with properties when dealing with a great number of OLTP [19] (Online transaction processing) transactions. This database is commonly used in the world of finance. Simple part of ECP user interface is shown on Figure 6.

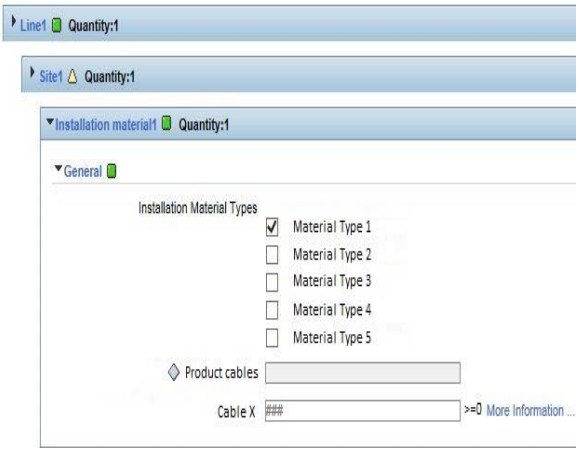


Figure 6. ECP UI example

Sales and marketing personnel of Ericsson are using this application. ECP enables users to find and configure Product Packages that originate from the ONE SAP system. Product Packages are configured using ECP, tendered using Verdi (Ericsson proposal tool) and ordered through ONE system. The functionality of ECP is divided in two parts – one for end users and one for product information owners. End users of ECP have read only options, meaning that they are able to run configuration models, save carts, generate reports and other specific documents per that configuration. While doing a configuration, the user is being guided with status icons which are described in Figure 7.

Icon	Icon location	Description
	Class	Indicates that the configuration is not fully specified.
	Class	Indicates that the configuration is fully specified.
	Class	Indicates conflict between chosen option values.
	Characteristic	Indicates that user input is required for that option.
	Characteristic	Indicates that the option was set by the user (successful).
	Characteristic	Indicates conflict between chosen option value and another option.
	Characteristic	Indicates 'No entry possible'

Figure 7. ECP icon description

ECP products that can be configured with the Interactive Product Configuration are named Configurable products.

There are two kinds of configurable products:

- Normal configurable product packages,
- Coupled product packages.

Normal configurable product packages are the single packages that can be configured with Interactive product configuration. The resulting price objects with quantities and reference prices are used as a base for preparing a customer proposal.

Coupled product packages refer to a configuration that combines several product packages in one model. These models may allow configuration of whole sites or each solution. Handling of Coupled product packages is done via knowledge base orchestration. The configuration model ensures that all packages fit together and reduces the number of options that needs to be entered, allowing the user to quickly finish configuration. Coupled product packages are also called as Solution product packages.

Non-configurable product packages refer to simple products that are not yet modelled as product packages. These products cannot be configured using the Interactive product configuration. They are registered in Product Information Management (PRIM) [13]. A non-configurable product consists of the following:

- Price objects,
- Vendor products,
- Standard modules.

Price objects are being attached to a product package during its configuration. Standard modules or delivery objects are not visible in configuration, they can be viewed in the saved cart which is created when the user saves the configured solution.

Cart item is usually a folder which contains following items:

- Configured model by user,
- File with list of price objects and standard modules,
- Drawing files.

IX. VERDI

VERDI is the Ericsson proposal tool and it is an integrated part of the Global IS Landscape. VERDI supports the Sales and Marketing process and provides input to the Supply process. The purpose of VERDI is to optimize the Sales and Marketing and the Supply processes by:

- Supporting the entire Ericsson product portfolio,
- Enabling access to correct information (product data, configuration support and prices) in a user friendly way,
- Electronic interfaces instead of manual transfer of data,
- Speed up and facilitate the proposal process,
- Support for workgroups and re-use of data by storing information for a specific proposal in a common database. [14]

X. CVIST

CVIST is Configuration Visualization Tool developed as a document generation tool and graphical drawing tool for Ericsson telecommunication solutions. Tool has been enhanced to be able to retrieve and read xml files with drawing information for SSC models or xml files generated from the configuration key of the Variant Configurator Package. This enables the modelers to replace the old configuration keys (240 digit key where all digits is a reference to a part of the layout) and use the actual configuration to describe the layout. [15]

CVIST output generates PDF files with various views including cabling documents and storage of those documents on the server. This output is used for assembly of Radio Base Station (RBS), node test in factories and tender in sales departments.

Views that can be generated from the CVIST are sorted in several groups:

- RBS View: Front Assembly View, Left, Right, Top, Bottom, Back, Door,
- Component View: Allocation of boards in the subracks (Radio, Power, DU adapter),
- Cabling View: Drawing of Cabling between boards (Allocated in/or between subracks),
- List View: Cable List of the configuration.

XI. IMPLEMENTATION PROCESS

Implementation process of the telecommunication solution starts with creation of material master data in SAP ONE. Master data in ONE is both material master data and BOM data.

Solution model developed in SME must contain all requirements from customers following rules for price and supply structure. The model is considered finished when all price and delivery objects are created in specific amounts per each user configuration solution.

Required structure of package that will be visible in ECP has to be created in PP Designer, as well as new price objects that have to be imported to ECP. Verification of pricing, meaning that imported price objects are completed with pricing information such as Fire code, estimated costs, workgroup, system pricing category etc. has to be done before the price object is released.

To be able to transfer a specific product package model to ECP/IPC, a Knowledge Base Object and Run Time Version (RTV) needs to be created in SAP ONE. Each new KB has to be transferred to preliminary ECP mode first and then verification of the solution can start. Verification is done after new requirements are tested and

after all legacy tests have been passed successfully. In case that verification failed, modelers have to implement fixes in ECP and deliver new patch to preliminary ECP. Successful verification means that KB can be transferred to release ECP and it is ready for use by end users.

XII. REGRESSION AND PERFORMANCE TEST

Regression testing is a type of SAP Configure, Price, and Quote for solution sales configuration testing that ensures that previously developed and tested telecommunication solution models still perform the same way after the new introduced version of KB. [16] [17]

The purpose of regression testing is to ensure that each of the identified test cases present a complete working cart and have a valid configuration and a valid drawing. Test cases are being discussed and identified for the release along with product owners. Product owners are responsible for creation of most common user model solutions on first place, but it is also important that there is a specified legacy of test cases which are crucial to secure the quality of solution models. Execution cycle shall be halted if there are failed cases and the next cycle of test will start immediately after the bug has been fixed and the new knowledge base has been delivered. Frequent cycles of regression tests assist with the quick analysis of when and why some errors were introduced, causing troubleshooting and fixing of errors less time consuming.

Another type of testing which is required for telecommunication solution models is performance testing. Performance testing of telecommunication solution models is performed to determine how a model performs in terms of responsiveness and stability while trying to recreate selected solution carts. Parameters included in performance statistics used as quality assurance are environment parameters and model latency measurements.

XIII. CONLUSION

Configuration creation for complex telecommunication solutions was no longer possible with the configuration engine that was used and which reached its limits. After required study and evaluation through a proof of concept, a new configuration engine was selected, SAP Configure, Price, and Quote for solution sales configuration.

The main advantages of using new engine were the ability to perform bottom-up configuration as well as the normal top-down approach and more effective object-oriented modeling with linear complexity scaling.

With new engine, there were introduced new methods and subsystems to secure new, advanced ways of configuring teleccomunication products while ensuring support of existing, legacy configurations and solutions

Present Ericsson's system is compound of various subsystems and an increase of perfomance in any of them cause tremendous improvement to the whole system. New configuration engine is a part of Ericsson system which included efficient execution of solution models providing future-proof solutions while affecting customer experience.

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Solution for Detecting Sensitive Data Inside a Data Lake

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This paper is the result of a project realized by a team of current master's degree students. The team created an algorithm for recognition of sensitive data, primarily name, surname and OIB (Croatian personal identification number). Same algorithm iterates across given unstructured texts and appoints tags for documents considering the existence of specific sensitive data. This process offers a way for companies to narrow down the search for personal information if a client demands removal of his data. Similar algorithm was implemented for working with server logs as well, which are represented as data streams and analysed in real time. To provide insight on the quantity of sensitive information and how it is distributed across different types of documents the team created a dashboard that shows statistical data accumulated by developed algorithms. The solution is stored on Cloudera, Apache Hadoop-based open source platform designed for data management and analytics, which is deployed on Microsoft Azure cloud infrastructure.

I. INTRODUCTION

The General Data Protection Regulation (*GDPR*) is a new law established by the European Parliament, the Council of the European Union and the European Commission, designed to ensure greater protection of individual rights of EU citizens, especially in the area of personal data protection. GDPR's purpose is to replace the current DPD (*Data Protection Directive*) which has been in force for more than 20 years. From the time the DPD entered into force, technology has progressed significantly and the amount of data processed on daily basis has become much bigger.

Main focus of the GDPR regulation is the term "personal data". The document states that *"personal data" means any information relating to an identified or identifiable natural person ("data subject"). An identifiable natural person is one who can be identified, directly or indirectly, in particular by reference to an identifier such as a name, an identification number, location data, an online identifier or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person* [1].

GDPR defines the basic rights that citizens have regarding the protection of their personal data. Among other things, the regulation provides the citizens with the "*right to erasure*" explained later in the document. For the purpose of making this regulation aspect achievable, the team decided to offer its solution.

Sections II and III give an insight into motivation and problem definition for the paper. In section IV, the implemented system is architecturally described and presented. Section V gives the overview of implemented algorithms for detection of sensitive data inside stored text documents and data streams. Finally, section VI provides insight into data visualization of the given results along with their possible interpretation.

II. MOTIVATION

According to the GDPR regulation, personal data must be *processed lawfully, fairly and in a transparent manner in relation to the data subject*. It should only be *collected for specified, explicit and legitimate purposes and not further processed in a manner that is incompatible with those purposes*. Personal data should also be *accurate and, where necessary, kept up to date*. Furthermore, it should be *kept in a form which permits identification of data subjects for no longer than is necessary for the purposes for which the personal data are processed*. [1]

Another important part of the GDPR regulation is the extension of the data-subject rights defined in previous regulations. Firstly, the data-subject has the right to be informed about the processing of its personal data and the right to access its personal data and supplementary information. Personal data must be rectified if it is incomplete or inaccurate and data-subject has the right to suppress the processing of personal data. The right to data portability allows data-subjects to obtain and reuse their personal data which allows them to move, copy or transfer personal data between different IT environments in a safe and secure way. Another important right of the data-subject is the "right to erasure", or the "right to be forgotten" [2], for example, in circumstances where the data is unlawfully processed or no longer necessary for the purpose for which it was collected.

This change will require new system developments to incorporate these regulations. Specially, reconstruction of older systems, whose design does not support the requirements of this regulation, can become a very expensive and complex task.

III. PROBLEM STATEMENT AND DEVELOPMENT PROCESS

Sensitive data in IT systems can be found inside various shapes and formats as well as in many different locations. In order to better comply with the rules prescribed by the GDPR, one of the most important tasks is to properly locate all sensitive data, and then record the information about their location.

Since sensitive data can appear in documents of different formats, data lake is an excellent solution for their storage. A data lake refers to a massively scalable storage repository that holds a vast amount of raw data in its native format («as is») until it is needed plus processing systems (engine) that can ingest data without compromising the data structure [3].

All types of data, structured, semi-structured and unstructured, from a variety of sources, can be stored inside a data lake. It's like a data pool in which the schema and data requirements are not defined until the data is queried [3]. The data in the lake becomes accessible as soon as it is created (again in contrast to data warehouses designed for slowly changing data) [3].

Work on the project itself was split into some general phases, starting with the concept creation then followed by tool assessment and selection, after which came the system development itself. The team decided to break down the process into individual tasks but to work on them parallelly and on the same location. Main goal behind this approach to product development was to achieve a single coherent system which was uniform in every way possible. The result produced was as planned, there were no inconsistencies between the used tools or programming languages and a functional platform was developed.

IV. IMPLEMENTED SYSTEM

The entire solution is based on two algorithms, one for detection of sensitive data in stored text documents which is implemented in R [5] programming language and another one for detection of sensitive data in streams represented as server logs implemented in Python [6]. Both algorithms run on Cloudera [7] CDH (*Cloudera Distribution Including Apache Hadoop*) virtual machine with CentOS 7 Linux operating system deployed on Microsoft Azure cloud platform [8]. The entire system diagram is shown in Figure 1.

The Apache Hadoop software library is a *framework that allows for the distributed processing of large data sets across clusters of computers using simple programming models. It is designed to scale up from single servers to thousands of machines, each offering local computation and storage* [9]. For the purposes of this project Hadoop runs in pseudo-distributed mode meaning that Hadoop is installed on a single virtual machine and the processing is distributed on all of the cores/processors of that machine. Cloudera CDH is one of the most popular open source distributions of Apache Hadoop and it includes several other related open source projects for working with large amounts of data.

Both text documents and server logs can be stored directly on Hadoop's file system in its native format. That kind of *storage repository that holds a vast amount of raw data in its native format, including structured, semi-structured, and unstructured data* is called a data lake [10]. The main advantage of this architecture is that data can come into the data lake from anywhere, including online transaction processing (OLTP) or operational data store (ODS) systems, an EDW, logs or other machine data, or from cloud services. These *source systems* include many different formats, such as file data, database data, ETL, streaming data, and even data coming in through APIs [11].

Each document in a lake is assigned a unique identifier and tagged with a set of tags. Tags are attributes which represent the existence of a certain type of sensitive information. Data is smoothly ingested into the data lake, where it is managed using metadata *tags* that help locate and connect the information when business users need it. This approach frees analysts for the important task of finding value in the data without involving IT in every step osf the process, thus conserving IT resources [11].

For the purpose of the mentioned "tagging" process in the data lake, the team had developed two algorithms explained in detail in the next chapter. The results of both algorithms are CSV files (*Comma-Separated Values*) [11] which are stored in one folder on HDFS (*Hadoop Distributed File System*) where they can be accessed and analysed using the Impala platform [13]. Apache Impala is an open source platform that allows executing interactive SQL queries directly against data stored in Hadoop Distributed File System. Impala enables the creation of a data structure when the actual data is needed. For the purposes of storing tag data, the Impala table "tags" is created. New data is added to the Impala table simply by adding a new file to a folder on HDFS using the Linux command line. This data represents the locations of detected sensitive data.

The tagging process can be performed at uniform intervals that the company previously defined depending on their business needs. For example, for new documents that are created on daily bases, the algorithm can be executed at the end of each business day. For data streams, the tags can be created almost immediately after the data arrives using the data stream tagging algorithm, and the tags can be stored on HDFS shortly after the sensitive data is initially created. When a customer comes with, for example a "request for erasure", the process of locating sensitive data inside a data lake becomes quite simple, therefore saving time and resources.

Impala tables and queries can be used for another important purpose – data analysis. In addition to the "tags" table, additional tables and views can also be created on Impala which could contain data that would be relevant for later analysis. By using this approach, it is

easier to analyze and visualize data because the data retrieved using Impala is in a structured form. Furthermore, visualization tools are mostly designed to work well with structured data and not with unstructured or semi-structured data usually found within data lakes. By creating views directly inside the Impala platform, most of the work load required for data analysis is shifted to the cloud. That way most of the analysis can be carried out by SQL queries that create views. Moreover, by using SQL queries to analyze data instead of sending entire data sets over the network, the entire solution runs faster and requires less bandwidth.

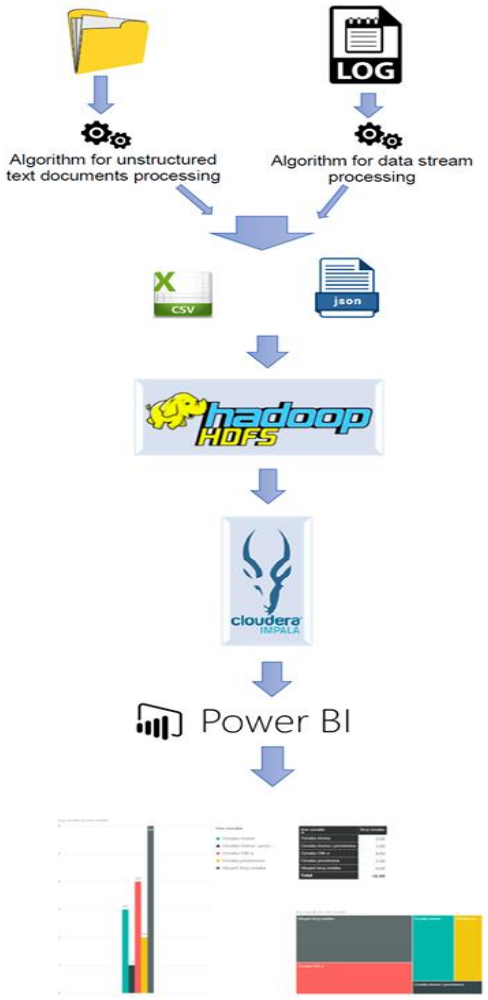

Figure 1. System diagram

V. SENSITIVE DATA DETECTION ALGORITHMS

Two types of detection algorithms were created considering the sort of input file they take in for analysis. These kind of input types represent data types which could actually be found in businesses. Unstructured text documents refer to, for example, contracts or stored system information while a data stream represents real-time system log files.

A. Stored text documents processing

Algorithm for unstructured text documents processing was developed in programming language R, within the development environment RStudio [14]. The main task of this algorithm is to recognize the persons sensitive data inside documents, primarily name, surname and OIB (Croatian *personal identification number*).

These documents are stored within the directory located on the Cloudera platform from where the main R script fetches them and executes the above mentioned algorithm. For the purpose of implementation of this part of the project, a list of most common Croatian names and surnames was acquired from the business firm *Poslovna inteligencija*. Considering the Croatian language has different forms of words (seven cases for each noun), the team implemented an additional program written in C# [15] language that transformed the mentioned list of names into a text entry in which each line contains a single name written in all cases. Nouns are declined through cases which are not always the same for every noun due to the existence of dialect specific names. Necessary script was developed to try covering all of these specifics, but further work could always be made on this subject. The existence of a name or surname within the document is the search trigger for OIB's existence which is recognized as a standard 11-digit record. Without the appearance of the name or surname within the text, the OIB itself is a regular set of 11 numbers which we can't associate with someone's identity and therefore can't consider it sensitive information.

Within the main program, loading of names, surnames and documents is implemented in separate functions. Firstly, the mentioned list of names is loaded and each of them is assigned a class "Name" whose attributes are actually all seven cases (*nominativ, genitiv, dativ, akuzativ, vokativ, lokativ, instrumental*). A similar thing is done with surnames. Also, documents from the directory are loaded and each of them is processed as a "Document" class that consists of the document name, path to the document and the text itself. All generated "Document" classes are stored in a single list across which the detection of sensitive data is performed. This is done by searching for the mentioned names and surnames in the text of each document. Depending on the result of the search, tags are created. Tags are a part of a structure created to better describe the data inside the lake. Each document's identifier (which consists of its name combined with the date the text analysis took place) is associated with a set of three tags which are nothing more than attributes which describe the existence of a certain type of sensitive data inside the document. For example, if a document contains any name inside it, "tagName" will be set to TRUE. This way of tagging can serve as metadata for faster locating of documents which contain sensitive data.

Executing the main program results in two types of results: records in CSV format and records in JSON (*JavaScript Object Notation*) [16] format. The results files names contain the date of execution which makes

them unique and can be stored in a shared directory. Further statistical visualization is performed over the results in the CSV format, while results in JSON format are created for the purpose of further implementation and improvement of the algorithm. Inside the results files three tags are associated with document identifiers as seen in the examples in Listing 1 and Listing 2.

```
" documentname ","tagname","tagsurname","tagoib"
"Documents/contract1.txt_2018-01-
11",TRUE,TRUE,TRUE
"Documents/contract2.txt_2018-01-
11",TRUE,FALSE,TRUE
```

Listing 1: Results in CSV format

```
[
{
"DocumentName":"Documents/contract1.txt_2018-01-
11",
"tagName" : true,
"tagSurname" : true,
"tagOib" : true
},
{
"DocumentName":"Documents/contract2.txt_2018-01-
11",
"tagName" : true,
"tagSurname" : false,
"tagOib" : true
}
]
```

Listing 2: Results in JSON format

B. Data stream processing

Algorithm for data stream processing was developed using programming language Python along with interactive cell PySpark [17] under Apache Spark [18]. In order to process a huge number of records inside a data stream without limitations, efficiently, quickly and with the use of simple data structures, the team included the Pandas library [19] developed for Python.

To achieve the purpose of this part of the project, it was necessary to find the data records containing user IP addresses, their names and surnames. Given the inability to find such data collection, the team modified a data set consisted of server logins made by a user accessing the system. A suitable format for the analysis was created by passing through the document records and inserting randomly selected names and/or surnames into randomly selected records. There was no need for insertion of IP addresses as the existing files already had the appropriate records. Developed format was believed to be a good example of a real-life scenario data stream that could be generated inside an everyday business environment. The names and surnames used for random insertion are the same as those used for processing stored text documents.

After creating a suitable format of a data stream, the implemented algorithm reads file rows in blocks of a certain size because of the large file length. Before reading the file, algorithm loads two arrays of data, one with all of the most common Croatian names and the other one with surnames. A block of predefined size is first loaded into Panda's two-dimensional data structure called data frame. Rows represent the index of rows in the data set while columns represent a variety of information in the given data set. This structure is easy to search and it is easy to access a specific part of a record. For each record the algorithm is looking for an IP address form and, at the same time, it is checking for a name or a surname match based on the mentioned arrays. For each match found, the algorithm creates a four-tier structure that is entered in the results file containing the row number of the analysed line along with three tags for each type of sensitive data. If the line contains an IP address, name and/or surname, the corresponding tag is set to TRUE, otherwise FALSE. Due to the possible different kinds of application of this data the results are stored as previous algorithm results, in two formats: CSV and JSON.

VI. RESULT INTERPRETATION AND DATA VISUALIZATION

Data visualization in the project was made with Microsoft Power BI [20] tool, more specifically, a free version of "Power BI Desktop". This program provides a very intuitive connection to many data source types. It was selected for this project due to existing embedded support for Impala data source. The Power BI tool can load the data from the Impala system in the form of tables and make direct SQL queries over them.

The views for the visualization were previously prepared in Impala. After connecting to the Impala data source, within the Power BI tool it is possible to display the data from the views and perform statistical processing using functions. These functions can be applied over the entire data or only over some of its parts. Processing results can also be graphically displayed. Power BI tool was used for creating a dashboard that consists of several graphs displaying the results of both algorithms.

Analysis and display of data in Power BI are dynamic. In the case of data change on the data source, results are refreshed within the Power BI tool. In that case all statistical functions will be re-calculated and all graphs will be re-drawn. This approach is appropriate for working with large data sets because of their constantly increasing volume.

Created visualization based on the sample text documents and requests for erasure were interpreted inside sample dashboards which still don't hold any bigger analytic value. Future improvements of the algorithms, primarily in the way of adding more document tags, along with more detailed information concerning the request itself (such as request origin, request applicant information etc.) would definitely bring more meaning to generating results visualization. Given such visualization, data managers could get insight into

some patterns such as a number of certain tag appearances or data anonymization requests location origins. Such knowledge can ultimately assist them when managing data on a big scale.

VII. CONCLUSION

The developed project offers a proof-of-concept system which is founded on the idea of a single platform containing all the necessary data, tools and scripts for a successful solution implementation. Developed product detects subjects personal information along with appropriately tagging the files which involve the same.

The student team working on the project expanded their knowledge over the involved tools and concepts used while developing a solution. The project proved to be quite of a challenge since the students lacked a lot of experience prior to the engagement in solution integration, but with a good mentorship along with a big amount of working hours, the product was deemed functional.

Like in every other software solution there is always room for improvements. The team considered a lot potential upgrades of the developed system such as providing additional document tags, integrating algorithms for semantic analysis of more different file types along with some structural code upgrades which could provide an increase to the algorithm processing speeds.

ACKNOWLEDGMENT

The authors would like to give special thanks to the business firm *Poslovna inteligencija* that provided the space and infrastructure needed to work on the project as well as the firm employees, Tomislav Hlupić and Nikola Kljajo, for their undivided support and guidance during the realization of this project.

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General-Purpose Modeling Tool

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Abstract – This document describes the functionality of the General-Purpose Modeling Tool application, a platform designed for enabling collaboration between people participating in different areas of the model development workflow (i.e. domain experts, database modelers and technology experts), facilitating data management, data processing and versioning. The focus will be on showing the solution approach regarding the challenges of making various aspects of the tool a reality, without going too deep into technical details concerning the implementation itself.

I. INTRODUCTION

A common approach in problem solving is modelling it using a relational database model [1]. Be it a specific problem, or a group of similar problems, it would make sense to generalize and centralize the logic related to their development, meaning implying that all relevant data is residing in one database and all data models are tailored in similar fashion. Furthermore, it would be beneficial to include members from different areas of the development workflow (people who work with the same resources but make use of them in different manners) into the development process to achieve collaboration between domain experts, database modelers and technology experts. [2]

It is important to have the ability to version database models as they evolve as well as to have versioning of existing functionality as they branch out into new models with their own lifecycles, so that in some point in time they could be merged back with the product they originated from (figure 1). Versioning different model versions and functionality enables the feature of output generation versioning (the resulting output code produced). This innovative solution implies a platform supporting the development of problem-specific contexts, following general principles of modeling, while accommodating the possibility of modeling according to unique, exceptional problem-related requirements. It becomes possible to make unique, specific implementation versions a reality and introduce automation of item management and output generation, as well as automation of updating the production system with new data. The absence of mentioned features in the world of modeling [3] is the main reason for the development of the General-Purpose Modeling Tool application. Presented lies a specific software solution aiming to embody unity and automation of the model development workflow and its main features are described in the following sections of this document.

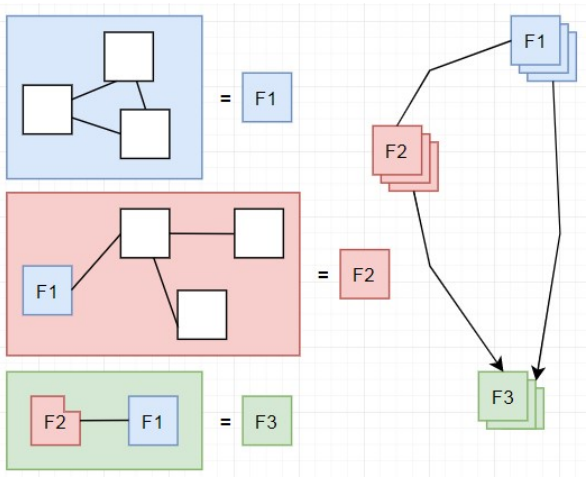

Figure 1. Data Model Relations and Version Relations

The paper is structured as follows. Section II is a short overview of the overall application architecture, as well as an explanation for the choices of technologies used for feature implementation (figure 2). In section II.A. It is described how a certain degree of access must be allowed to both programmers and non-programmers into a database of items used by the respective problem. The necessity to incorporate a database immune to errors, due to frequent structural and data changes, and structurally and functionally adaptable to the dynamic natures of different problem models, is the topic of section II.B. Section II.C explains the need for a kind of an IDE (Integrated Development Environment) for designing the logic of the output code, which is to be generated for the automation process, while section II.D explains how the application generates output reports, usable externally to achieve desired automation results in the production system. At the end of the document, a conclusion is provided in section II.

II. APPLICATION ARCHITECTURE

Due to a large userbase of people working in different areas of the development workflow and various requirements of the graphical user interface, such as smooth transitions when switching between functionality and rendering of content based on large quantities of data, as well as the desire to not have any local download and installation requirements, the natural decision was to develop the General-Purpose Modeling Tool application as a RESTful web application [4] (the user interface logic is handled on the front-end and the back-end is only

contacted when data is to be retrieved or updated), driven by the Angular5 JavaScript framework for the front-end and hosted by a NodeJS back-end server in conjunction with a MySQL database server (figure 2).

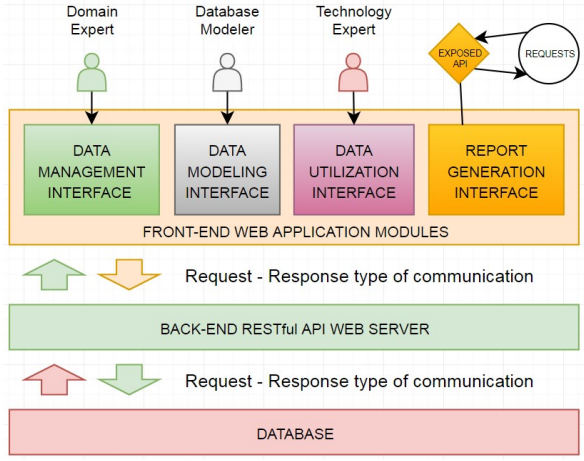

Figure 2. General Purpose Modeling Tool application architecture

The front-end functionality has been divided into four modules, components which differ in functionality and purpose (they have different targeted audiences, meaning restricted access to certain user groups). Those front-end modules do not communicate with each other, but with the back-end server when data is to be retrieved or updated (figure 2). Changes in data are reflected in each module and that serves as sort of a link between them:

- The Data Management Interface exposes the data of the models inside the database in a user-friendly way, while the model structure itself is not modifiable, guaranteeing a high degree of security in terms of modifications done. It is meant to be used by domain experts, who do not require any database or modeling knowledge. The graphical layout is designed using the Data Management Interface Designer, child module of this module, by the modelers and technology experts.
- The Data Modeling Interface enables the highest degree of access to the database, since both the data and structure of models can be modified here. Targeted users are database modelers (database developers with MySQL knowledge). It allows for structure, data and functionality reusability of models in order to implement more complex models. This can be achieved by branching wanted version of multiple data models and merging wanted parts into new data model. Due to versioning support, it is also possible to merge the models and their data.
- The Data Utilization Interface is a collection of different, unique child modules meant to be used by different technology experts, so that they could provide data processing logic to assure the generation of appropriate output reports via the Report Generation Interface. The model data or structure cannot be modified in the context of this module, it is read-only.
- The Report Generation Interface allows for retrieval of output in the form of textual files or APIs (simple pages with raw data and without design), created by combining data from the database with the logic defined in the Data Utilization Interface. The output can be any kind of procedural code, input for some proprietary technology environment (ELIS [8], IE-Select [9] in case of Ericsson), or standardized format later used as input for other environments. Outputs can also be connected via APIs to other environments where they can trigger the generation and transfer of necessary data, properly formatted, into their environment.

There are also the following benefits of the technologies used for the realization of the application:

- The logic of the Data Utilization Interface modules must be written in JavaScript code, which is evaluated upon execution and handles data processing, allowing for aggregation, substitution, and sorting in any desired fashion.
- MySQL brings stored database procedures and database triggers (procedural code executed at certain times, such as when data is selected, updated, or inserted into a table) into play, which support programmatic code with control flow and looping – offering a more programmer-friendly approach to modelers (database developers), opposed to the classical way of writing queries.
- Logical separation of the front-end, back-end and the database allows for better extensibility and modularity in the future as well as maintenance. Any new front-end modules, or child modules are introduced in separate context, not hindering the functionality of existing. The same applies to new back-end functionality.
- As mentioned, most back-end services can be accessed by other applications and contribute to desired interoperability between systems within businesses (exposed APIs of the Report Generation Interface).
- The modularity of the front-end components is also a beneficial security feature and a checkpoint for possible feature expansions in the future.

A. Data Management Interface

Data management assumes the role of updating data without modifying the structure, which tends to be a frequent and tedious task, especially resulting in human

made errors if allowed to be done directly inside a database. It becomes an emphasized issue when people without appropriate database knowledge are allowed access to execute changes to the database directly. Since Domain Experts are not required to have such knowledge the platform must provide them with an interface to access the data in an understandable way and with user friendly read and write options (which imply a high level of error resistance upon data modification and restrictions from modifying the model structures).

In the General-Purpose Modeling Tool application, the database modelers and technology experts are responsible for designing the Data Management Interface through the Designer sub-module implemented solely for that purpose. The Designer sub-module is not accessible to Domain Experts, even though it is a part of the Data Management Interface (figure 3).

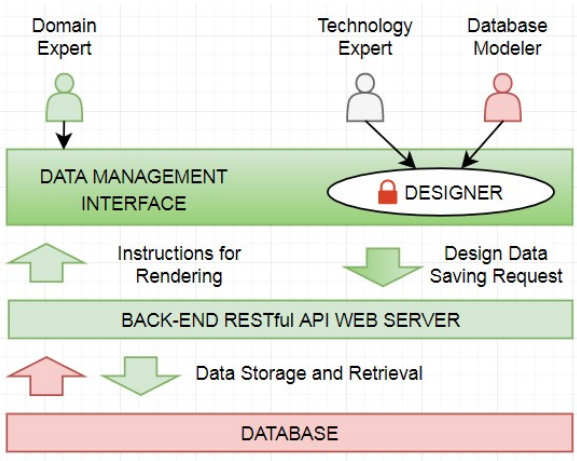

Figure 3. Data Management Interface module context

A database resource, data source, be it a simple table, a complex relation between tables or a stored procedure result, is exposed by a composed visual layout in the earlier mentioned Designer. The graphical elements in the layout represent model properties (columns of tables) and are bound to the data source in question. Html *Tables* are used for displaying data for simple reading purpose (figure 4), multiple rows at once with pagination and filtering functionality available thanks to JavaScript.

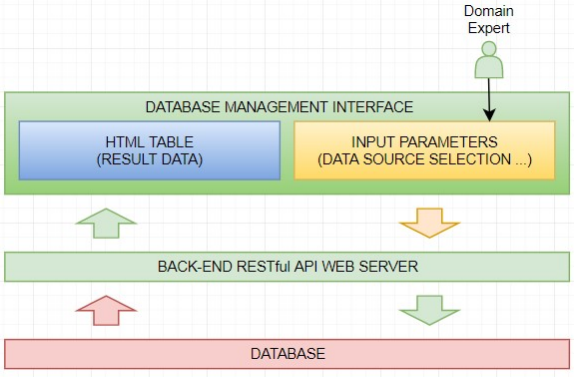

Figure 4. Data Management Interface data viewing

In the context of editing or inserting data (one row at a time), *Input Fields*, *Labels*, *Checkboxes* and *Radio Buttons* are used for the visual representation of data. Client-side validation is implemented to make basic checking whether entered data matches the type of the model property types, while stored database procedures and database triggers can be used for server-side validation to further validate the input upon submission. They can return detailed error messages to tell the user more about what has gone wrong (figure 5). Importing large amounts of data from Excel files is supported, but formatting rules for each column must be respected and no client-side validation exists, only server-side.

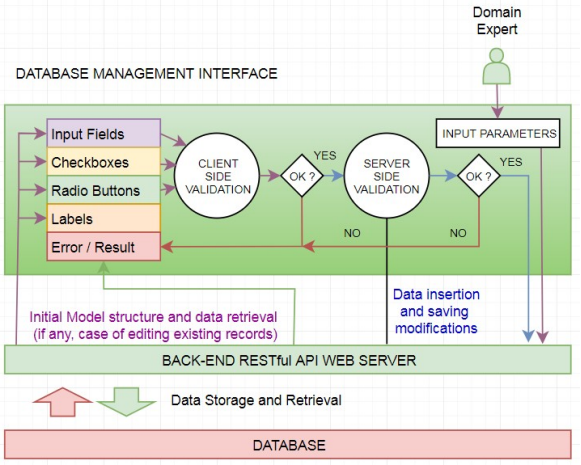

Figure 5. Data Management data insertion and modificaiton

Input data is passed down to a stored database procedure declaration in JavaScript upon submission, which calls the actual database procedure. The values are being validated inside the database procedure, if validation logic exists, and an attempt is being made to save the changes. If database triggers are implemented, they execute additional validation before data is stored and do any required modifications to the data after it is added. Both database procedures and database triggers can return informative messages to the user at any time during their execution.

B. Data Modeling Interface

For the needs of the General-Purpose Modeling Tool application, a master database is used in order to keep track of all other databases, where each corresponds to a problem broken down into a relational database model. Each of the problem-specific databases has several generic core tables, in addition to the tables unique to their implementation. The master database and core tables are concerning the application architecture itself and are not meant to be accessible by any of the users, therefore a unique implementation of a module that would accommodate all of these customizations and expose limited content was implemented. Database modelers are the only group of users meant to work with the database and are therefore the only ones with access to this module (figure 6).

Much like SQLyog [10], Navicat [11] and other graphical database management and development software, the Data Modeling Interface is a graphical component with similar features, custom tailored to suit the requirements of the General-Purpose Modeling Tool application. In addition to the previously stated architectural demands, the requirement of custom graphical features, in order to provide visualization of the versioned data in separate contexts, was the reason for not using any of the mentioned publicly available solutions, but to develop a stand-alone module instead.

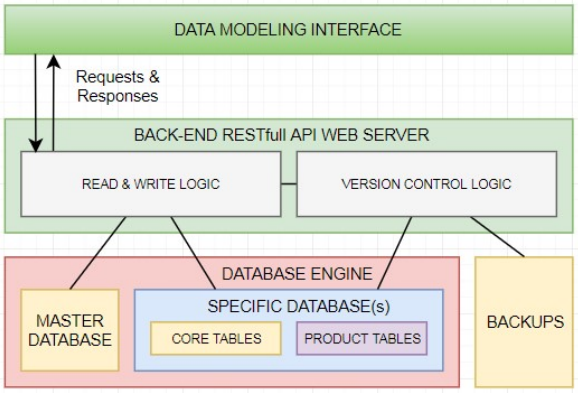

Figure 6. Data Modeling Interface context

Database structure and data are being separately saved as textual files with version and date information in the file name, stored on the hard drive. By comparing two or more structural or data files (logic in the back-end server) the differences between them are calculated and presented in a standardized fashion, showing how the database structure and values changed over time, implicating the work done by technology experts or domain experts who maintain the data. With the visual aid of a jQuery plugin for displaying versioned code, reverting changes becomes as simple as executing a desired structural file with the corresponding data file in order to restore the system back to how it was in a specific point in time.

C. *Data Utilization Interface*

The most complex module implementation of the General-Purpose Modeling Tool application is the Data Utilization Interface module. It is made of several sub-modules, necessary to supply the production system with all the necessary generated output, of which the most important ones will be individually explained throughout the remainder of this section (figure 7). Ahead lies a real-life example of the data utilization interface as being used by SSC [13] / VC [12] technology experts. Only technology experts have access to this module and it's features (SSC / VC programmers in the mentioned example).

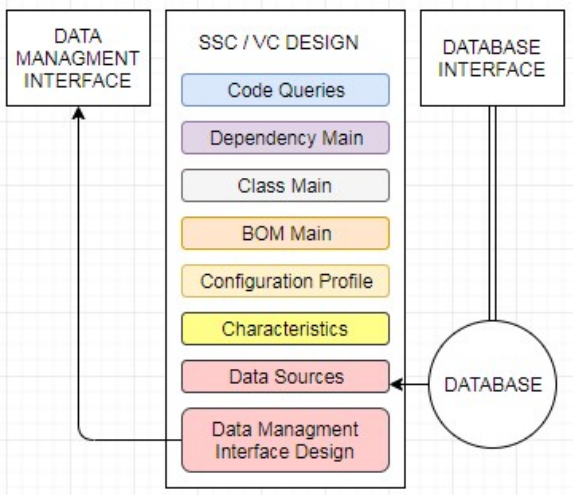

Figure 7. Data Utilization Interface context

1) *Data Source View Form*

Even though a technology expert, SCC / VC programmer in the example, is not responsible for designing the product database neither to maintain it, they need a certain degree of access to be aware of the structure and data present in order successfully process it. The Data Source View Form sub-module provides insight into the database and acts as a quick-access, read-only version of the database module.

2) *Code Query Form*

Processing data stored in the database and generating code based on string concatenation and substring substitution is the task of the Code Query sub-module. Constraint-based programming has many limitations - it requires simple, clear lines of instructions, obeying a given syntax, which potentially implies large amounts of code to properly define cases embodying complex logic. By using JavaScript [14] to append strings to a globally defined output variable, it is possible for the programmer to work in a more sophisticated manner, with more convenient coding features, such as loops, and mass generate parts of code to later be used in constructing SSC / VC dependencies. [15] Another global JavaScript variable to be mentioned, *db*, is an array of database tables, database stored procedures, and database views, which can be looped through to access their respective structures and data in order to append them into the resulting output (figure 8).

Codemirror, a jQuery plugin, was used to implement the JavaScript editor area with powerful syntax error detection functionality included [16]. The JavaScript code processing is done via the *eval()* method, which is implemented as part of the JavaScript language. A preview of the interpreted code can be displayed in the preview window below the editor area (figure 9).

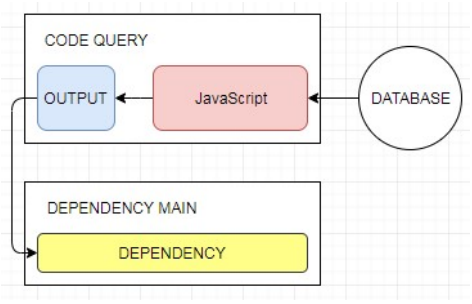

Figure 8. Dependency code generation workflow

It is important to point out the opportunity for workflow flexibility here. One example would be that of data being thoroughly prepared in the database by the data modelers, so the technology experts (SSV / VC programmers) only need to use simple JavaScript loop functionalities to make use of it. Another example would be that of the database only containing table definitions with data and entire processing logic being done by JavaScript. The third and most logical case is utilizing both previously mentioned approaches and getting the best out of the two worlds. [17] The key for successful modeling of a product is of course the cooperation of everyone involved, primarily the data modelers and technology experts.

Figure 9. Code Query editor and generated code preview

3) DependencyMain

On their own, Code Queries only generate chunks of code, which is indeed their purpose, but those chunks need to be assembled and ordered to produce a meaningful block of code. That is done in the Dependency Main sub-module. In certain cases, one code query is enough to make up the entirety of a dependency, but complex logic normally must be broken down into less complex parts.

4) Other sub-modules

The remaining sub-modules of the Data Utilization Interface are of administrative nature, required to ease the maintaining of data, which is a part of the output produced by the Report Generation module. Data contained here is used internally by the application mainly for output verification and structuring purposes. It is also required in the process of integrating the output into the production system.

D. REPORT GENERATION

Output produced by the General-Purpose Modeling Tool application are either textual files or raw web pages with with data structured in JSON format [18]. In the context of the SSC/VC example that would be files with the following generated content:

- An array of Classes with descriptive data and lists of Characteristics bound to them.
- An array of Characteristics with descriptive data.
- An array of DependencyNets with descriptive data and lists of Dependencies bound to them.
- An array of Dependencies with descriptive data and matching logical code.
- A ConfigurationProfile with descriptive data and lists of all Classes and Dependencies bound to it.

The above-mentioned files require to be processed in order to be of use to the production system and for that additional tools are used, which are not a part of the General-Purpose Model Tool application. In the case of SSC, it is only a matter of re-structuring the files into the workspace of SME plugin for Eclipse [19], but in the case of VC it becomes more complicated – either access to the SAP server is needed, or GUI scripting [20] needs to be done for executing large amounts of changes [7].

III. CONCLUSION AND FUTURE WORK

The General-Purpose Modeling Tool [21] application is a modern, multi-user web application intended to be integrated into the SSC / VC workflow with the goal of changing how product modeling and data maintenance are done, as well as uniting groups of people from different areas of the workflow and offer them a common platform for working. SSC / VC constraint code writing takes less time and offers less manual, repetitive work. Data maintenance is done on the same platform and validated, enforced, by the code written by SSC / VC programmers, who are responsible for processing it later.

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Grafovske baze podataka – pregled istraživanja i budućih trendova

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***Sažetak* - Koncept NoSQL baza podataka obuhvaća niz tehnologija za alternativni (nerelacijski) pristup upravljanju podacima. Kao jedna od kategorija NoSQL baza podataka, grafovske baze podataka specifične su po prikazivanju podataka u obliku čvorova i veza u grafu nad kojima se prilikom izvršavanja upita izvršavaju različiti algoritmi iz teorije grafova. Društvene mreže najčešći su scenarij korištenja grafovskih baza podataka, budući da je osobe i veze između njih „najprirodnije" prikazati kao čvorove i veze u grafovskim bazama podataka. U ovom ćemo radu napraviti pregled dosadašnjih istraživanja vezanih uz grafovske baze podataka općenito, sustave za upravljanje grafovskim bazama podataka i upitne jezike za interakciju s grafovskim bazama podataka, te ćemo posebnu pozornost obratiti na buduće trendove razvoja ove zanimljive i sve popularnije kategorije NoSQL baza podataka.**

Ključne riječi - grafovske baze podataka; NoSQL; Neo4j; upitni jezici

I. UVOD

Grafovske baze podataka predstavljaju kategoriju NoSQL baza podataka čiji je koncept predstavljen 2009. godine. Koncept grafova u bazama podataka spomenut je i u ranijim istraživanjima tijekom 1970-ih godina u mrežnim bazama podataka, ali se u tom razdoblju relacijski model ipak pokazao kao bolje rješenje za pohranu podataka. Posljednjih nekoliko godina ideja je ponovno zaživjela kroz koncept NoSQL grafovskih baza podataka koje, zahvaljujući mogućnosti efikasne pohrane i pretraživanja međusobno povezanih podataka (s naglaskom na pohranu informacija o vezama između entiteta) bilježe stalni porast broja korisnika. Danas je upotreba grafovskih baza podataka dosta široka; najčešći scenariji korištenja grafovskih baza podataka su društvene mreže [1]–[4], sustavi za preporuke (primjerice, filmova) [5], detekcija financijskih prijevara ili računalnih virusa [6], itd. Međutim, uzimajući u obzir suvremene trendove u znanosti i praksi, objavljena su istraživanja u kojima je područje korištenja grafovskih baza podataka prošireno na Internet stvari (engl. Internet of Things) [7], rješavanje transportnih problema i javni transport [8]–[11], sustave za opskrbu električnom energijom [12], [13], biokemiju [14], medicinu (posebice genetiku) [15], itd. Grafovske baze podataka primjenjuju se i turističkim aplikacijama [16], te za potrebe popisa stanovništva [17] i *crowdsourcing*-a [18].

S obzirom na navedeno, može se zaključiti da područje grafovskih baza podataka budi sve veći interes kod šireg broja korisnika (istraživača, programera i sl.). Cilj ovog rada je u preglednom obliku prezentirati dosadašnja istraživanja, te glavne ideje i buduće smjerove istraživanja u području grafovskih baza podataka. Inicijalnim pretraživanjem literature utvrđeno je da se istraživanja u području grafovskih baza podataka provode u više različitih smjerova (primjerice, optimizacija grafovskih baza podataka općenito, područja primjene grafovskih baza podataka, dubinska analiza grafovskih baza podataka i strojno učenje, upitni jezici i sučelja za rad s grafovskim bazama podataka, itd.), pa će u narednim poglavljima biti napravljen pregled istraživanja u tim smjerovima.

Struktura ovog rada je sljedeća: u Poglavlju 2 su nakon objašnjenja karakteristika grafovskih baza podataka prikazana istraživanja o grafovskim bazama podataka i pristupima poboljšanju njihovih performansi. U Poglavlju 3 napravljen je pregled grafovskih modelaa podataka razvijenih i korištenih u prošlosti, te suvremenih grafovskih modelaa podataka koji se danas koriste u grafovskim bazama podataka. Poglavlje 4 sadrži pregled istraživanja vezanih uz upitne jezike i sučelja za rad s grafovskim bazama podataka, dok su u Poglavlju 5 navedeni budući trendovi razvoja grafovskih baza podataka.

II. GRAFOVSKE BAZE PODATAKA

Grafovska baza podataka sastoji se od niza čvorova međusobno povezanih usmjerenih vezama. Kao što je već spomenuto, grafovske baze podataka su najprikladnije za pohranu međusobno povezanih podataka jer omogućuju i pohranu informacija o vezama između entiteta.

Osim nativnog kreiranja grafovske baze podataka, nekoliko je skupina autora predložilo pristup transformacije relacijske u grafovsku bazu podataka [19] ili kreiranja grafovske baze podataka na temelju ER (engl. Entity Relationship) dijagrama [20]. U usporedbi s relacijskim bazama podataka, grafovske baze podataka smatraju se boljim načinom prikazivanja međusobno povezanih podataka, što su pokazala i brojna istraživanja. Primjerice, u [21] autori uspoređuju različite sustave, uključujući relacijske i grafovske baze, a za potrebe izrade web aplikacija. Autori navode da je grafovski model podataka najtočniji s aspekta modeliranja stvarnosti, dok PostgreSQL ima najbolje performanse.

Jedan od najčešćih načina optimiziranja performansi grafovskih baza podataka (i baza podataka općenito) je korištenje indeksa. Postoji niz istraživanja u kojima su predloženi novi indeksi za grafovske baze podataka; u [22], autori predlažu GIRAS, dok u [23] autori predlažu indeks naziva Lindex, koji indeksira podgrafove sadržane u grafovskoj bazi. Za pohranu većeg broja čvorova i veza, u [24] autori predlažu korištenje kompresije kako bi nastala komprimirana baza bez gubitka informacija.

III. MODELI GRAFOVSKE BAZE PODATAKA

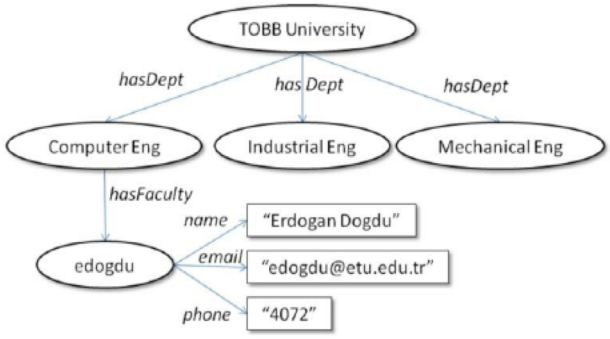
U bazi podataka podaci se pohranjuju kao odgovarajuće strukture u modelu podataka nad kojima se izvršavaju određene operacije koje taj model podataka podržava. Koncept i elementi modela podataka zajednički su svim vrstama baza podataka; svaki model podataka sadrži strukturalni, operativni i integritetni dio [25]. Kao što se za implementaciju podataka u relacijskim bazama podataka koristi relacijski model, u grafovskim bazama podataka se za to koristi grafovski model podataka. Podaci iz grafovskog modela podataka se zatim fizički mogu pohraniti nativno (u obliku grafa) ili u obliku drugih podatkovnih struktura (npr. tablica, parova ključ-vrijednost, i sl.). Iako je tijekom godina razvijeno nekoliko grafovskih modela podataka, općenito se komponente grafovskog modela podataka sastoje od sljedećih elemenata [26]:

- strukturalnu komponentu čine elementi grafa (čvorovi i veze)
- operativnu komponentu čine operatori algebre grafova za transformaciju grafova (traženje uzorka u grafu, podgrafovi, putanje, itd.)
- integritetnu komponentu čine integritetna ograničenja nad shemom ili podacima (primjerice, jedinstveni nazivi oznaka čvorova)

Prema tome, model podataka u pozadini grafovskih baza podataka se može predstavljati u obliku usmjerenog grafa koji se sastoji od čvorova (entiteti iz stvarnog svijeta) i veza (povezuju čvorove, gdje jedan predstavlja izvorišni, a drugi odredišni čvor). U usporedbi s relacijskim bazama podataka, grafovske baze podataka su fleksibilnije s obzirom na shemu (unos novih i promjena postojećih čvorova i veza ne zahtijeva promjenu postojećih čvorova i veza). Osim toga, čvorovi u grafovskom modelu podataka sadrže fizičke pokazivače na sebi susjedne čvorove s kojima povezani (svojstvo indeksa bez susjedstva), što značajno utječe na brzinu izvršavanja upita i pretraživanje baze podataka.

Detaljan pregled grafovskih modela podataka razvijenih tijekom niza godina napravili su R. Angles i C. Gutierrez [26], a u kasnijem radu Angles je napravio usporedbu suvremenih grafovskih modela podataka [27]. Neki od značajnijih grafovskih modela podataka razvijenih u prošlosti su:

- GRAM [28] model je bio prvenstveno namijenjen pretraživanju hipertekstova (hipertekst predstavlja graf u kojem su čvorovi dokumenti, a veze poveznice između dokumenata),
- GOOD [29] model je razvijen kao odgovor na pojavu objektno-orijentiranih programskih jezika poput Smalltalka radi efikasnog prikaza podataka u objektno-orijentiranim bazama podataka
- GROOVY [30] grafički model čija se osnovna struktura hipergraf koristila za prezentaciju složenih objekata i objektno-orijentiranih mehanizama



Slika 1. Primjer RDF modela podataka [56]

Danas se u grafovskim bazama podataka najčešće koriste sljedeći modeli podataka:

1. RDF (engl. Resource Description Framework) model podataka
2. grafovski model podataka sa svojstvima (engl. property graph data model)

A. RDF model podataka

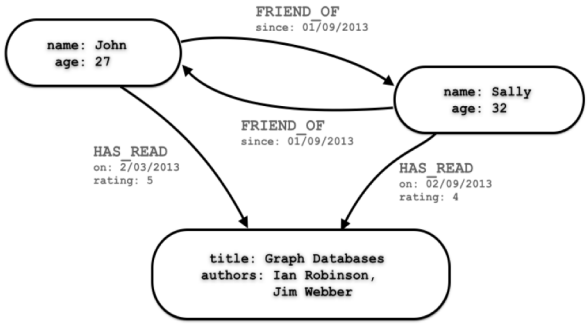
RDF je standardizirani format za prikaz podataka na Webu u obliku usmjerenog grafa s oznakama [31]. RDF tretira entitete kao resurse koji su na modelu podataka prikazani kao trojke *subjekt-predikat-objekt*, gdje subjekt označava entitet koji se opisuje, predikat označava svojstvo subjekta, a objekt vrijednost svojstva subjekta [26]. Niz međusobno povezanih RDF trojki čini RDF izraz (engl. expression), a niz RDF izraza se prikazuje kao RDF graf. Na slici 1 prikazan je jednostavan primjer RDF grafa. Prikazani graf sastoji se, primjerice, od RDF izraza koji označavaju koje odjele ima određeno sveučilište "TOBB University". U navedenom primjeru "TOBB University" predstavlja RDF trojku, dok traženi RDF izraz ima oblik "<university><hasDept><department>".

Za pretraživanje RDF modela podataka razvijen je i koristi se SPARQL upitni jezik čija je sintaksa slična sintaksi SQL-a. SPARQL upit se temelji na definiranju uzoraka za pretraživanje (engl. pattern matching) te varijabli koje se tijekom procesiranja upita zamjenjuju pronađenim podacima [26].

B. Grafovski model podataka sa svojstvima

Model podataka sa svojstvima (engl. property graph data model) prikazuje podatke u obliku čvorova i veza između čvorova. Danas je ovaj model službeni model Neo4j SUGBP-a, najpopularnijeg sustava na tržištu. Za razliku od RDF modela podataka u kojem se svojstvo čvora prikazuje kao dodatna veza i čvor u modelu, svojstva čvorova, ali i veza, se u modelu podataka sa svojstvima prikazuju izravno kao svojstva čvorova u obliku parova ključ-vrijednost (ključ predstavlja naziv svojstva, dok je vrijednost stvarna vrijednost određenog svojstva).

Ovakav način prikaza smanjuje suvišnu kompleksnost modela podataka, ali i pojednostavnjuje definiranje upita i uzoraka za pretraživanje. Za dodatnu klasifikaciju čvorova i veza moguće je definirati i jednu ili više oznaka (engl. label) čvorova i veza.



Slika 2. Primjer modela podataka sa svojstvima [55]

Na slici 2 prikazan je jednostavan primjer modela podataka sa svojstvima koji se sastoji od 3 čvora; dva čvora predstavljaju osobe sa svojstvima "name" i "age", dok jedan čvor predstavlja knjigu sa svojstvima "title" i "authors". Čvorovi su spojeni vezama s oznakama "HAS_READ" i "FRIEND_OF" koje također imaju svoja svojstva.

IV. UPITNI JEZICI ZA GRAFOVSKE BAZE PODATAKA

Prije pojave grafovskih baza podataka razvijen je niz upitnih jezika za grafove u kojima su implementirani koncepti objektno-orijentirane paradigme; G-Log [34] je koristio karakteristike deduktivnih i objektno-orijentiranih baza podataka, GraphDB [35] integrira koncepte objektno-orijentiranog modeliranja i modeliranja graf struktura, te GOQL [36] za prikaz i pretraživanje multimedijskih grafova.

S pojavom prvih grafovskih baza podataka nastavljena su istraživanja vezana uz efikasno pretraživanje grafovskih baza podataka. He i Singh su razvili GraphQL upitni jezik namijenjen pretraživanju heterogenih atributa i struktura u grafovskim bazama podataka [37]. Osnovna jedinica obrade u GraphQL upitnom jeziku je uzorak u grafu, dok graf predstavlja osnovnu jedinicu informacije.

GraQL [38] je upitni jezik za pretraživanje grafova s atributima (engl. attributed graphs) u grafovskim bazama podataka s visokim performansama u klasterima. Zbog problema particioniranja grafova, autori ističu efikasno mapiranje sustava za upravljanje grafovskim bazama podataka i klastera te efikasno izvršavanje kompleksnih upita nad graf bazom podataka kao još uvijek prisutne izazove koje je potrebno svladati.

Za pretraživanje modela podataka sa svojstvima koriste se upitni jezici Cypher i Gremlin. Gremlin je jezik za obilazak grafa i danas se rjeđe koristi jer je za definiranje upita potrebno poznavati sintaksu jezika koja je nešto kompleksnija, dok je Cypher zbog svoje jednostavne sintakse slične SQL-u popularniji među korisnicima i službeni upitni jezik za Neo4j bazu podataka. Što se tiče performansi navedenih upitnih jezika, one su slične u slučaju jednostavnijih upita, dok Gremlin ostvaruje bolje performanse u slučaju obilaska grafa u više razina [32], [33].

Osim SPARQL-a, Cyphera i Gremlina, tijekom posljednjih godina razvijen je i PGQL, upitni jezik namijenjen pretraživanju grafovskog modela sa svojstvima (engl. property graph model). Kao i Cypher, PGQL je deklarativni upitni jezik i temelji se na paradigmi pronalaženja uzoraka u grafu (engl. graph pattern matching) [39], no, u usporedbi sa Cypherom, PGQL nudi neke dodatne mogućnosti i operacije (primjerice, formulaciju upita za pretraživanje regularnih putanja).

U novije vrijeme pojavio se novi pristup pretraživanju podataka u grafovskim bazama podataka čiji je cilj olakšati pretraživanje grafovske baze podataka korisnicima koji nisu upoznati s domenom ni sintaksom upitnih jezika, a jedan od načina je formulacija upita zadavanjem primjera u tzv. egzemplarnim upitnim jezicima (engl. exemplar queries). Formalizacija navedenih upitnih jezika dana je u [40], gdje su autori prikazali fundamentalnu razliku u odnosu na klasične tzv. query-by-example (QBE) upitne jezike. QBE upitni jezici omogućuju korisniku da na sebi razumljiviji način formulira upit, koji ujedno predstavlja i primjer, te se izravno evaluira od strane mehanizma za procesiranje upita (engl. query processing engine). Suprotno tome, egzemplarni upitni jezici [40] služe za specifikaciju tipa elemenata koje korisnik očekuje u rezultatu, odnosno uzorka iz željenog skupa vrijednosti u bazi podataka, što se u algebri grafova svodi na traženje odgovarajućih izomorfnih grafova. Dosad je razvijeno nekoliko vizualnih upitnih jezika za grafovske baze podataka (primjerice, DaVinci [41], GBLENDER [42], Gremlin By Example [43], itd.) .

Kao jedan od većih nedostataka grafovskih baza podataka (i NoSQL baza podataka općenito) ističe se nepostojanje standardiziranog i jedinstvenog upitnog jezika ekvivalentnog SQL-u u relacijskim bazama podataka. Jedna od posljedica navedenog problema je otežana migracija podataka između sustava za upravljanje grafovskim bazama podataka (SUGBP) koji koriste različite upitne jezike i modele podataka [44].

Prema tome, definiranje standardnog upitnog jezika za grafovske baze podataka predstavlja značajan izazov u sadašnjim i budućim istraživanjima. Neo4j korporacija je 2016. godine pokrenula projekt nazvan "openCypher" čiji je cilj standardizacija najčešće korištenog Cypher upitnog jezika [45] na čemu će se raditi kroz sljedećih nekoliko godina. U [44], autori su prikazali formalnu specifikaciju openCypher upitnog jezika korištenjem relacijske algebre koju su proširili operatorima nad grafovima (npr. dohvaćanje čvorova, veza i putanja).

V. DISKUSIJA I SISTEMATIZACIJA ISTRAŽIVANJA

Kao što je već spomenuto, istraživanja u području grafovskih baza podataka bave se različitim problematikama, a u ovom radu su navedena istraživanja sistematizirana unutar sljedećih kategorija:

- grafovske baze podataka i optimizacija njihovih performansi
- modeli grafovskih baza podataka
- upitni jezici za grafovske baze podataka
- dubinska analiza grafovskih baza podataka
- primjena grafovskih baza podataka u strojnom učenju

Identificirana istraživanja u navedenim područjima prikazana su u Tablici 1TABLICA *I*.

TABLICA I. PREGLED ISTRAŽIVANJA U PODRUČJU GRAFOVSKIH BAZA PODATAKA

Područje istraživanja	Istraživanja
Grafovske baze podataka i optimizacija performansi	[19], [20], [21], [22], [23], [24]
Modeli grafovskih baza podataka	[26], [27], [28], [29], [30], [32], [33]
Upitni jezici za grafovske baze podataka	[32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42], [43], [44], [45]
Dubinska analiza grafovskih baza podataka	[46], [47], [48], [49]
Primjena grafovskih baza podataka u strojnom učenju	[50], [51], [52]

VI. BUDUĆI TRENDOVI

Uz već navedena istraživanja u kojima se područje primjene grafovskih baza podataka sve više proširuje i prilagođava suvremenim trendovima u razvoju tehnologije, pregledom literature identificirano je još nekoliko značajnijih trendova razvoja ove NoSQL tehnologije, poput rudarenja grafovskim bazama podataka, primjene u strojnom učenju, te implementacije grafovskih baza podataka u oblaku i distribuiranom okruženju.

Dubinska analiza grafovskih baza podataka (engl. graph mining) se odnosi na ekstrakciju novog znanja iz podataka pohranjenih u grafovskoj bazi podataka [46] i obuhvaća velik broj različitih tehnika koje se u literaturi kategoriziraju kao tehnike klasteriranja i klasifikacije grafova, te dubinske analize podgrafova [47]. Tijekom godina objavljen je niz znanstvenih radova u kojima su autori objavili nove pristupe, algoritme ili tehnike iz svake od prethodno navedenih tehnika.

U [48], autori su predstavili GRAMI okvir za otkrivanje učestalih podgrafova unutar jednog velikog grafa. X. Yan i J. Han su u svom istraživanju pristupa za pronalaženje čestih uzoraka u grafovskim bazama podataka predstavili novi algoritam gSpan [49] koji, u usporedbi sa sličnim pristupima, na efikasniji način pronalazi česte podgrafove.

U području strojnog učenja tehnike poput klasifikacije i klasteriranja grafova koriste se u detekciji objekata ili uzoraka [50], [51]. Osim toga, H. Bunke i K. Rispan su u svom radu [52] analizirali napredak u području klasifikacije grafova i primjene navedene tehnike u analizi dokumenata.

Zbog suvremenog porasta količine podataka koje nije moguće procesirati samo na jednom računalu, javlja se potreba za distribuiranim bazama podataka koje će riješiti taj problem na efikasan način. Kad se radi o distribuiranim grafovskim bazama podataka, izazov je još veći budući da je potrebno particionirati graf. B. Shao, H. Wang i Y. Li su predstavili Trinity mehanizam za distribuiranu grafovsku bazu podataka u oblaku [53] koja, zahvaljujući optimiziranom upravljanju memorijom, omogućuje efikasno dohvaćanje distribuiranih podataka.

Grafovske baze podataka mogu se primijeniti i u području poslovne inteligencije (engl. business intelligence) u kontekstu analize povezanih podataka. U [54], autori su predstavili sustav za integraciju i analizu podataka temeljenu na grafovima, odnosno vezama između čvorova u grafu. U razvijenom sustavu, integracijom podataka iz heterogenih izvora dobivaju se graf koji sadrži stvarne podatke iz izvora i graf s metapodacima koji se u sljedećim koracima mogu dodatno analizirati.

VII. ZAKLJUČAK

Grafovske baze podataka predstavljaju područje NoSQL tehnologija koja posljednjih godina budi zanimanje kod različitih vrsta korisnika. U ovom radu napravljen je pregled literature vezane uz grafovske baze podataka kako bi se identificirale dosadašnje, kao i buduće, teme istraživanja. Budući da se područje grafovskih baza podataka pokazalo prilično širokim i pronađen je velik broj istraživanja, u ovom radu analizirana su istraživanja vezana uz grafovske baze podataka općenito i njihove performanse, dostupne grafovske modele podataka, upitne jezike za rad s grafovskim bazama podataka, te buduće trendove razvoja grafovskih baza podataka.

ZAHVALA

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INVITED PAPER

Will the GDPR slow down development of Smart Cities?

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Summary - After four (4) years of preparation and debate the General Data Protection Regulation (GDPR) was approved by the EU Parliament on 14 April 2016. Enforcement date is 25 May 2018. The EU General Data Protection Regulation replaces the Data Protection Directive 95/46/EC and was designed to harmonize data privacy laws across Europe, but also to protect and empower all EU citizens data privacy and to reshape the way organizations across the region approach data privacy. This Regulation is a legal act which is mandatory and fully valid for all EU Member States. Thereby, Member States may additionally regulate certain areas of personal data protection. Apart from being more appropriate for today's era of fast speed Internet and Internet of things (IOT), the new Regulation is essentially more extensive, more accurate, and involves the questions of personal data risk. Considering the fact that personal data is being processed in the E-business and E-government, and in addition to introduction of some smart-city functions, it's possible to indirectly collect personal data. The GDPR is extremely important and it's one of the key legal documents for the further development of the digital economy and administration. As this year's MIPRO almost coincides with the date of full implementation of the Regulation, it was an additional incentive to decide on a subject of invited lecture on GDPR.

Key words: personal data, GDPR, smart city

I. INTRODUCTION

With the GDPR's entry into force a legitimate question appeared; whether a new, and substantlly stricter form of personal data protection in Europe will limit the development of Smart Cities?

Although smart city deals with a citizen as a single or a group of citizens (e.g. in traffic), and with a smart city development system, personal data usually aren't important, they are collected simply by applying technology (e.g. video surveillance).

The new General Data Protection Regulation (GDPR) [1] begins to fully apply on 25 May 2018. This is a new act that regulates the matters of personal data protection in the EU countries in a very different way. Let us remember that the first modern act relating to this area is the Convention on the Protection of Individuals regarding the automatic processing of personal data [2] of the Council of Europe (Convention 108). This is the Convention of the Council of Europe, but since all EU members are also members of the Council of Europe, the Convention has been generally applied and applies within the EU.

The European Union has reformed the area of personal data protection in 1995 when the Directive 95/46/EC of the European Parliament and of the Council of 24 October 1995 on the protection of individuals with regard to the processing of personal data and on the free movement of such data [3] came into force. This Directive, together with Convention 108, is the foundation for the adoption of national personal data protection laws, the establishment of national regulatory agencies and the existing personal data protection model, which has been developed by so far.

Since the adoption of Directive 95/46/EC has passed many years, and it has begun to show some disadvantages, and legal practice has also shown that some standards can be regulated in a better manner. That is the reason why it all started with the adoption of a new regulation, and after a couple of years the GDPR was adopted.

This paper is written as a contribution to an invidited lecture for the International Convention MIPRO – for the section of Digital Economy and Government/Local Government/Public Services, and aims to show how new and accurate researches are needed in this area.

II. GDPR KEY CHANGES

As the GDPR has been and it still is written about, we are only listing the key changes in relation to the existing regulation, as the European Union itself states on specialized sites.

The aim of the GDPR is to protect all EU citizens from privacy and data breaches in an increasingly data-driven world that is vastly different from the time in which the 1995 directive was established. The conditions for consent have been strengthened, and companies will no longer be able to use long illegible terms and conditions full of legalese, as the request for consent must be given in an intelligible and easily accessible form, with the purpose for data processing attached to that consent. Under GDPR organizations in breach of GDPR can be fined up to 4% of annual global turnover or €20 Million (whichever is greater). This is the maximum fine that can be imposed for the most serious infringements e.g.not having sufficient customer consent to process data or violating the core of Privacy by Design concepts. [4]

Data Subject Rights are: Under the GDPR, breach notification will become mandatory in all member states where a data breach is likely to "result in a risk for the rights and freedoms of individuals". Part of the expanded rights of

data subjects outlined by the GDPR is the right for data subjects to obtain from the data controller confirmation as to whether or not personal data concerning them is being processed, where, and for what purpose. Also known as Data Erasure, the right to be forgotten entitles the data subject to have the data controller erase his/her personal data, cease further dissemination of the data, and potentially have third parties halt processing of the data. Also, the Article 23 calls for controllers to hold and process only the data absolutely necessary for the completion of its duties (data minimisation), as well as limiting the access to personal data to those needing to act out the processing. Full list of new changes are assesible at cited page [4].

Preambule of GDPR has 173 paragraphs. Therefore, the GDPR has extensive and precise provisions, and for their non-compliance are foreseen vey high penalties, there is already a whole set of principles which should be respected in the process of application.

III. SMARTY CITY

A common definition of a 'smart city' has not yet been determined. Many authors use various definitions to clarify what is a 'smart city'. Authors define it as a city that bets a lot on the quality of living and where the citizens are involved as main actors in decision processes [5].

However, one can find several identical links that have all the definitions. Cities have a duty to fulfill the needs of their citizens through various systems. The types of systems are by no means exhaustive, but certainly include public services such as light management, traffic and transport organisation, waste and water management, administration policies, security, energy sustainability and information services. Regular cities operate and supervise every system as a separate unit, which in return produces more costs for taxpayers with slight to no improvements in the quality of living. On the contrary, 'smart cities' use Information and Communications Technologies (ICT) with Internet of Things (further: IoT) to create connections and interactions between some or all of the systems, cutting expenses and improving the quality of life for citizens during the process. [6]

IV. SMARTY CITY AND GDPR ARE NOT ALWAYS CONNECTED

Not all systems linked to Smart City will be directly related to basic data, especially those that are not of a high-tech nature. For example, carpooling; if we don't include applications for finding a driving partner, but only parking lots at the entrances of the cities, or next to the motorway entrances, then it won't have any relation to personal data.

It's similar to the systems which are not directly related to the people, for example data used for irrigation, or waste removal. The need for irrigation of the park is not directly dependent on the people who live there. There is a need to dispose of garbage cans (out of schedule), because the system detected an unpleasant smell, or are simply full - depends on people, but nevertheless in this example nobody collects one's personal data

However, there are activities where such division is not so simple. For example, a network of cycling trails; if not under video surveillance it has no connection with personal data, due to the fact that there is no personal data collection of natural persons who cycle on such trails. Still, if the city has a bicycle-sharing system (public bicycle system); one of the commercial models (e. g. Nexbike), or even its own, then when using city bikes; which is usually authorized and paid by credit cards; the personal data will inevitably be collected.

Let us also mention here how Smart City Models often use the IoT. And in that case, it's necessary to collect, access and dispose personal data appropriately. "Everyone acting in the IoT – no matter whether individual persons or business entities – must be able to decide for themselves what happens with the data they produce and for what purposes this may be done. The most important prerequisites for this are transparency and technical protection against misuse." [7]

V. CAN SMART CITY REPRESENT DANGER FOR PRIVACY?

Finally, we are asking the main question - will GDPR slow down the development of Smart City? The answer gives us the citation of several important parts of the Regulation.

In some cases, for example, microdemocracy (discussion and decision-making at the local level); there will be no larger scale problems - the respondents will give their own data with the consent if they like to participate in the discussions, and the controller must only precisely fulfill the tasks imposed by the GDPR. But what about systems where there are different levels of automation, and where a natural person does not report voluntarily?

According to the Art. 5. of the Regulation, personal data shall be: "adequate, relevant and limited to what is necessary in relation to the purposes for which they are processed", also "kept in a form which permits identification of data subjects for no longer than is necessary for the purposes for which the personal data are processed; personal data may be stored for longer periods insofar as the personal data will be processed solely for archiving purposes in the public interest, scientific or historical research purposes or statistical purposes".

This clearly states that the collection of personal data for the purpose of developing Smart City must be precisely defined, with appropriate legal rules, and special attention should be paid to keeping the data; by which a natural person can be identified; which shouldn't be longer than it's necessary. Certainly, data can then be kept for statistical and other purposes, such as production of a traffic model, but they should be anonymous.

The Art. 6 of the Regulation determines that personal data processing is legitimate if certain conditions are met, and it states: "processing is necessary for the performance of a task carried out in the public interest". Therefore, when collecting data of public interest, it should be evident in the documents that it's precisely the public interest.

Unlike previous regulations, the GDPR explicitly states the issue of security of personal data processing, as explicitly stated in the Art. 32 of the Regulation: "Taking into account the state of the art, the costs of implementation and the nature, scope, context and purposes of processing as well as the risk of varying likelihood and severity for the rights and freedoms of natural persons, the controller and the processor shall implement appropriate technical and

organisational measures to ensure a level of security appropriate to the risk." Here, the GDPR enters into area which has so far been regulated by information security systems, by the series of standards ISO/IEC 27000. [8]

It should take into account that, especially in smaller places, even a regular video surveillance system may pose a threat to privacy according the GDPR. Let us recall the basic definitions of personal data, the Art. 4: 'personal data' means any information relating to an identified or identifiable natural person ('data subject'); an identifiable natural person is one who can be identified, directly or indirectly, in particular by reference to an identifier such as a name, an identification number, location data, an online identifier or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person.

By this definition, the natural person can be identified by the car which drives - if the place is small enough, and even in the city of tens of thousands of people, the car would be found by the colour and the vehicle type, even when driven by the single individual - then it can be recognized even without knowing the registration plates. In certain cases, if a surveillance footage comes into possession of a malicious person, a very serious privacy breach may arise.

VI. CONCLUSION

Does the application of the GDPR affect development of Smart City models? Already, *prima facie* on the basis of the analysis we can say that it affects. Today, the protection of personal data has been raised to a very high level in the EU, and since Smart City deals with people in their urban environment and by the quality of their life - personal data collection comes to as inevitable.

Should we be afraid of the GDPR? Not at all. Although, the beginning of the GDPR application has been related to the large marketing campaigns that offer various forms of education, the truth is, however, slightly different. The GDPR is upgrade of the existing regulation, and not a brand new document, or even a bureaucratically imposed document. An organization that has protected its personal data, by so far, and which has at least informal implementation of information security standards, will find that adapting to the new framework is just a step further, continuing of the existing regulation. An organization that showed ignorance to their personal data, or the personal data is the problem, certainly, within such organization a lot of effort will be necessary to adapt the Regulation.

Similarly, those who systematically started with the development of Smart City elements would not have any greater problems with the application of GDPR. Moreover, the GDPR can help to build a quality model of a Smart City. On the other hand, those who, by developing the Smart City model consider various partial forms of automation without a systematic approach, and development strategy – might be in trouble. It's enough to badly set a video surveillance of the traffic lights monitoring system, the personal data can then be abused in a small town.

What needs to be taken into consideration - various Big Data and similar models used in Smart City development are interested in processes and tendencies (e. g. road load per hour), rather than in natural persons and their personal data.

First of all, it's necessary, wherever is possible to use the pseudonymisation mentioned in Art. 4 of the GDPR: 'pseudonymisation' means the processing of personal data in such a manner that the personal data can no longer be attributed to a specific data subject without the use of additional information, provided that such additional information is kept separately and is subject to technical and organisational measures to ensure that the personal data are not attributed to an identified or identifiable natural person.

Certainly, the best policy is to use the full anonymity, in accordance with the Art. 89 of the GDPR: "Processing for archiving purposes in the public interest, scientific or historical research purposes or statistical purposes, shall be subject to appropriate safeguards, in accordance with this Regulation, for the rights and freedoms of the data subject. (…) Where those purposes can be fulfilled by further processing which does not permit or no longer permits the identification of data subjects, those purposes shall be fulfilled in that manner. Fully anonymous data cease to be personal data, as no natural person can be identified out of them.

There are also some aspects of Smart City projects which include personal data, such as participating in discussions in various models of micro-democracy, where the consent is given by the respondents themselves. In these cases, the high quality of application of ISO/EIC 27000 standards can come as a help.

In short, the GDPR shouldn't be seen as a ''danger''for the Smart Cities, but as a series of conditions which can be helful in the development of the Smart City models. Moreover, citizens will rather accept Smart City which will not remind them of some form of "Big Brother", or totalitarian control over their personal freedoms. Thus, the GDPR can also help in developing Smart City models, because its implementation guarantees a higher level of personal data protection, thereby reducing the fear of possible abuse of the control functions of the smart city.

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PAPERS

Spatial Data and Processes Integration in Local Governance of Bosnia and Herzegovina

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Abstract **- The paper presents integration of spatial data and processes in local administration, or how to develop integral spatial information system for local government. Firstly, it is necessary to identify existing problems, then define the goals, and finally choose the appropriate solution. The obstacles that inhibit such approach are already recognizable in many municipal departments and relate to insufficient utilization of existing information system due to diverse applications, and inaccessibility of datasets located at various locations, and consequently, growing maintenance costs for the information system. The objectives to be pursued are: to integrate the functionality of the entire system, to enable the availability of spatial data to all employees, to ensure full interaction, cooperation and exchange of information between the mayor, officials and citizens, and based on this, to optimize the costs maintenance and further development of the information system. In this sense, the solution imposes centralization and integration of all spatial data and processes related to them, through a unique model and with web architecture at the level of the whole organization. Additionally, the benefits from implementation of such solution, as well as its impact on the work of the administration from economic and social benefits point have been analyzed.**

Keywords - spatial data, process, GIS, government, WebGIS

I. INTRODUCTION

Space is a resource that is subject to lots of influence and changes. The changes should be continuously monitored and influenced by appropriate measures and activities [1]. Spatial planning, as a part of such measures and activities, is a complex process based on the principles of scientific achievements in the fields of urbanism, spatial organization, geospatial analysis, environmental protection and other disciplines, as well as on the achieved standards in development and legislation [2]. The feature of a modern spatial planning is the application of geographical information systems in phases of planning, spatial analysis, decision making, plan implementation, maintenance and monitoring [3].

Today's trends linked to a wide availability of geo-information have a direct influence on the quality of all organizations work, especially the ones dealing with providing services to citizens [4]. The actual availability of digital data is a result of series of projects implemented in Bosnia and Herzegovina during the previous decade: digitalization of cadastral plans and land-registry data, harmonization of land registry and real estate cadaster, the implementation and maintenance of the integrated software for real estate cadaster database, the reference GNSS stations network, the preparation of cadaster data for census in 2013, spatial plans development for different administrative levels (entity, cantonal, municipality), aero photogrammetric and LiDAR imaging, local governments development through the Governance Accountability Project, and Growth-Oriented Local Development Project, the activities related to development of the spatial data infrastructure according to EU INSPIRE Directive etc.

The results of those projects are databases of geospatial data and information useful for work and everyday use to local governance services and citizens as final users [5]. These data include: high resolution photogrammetric images, cadaster data, urbanistic data, municipality areas, building addresses, 3D data, utility infrastructure, and all types of business data related to the work of municipality services. Different procedures, standards and instructions are also result of the projects. On other side, as shown on Fig.1, there are high demands for access to available information by all civil servants [6], data centralization [7], better interaction between the civil servants (in the sense of information, messages and tasks exchange) [8], and introduction of a uniform methodology and geo-information technology in all departments [9].

In order to use the available geo-information and to meet the operative needs of local government, the business processes support through the establishment of centralized spatial-information system is necessary [10]. Such system can enable a faster and more transparent

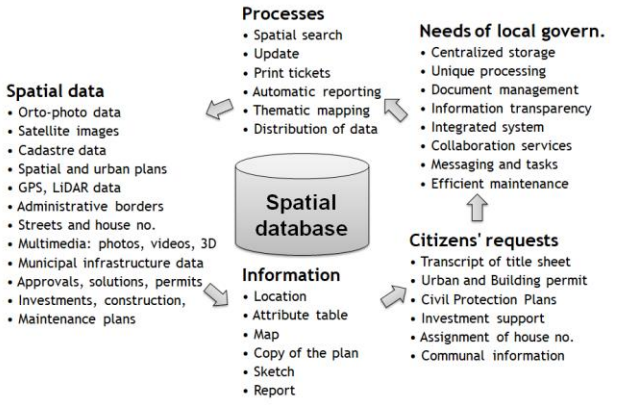

Figure 1. Citizens demands, and government needs impose integration of spatial data and processes into a centralized information system

construction requests management and simplified communication with the investors and offer citizens interactive access to services, information, and decisions.

According to the performed analysis of the local government information systems current condition, the need for the upgrade of the existing information systems with WebGIS component has arisen, which will enable a visual overview of all relevant information. This component represents an on-line interactive map and its implementation represents the improvement of the existing information infrastructure [11]. Implementation should be viewed through the following aspects: GIS platform improvement (client, database server, application server) [12], The inventory of the available data [13], The recognition of external data sources and access mode solving (by web services) [14], The analysis and improvement of uniform spatial information system data model [15], The implementation of web systems for spatial data presentation [16], and Staff education [17].

II. Current Situation Review and Local Governments Needs Assessment

Through the current situation analysis and assessment users' needs in local governments, it has been concluded that the solution needs to provide:

- comprehensive system functionality integration,
- availability of spatial data to all civil servants,
- complete interaction, cooperation and the exchange of information between the civil servants (from the mayor, deputy mayor, to the clerk and the citizen) when issuing the urbanistic-building documentation (consent, permit and formal decisions),
- optimal information system maintenance and further development costs.

This implementation includes the services of delivery and installation of technologies, application development and integration, digital data preparation and migration, and all other related consultant services. System implementation includes the following activities:

- functional and non-functional system specification,
- system configuration (system architecture, software architecture, data model),
- software installation and adjustment including database management system (integration, centralization and presentation of all data),
- implementation (spatial information system on web development for the location permit requests processing, and various permits issuance
- spatial data set delivery for a government area,
- Extract-Transform-Load data and metadata entry,
- users and system administrators training, and
- system maintenance and technical support.

III. Motivation and Goal for the Establishment of the Integrated Information System

The establishment of GIS in a web environment with the task of the integration of all existing subsystems enables the approach to the existing data and information and according to the defined access rights. Web GIS solution is used for the access to databases (internal or via web service) and enables reading reports from different subsystems. Its first role is integration of existing sub systems, then better quality of data and presentation, and finally the ability for a wide spectrum of users to access the information in an efficient and simple way. The software for the support of decision making processes in local governments should consist of web portal and more specialized applications. It should be flexible and easy to use tool for the automatization processes for permits preparing and various urban plan documents issuing.

A focus should be on governing processes related to decision making and different approvals and permits issuing, and the insight to urban and spatial plans, i.e. on GIS functionality unification with administrative procedures and modern spatial concepts. The aim is to provide a simpler and better insight with the integration of all services within a local government, to make the procedure of processing spatial planning documentation and other requests by the citizens faster and more automated. The solution is centralization and integration of data and processes through web orientated spatial information system for whole municipality, as on Fig. 2.

IV. Methods and Data for the Establishment of an Integrated Information System

For the establishment of an integrated information system at local government level it is necessary to recognize the needed data (centralization, integration and presentation of spatial data) and methods (approach with web portal for the interaction between a local government and the citizens) for the establishment of the system [18].

A. Centralization, Integration and Presentation of Spatial Data

Working with local governments, the authors of this paper noticed that most requests for data by the local administration are related to data that are already available to these local governments, but they have not been prepared for use adequately or the users are not aware of their availability. The solution is to make catalog of all data and to create one access point for the data.

Figure 2. City of Mostar Geoportal

The centralization of all existing urban and spatial planning documents means collection, structuring and placement of the existing planning digital documentation in the central server, i.e. integrated database, in order to enable the access for all users within a municipality/city administration [19]. Fig 3. shows example of integration and centralization of the existing spatial data which includes, at minimum, the following data sets:

- Orto-Photo from different epochs
- Cadaster data
- Regulatory plans
- Urban plans for particular urban areas
- Spatial plan
- Statistical and demographic information
- Spatial units and address data and
- Communal infrastructure / utility data

B. *Web Portal for the Interaction Between the Local Administration and Citizens*

Geoportal technology should be used for the interaction between the local administration and citizens. Geoportal enables the presentation of spatial data through an interactive map, with a simple choice of thematic layers to display and optimized intuitive search across all attribute data. Main characteristics of the systems are [20]:

- all data to be in one place – always available, regardless of time and location of use
- advanced technology applying
- system scalability and safety
- to be the tool for the support in decision making and communication with the public
- transparent presentation of all data on the Internet
- faster browsing and analysis of spatial information
- shorter decision-making period
- easier monitoring and analysis of spatial changes
- simplified data exchange between the organizations
- independence of the platform (Windows, Linux, Mac, iOS, Symbian, Android)

Such systems will enable the data presentation about the locations of important business-administrative institutions and organizations, business and public infrastructure (logistics, transport, traffic, communications, and finance), public safety and civil defense, cadasters (real estate, utilities, green areas), communal infrastructure, spatial planning documentation etc. Therefore, they should have the functionality adjusted for collaborative environment (the cooperation between more internal/external sectors and organizations), multiple access to web services, complete interoperability (simple

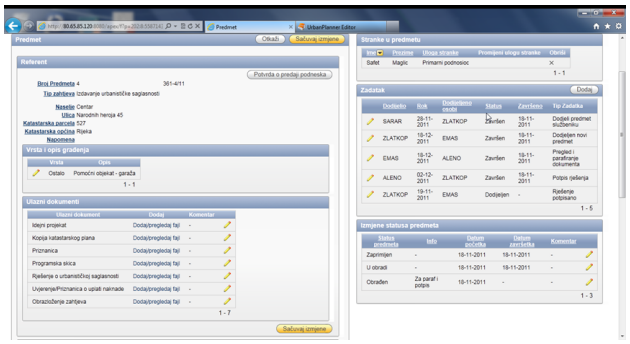

Figure 3. All documentation, tasks and statuses in one place

data update from most GIS/CAD or office tools) and multilanguage interface.

V. System Modelling and Use Case Example

Geographical information system (GIS) must be integrated into web system. The presentation is a very important component of user's interface, because user should be able to search, set queries and work with maps and other information (spatial and non-spatial). The presentation component must provide the representation of spatial information, map rendering, editing, queries definition and spatial analysis including [19]:

- The representation of spatial information (raster images and vector data from one or more sources in the form of maps, text, tables, graphs, diagrams and other).
- Map rendering (zooming and map content moving, title and text editing, presentation style management, current scale display, display of the current view on scaled map, distance measuring, info pointer for display the attributive information of interest).
- Editing (managing, update or adding spatial information on data server).
- Query definition and data selection (spatial queries setting including the selection of features and queries with the related attributes as well as providing of data browsing/filtering tools by spatial and/or non-spatial requests which automatically narrows down a set of possible solutions in graphic and alphanumeric presentations) narrowing the set of possible results in graphical and alphanumerical presentation) similar as on Fig. 4..

An Use Case in this paper is implementation of spatial planning documents issuing process, based on projects results in local governments of Bosnia and Herzegovina. System for document and spatial data management, with collaboration in an integrated information system should be a web application and its aim is to fasten and facilitate a usually complex and long-term process of issuing different spatial-planning documents, such as the location approval, building permit, usage permit etc. Such web application supports logical working flow from request receipt, status changes monitoring to permit issuing or request denial, and the advantages of its use are:

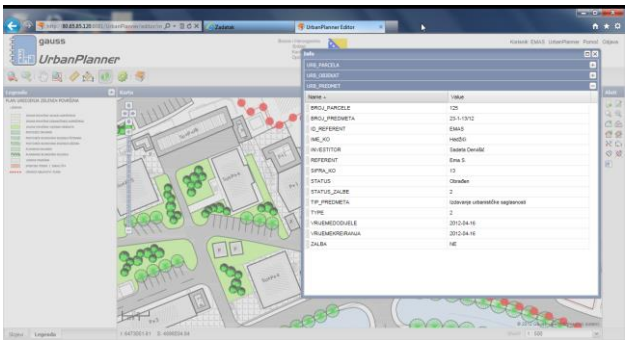

Figure 4. Access to data about lots and subjects

- Automated recording of attached document;
- Monitoring of administration occupancy and efficiency level;
- Simplified files management and collaboration;
- Statistical reporting, such as the work efficiency, file status, file processing duration;
- Workflow monitoring with actions and important dates related to that subject;
- Communication enabled through the system of messages and notifications related to tasks;
- The recording during file processing, and trough the changes in file status;
- Data validation;
- File archiving.

The advantages of such system including better services to the citizens are:

- efficiency improvement on permit issuing;
- easier use of the urbanistic documentation,
- requests and files monitoring in real time,
- efficient and prompt database maintenance,
- better informative decision making and
- fast access to all data within the system.

VI. Analysis and Discussion

E-governance uses the internet and GIS for the development of more efficient governance, because the maps can be viewed on the internet, and local governments raise their services level for business and public on a completely new level. Such cooperation between administrative organizations using GIS abilities to integrate data from various existing systems enables a maximum usability of the available data sets. Local governance web site can provide different services with GIS component, such as online mapping, paying fees or submitting requests, in a way that was not possible before. Fig. 5. presents such a web site.

Through the analysis of available and necessary data sets that are mostly used for everyday administrative tasks conduction, it was recognized that such information system consists of data about:

1. updated digital geodesic-topographic maps georeferenced in official coordinating system,
2. entity spatial plans and other planning documents,
3. municipal spatial plans,
4. natural resources with quantitative and qualitative characteristics etc.,
5. population,
6. infrastructure systems,
7. building and natural heritage and particularly protected areas,
8. environmental hazards (illegal building, soil, water and air pollution),
9. special risk areas (seismic terrain characteristics, land stability disorders, flood areas, areas endangered with the possibility of fire, areas exposed to possible influence of technical catastrophes and high pollution due to damages in production facilities)
10. personnel and legal entities dealing with spatial planning,
11. economy,
12. public services,
13. tourism,
14. communal services,
15. land use conditions and
16. other data important for integrated information system planning and maintenance.

A. *Financial Costs of GIS Installation for Local Governments*

During the process of decision making about the installation of GIS in local governments, the analysis of profitability must be always done. There are significant costs in the first phase of installation. Most of these costs are on once-only basis, but a part of the budget should be planned for maintenance running costs. ICT infrastructure presents the GIS framework, regardless of decision to purchase the equipment and on-premise installation or for rented cloud solution. Software means GIS application which includes database and data browser. Since data are the essence of each GIS, therefore the belonging costs may be significant. Development of initial database, which includes collection of different spatial, thematic or alphanumeric data, should be considered once-only cost. Regular maintenance of the database and collection of new data, depending of analytical demands, create running costs that are different for each year. Personnel costs include the tasks of management, database and information system development, but also trainings although they are outsourced – in cooperation with a partner. However, those expenses should be counted as personnel costs. There are also other costs, like space restructuring for once-only, and material consumption for running costs. Cost review is suggested in Table 1.

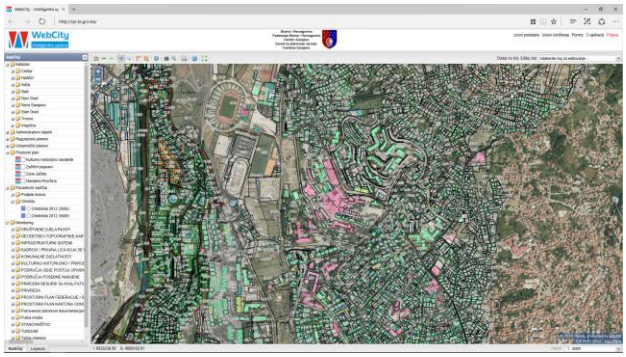

Figure 5. Sarajevo Canton portal, which enables access to spatial documentation for all municipalities

B. Benefits for Local Government

Benefits for a local government with the installation of such system are not only financial. According to the need, GIS system maturity phases must be in accordance to the e-management standard including:

- Full digital data availability, all data processing operations are conducted in digital form, and data move through different working platforms;
- E-publishing of all appropriate information on a webpage, in an organized and easily available way, appropriate for other government organizations, companies and citizens;
- E-interaction, all relevant interactions are conducted electronically via internet/intranet between the government organizations, and between the government and a company, i.e. government and citizens.

The first issue in the initiation of a new project is what will be achieved, i.e. what refund will be achieved with this project. The direct benefits or the refund should be connected to the decision on project initiation. In principle the benefits that can be considered: economic, social and direct benefits in governance work.

Economic benefit can be achieved through:

- Increased income, through the improvement of the existing systems: incomes from public utility fees, utility rate, location surcharge, Water Company, taxi vehicles licenses, bus licenses etc.
- Better financial management, project and investment management, property management.
- Improved resources management and planning, resources information system, lots and real estate management, state property management system, planning and building management system.
- Possibility for statistics and analysis of business environment and new technologies application.

Obvious social benefits include the improved services for the citizens, the transparency of the changes in space, including the building requests monitoring, information about public works, public security improvement through spatial monitoring of criminal offences occurrence, and the environment protection.

GIS is a tool which not only improves the government but also transforms it [20]. The benefits for the governance process are the improvement of effectiveness and the effectiveness of basic administrative processes of the government through systems such as: information control about the activities on the highest government level, public communications and internal communication system management, decision making and information and accumulated knowledge management.

C. Result Analysis

The authors of this paper have participated in the implementation of GIS system in about 100 local governments. Lots of them are still at the level of using GIS as desktop tool, and they have not been included in system analysis itself. In the last 5 years, about 10 local governments have decided to improve their work by transferring to integral WebGIS system on the level of the whole government. As it was said before, the benefits for the government and citizens are mostly of non-material nature and cannot be easily measured with money value, and they are mostly reduced to pure subjective recognition of the advantages of access to information.

However, the thing that the authors of this research have noticed, is a great increase in system usage itself. Considering 5 local governments generally similar in population (100,000 to 150,000), area (500 to 1,000 km^2), number of personnel (200 to 400), and annual budget (EUR 15 to EUR 25 million) there are conclusions.

Using GIS as desktop tools:

- Total number of system users was 10 to 30,
- There were no public users,
- Average number of GIS data access was daily (10 times) and monthly (200 times), with average session duration about 1 hour.

After moving to integral WebGIS:

- Total number of GIS system users was 50 to 100,
- There were 10 to 100 public users per day,
- Average number of GIS data accesses was daily (200 times) and monthly (5000 times).

TABLE I. COST REVIEW

Type	Once-only payment	Running costs
Infrastructure	hardware software data protection internet intranet	system maintenance data protection internet intranet
Data	Data usage (basic spatial data, theme spatial data)	updating new data collection
Personnel	project management geodatabase development IT experts training	system administration GIS personnel regular training
Future costs	material space restructuring	

Before the installation of data centralization web system, only few departments had the ability to access the system (property rights, physical planning), by the users who were trained for a particular GIS software, having a license and the privilege to data access. After the installation of WebGIS system, practically everyone has the data access with certain limits, and that is why the number of accesses drastically increases, but also the duration of the session has decreased, in average, because most users access the data for a fast check of an information.

VII. CONCLUSION

Since the land management is a very important activity for local governments, so the spatial data for appropriate management are an immeasurably important resource that should be appropriately developed and maintained, from the aspect of spatial data (land cadaster, underground installations cadaster etc.), transactional spatial data (call center live data, construction sites, inspectorate activities etc.), and metadata (information on data, such as the source, usage rights etc.).

In relation to that, it is important to outline the approach of system development for the whole organization, i.e. the implementation of standards such as central database, service-oriented architecture and web/mobile platform for public data sharing. Spatial data exchange monitoring includes the installation of an integrated information system in spatial planning, land use and environmental protection, which enables:

- interactive data exchange, more efficient database analysis and browsing, a supervision over the processes and occurrences in space for the purpose of appropriate decision making,
- productivity and efficiency increase in the process of spatial planning with coordination and communication between user's costs decrease,
- the improvement of planning process and physical planning general quality, and the quality of some decisions,
- the increase of the ability to analyze, and to monitor the influence in the whole area by using actual information about economy, energetics, traffic and other branches.

The benefits during the implementation of such solution have been described. The influence of its implementation has been partially assessed from the aspect of economic, social and direct benefits in the administrative work.

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Application of Social Network Analysis to Port Community Systems

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***Abstract* – Social Network Analysis is a unique and innovative concept in the global business management market that allows prediction of behaviour of various involved nodes (typically clients or customers) in a structured dependent network using commonly provided services. This methodology can be used by telecommunication providers to offer new targeted products before competition, prevent customer migration to the competition and rapid response to disruptive technological and economic changes in the market. There are a number of solutions supporting telecommunication providers in provision of SNA-based solutions and campaigns and the methodology can be adapted also for banking and finance industry. SNA offers handling of large calculations with adjustable parameters, adaptability of calculations according to business requirements and application to diverse IT infrastructures. In this paper the authors will present the main architecture of a viable SNA system and propose a novel application to the area of port operations with integration into existing Port Community Systems.**

Keywords: Social Network Analysis; Port Community Systems; ports; Big Data

I. INTRODUCTION

Social network analysis (SNA) is not a formal theory, but in fact a strategy used to investigate various social structures [1]. While the roots of SNA are derived from sociology, this method has found a widespread use in other practical applications, and especially in data aggregation and data mining, modelling of networks, user and client behaviour and churn calculations and various other business intelligence needs. SNA can be used in a variety of use-cases where appropriate dataset is available, so, for example, it is also used in counter-terrorism operations, especially in calculation of centrality measurement as an investigative tool [2].

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"Croatian Agency for SMEs, Innovations and Investments" (HAMAG-BICRO) was founded with the aim of supporting the development of small and medium-sized enterprises, improving the innovation process and encouraging investments [3].

Government of the Republic of Croatia is using a loan of the International Bank for Reconstruction and Development for execution of the *Second Croatia Science & Technology Project* – STPII that was started at July 31st 2013 and will be in effect until March 31st 2019. After 2015/2016 the tenders are closed and projects are in execution phase. Main goal of the STPII project is to enhance absorption of EU funds in the area of research and development by strengthening capacities of users and institutions [4].

HAMAG-BICRO is (as a loan beneficiary) in charge of executing five various programs of support to public and private users in various phases of the innovation process:

1. PoC (Proof of Concept),
2. RAZUM (Development of knowledge-based enterprises),
3. TEHCRO (Development of technology infrastructure),
4. IRCRO (Cooperative research and development), and
5. UTT (Support to Offices for technology transfer).

Within the framework of IRCRO program, in May 2015 project documentation has been submitted to HAMAG-BICRO according to program propositions, by Neos Ltd. from Zagreb, Croatia, titled "Neos SNA for Telco – an innovative system for anticipation of mobile telephony users" [5]. Project partner was the

Faculty of Electrical Engineering and Computing from University of Zagreb. Anticipated duration of the project was 18 months and final deliverable is a complete solution for SNA analysis of mobile telephony users, applicable also in other similar scenarios.

The project started in January 2016 and it was successfully completed within budget, time and quality by the end of June 2017. Project manager on behalf of Neos, Ltd. was Mr. Dražen Marković, project manager of the Faculty team was Ms. Bojana Dalbelo Bašić, PhD, while technical business project consultant acting on behalf of HAMAG-BICRO was Mr. Saša Aksentijević, PhD.

During the evaluation of the end result of the project, it became clear that developed software package can also be used for other purposes where structured data is available. Considering author's interest in Port Community Systems (PCS), one possible path of further development of SNA methodology will be proposed in this paper after project results are presented.

II. SOCIAL NETWORK ANALYSIS METHODOLOGY

Traditional analysis of users' behaviour is increasingly difficult to execute because of the following reasons:

1. Analysed sample is too small,
2. Number of set parameters is very limited,
3. Users are grouped very coarsely and the same rules are applied to all users in a group.

This approach to analysis and churn prevention (maintenance of the existing user base) requires consolidation of data in data-warehouse systems of mobile telephony operators, additional data aggregation that is usually done manually, this data is then exported to Excel format used by marketing and additional application of contextual analysis.

In this scenario the analysed data is prepared manually, which takes a lot of time and work of IT specialists, so it is generally not possible to satisfy on-demand requests. Consequentially, marketing and sales departments depend on others to do their job. Considering the volume of data, only small subset is analysed and this subset does not have to be representative for the whole set. Finally, this type of analysis relies on properties of a single subscriber (service user) and its attributes, like age, sex, address, used services, consumption average etc. However, in reality, all these attributes are less important than context and user's relation to other users (subscribers), because in social context, behaviour of a single user depends on his/her relation to other users.

When SNA methodology is used, the system automatically uses consolidated data contained in data-warehouse systems. Only necessary and strictly required data set is automatically loaded to SNA engine (consolidated data, data from transaction systems like CRM and billing and CDR – Call Data Record) data that is generated directly in mobile exchange and contains all relevant data for various communications. SNA enables employees of the marketing and sales departments to run generation of SNA network model and various use-case analysis, with custom parameter adjustment.

Taking into consideration authors' extensive experience with development of comparable systems using traditional approach, direct advantages of SNA methodology over traditional approaches are the following:

1. Input data is prepared automatically, and does not involve operator work,
2. Analysis is run independently from IT departments, there is no need to rely on availability of the other department and analysis can be run whenever it is required, and as often as necessary,
3. Data manipulation is executed using modern Web application, where operator access can be determined according to internal information security rules and practices,
4. Analysis is controlled via parameters, and there is no manual adjustment and long batch processing,
5. Entire available data set is used, not only a small, often unreliable sample,
6. Results are independent from the knowledge and skill of operators,
7. Finally, and most importantly, SNA methodology does not analyse only one subscriber, but also all of his/her connections, hence the name of the methodology.

III. NEOS SNA FOR TELCO PROJECT BASICS

Innovation of the SNA for Telco project is in integration of SNA methodology, applied mathematical theories and big data technology that enable quick and efficient data processing and calculations of required analysis for exact business activities and timely decision making.

Therefore, this product not only enables new analytical-predictive possibilities, but also a number of other advantages over classical approach like work automation, lack of IT department involvement in processes of the marketing and sales, more comfort in

work and additional features for all stakeholders. Finally, usage of SNA methodology can enable decision makers to keep their customers, enhance product packages and attract new customers. The following Figure shows the visualisation of SNA model with a small number of objects.

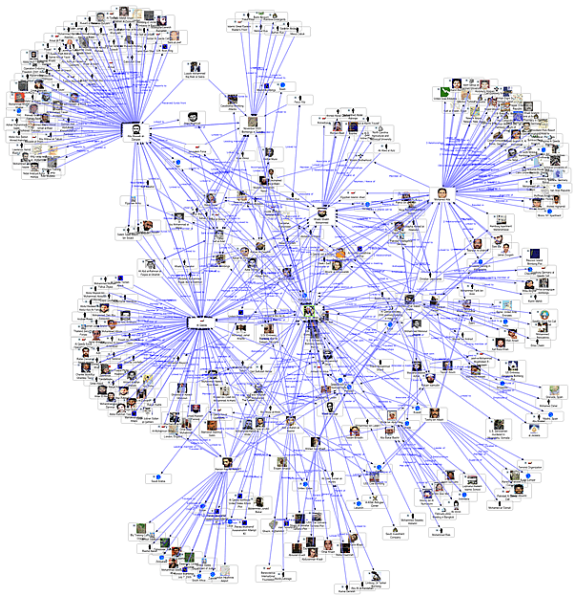

Figure 1. SNA network

SNA for Telco has several advantages over existing products. It can be installed in-house, using infrastructure of the operators, instead of moving data across borders, that can cause problems related to privacy and data management, even if the data is anonymized. Also, this product is highly customizable with adjustable parameters. All calculations can be adjusted to real work case scenarios of operators, they can be localized, new modules can be added and it can be installed across various infrastructure. General schematic depiction of the system is shown in Figure 2. System is fed with general existing data (CDR files, data from CRM and billing systems), SNA model is prepared and analysis and export is prepared according to various campaign scenarios.

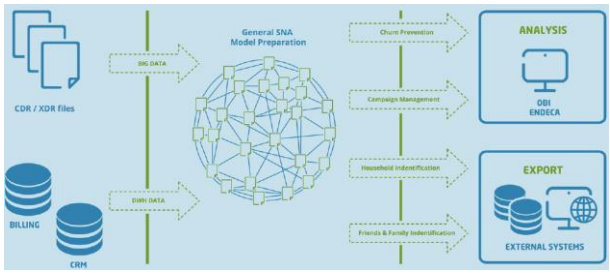

Figure 2. SNA system component blueprint

Technological components of the system are based on various Oracle technologies where each technology is used for particular function. Layout of the underlying technology is presented in Figure 3.

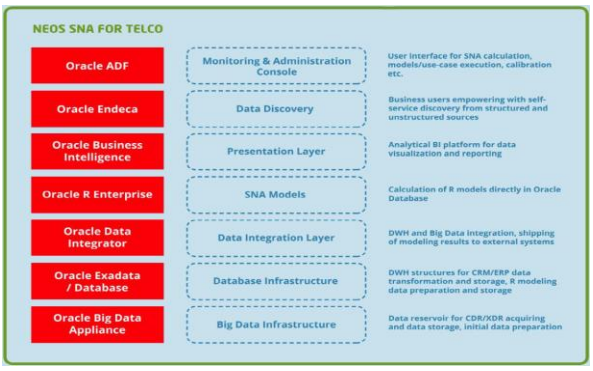

Figure 3. SNA system technological components

Development project itself consisted of several stages.

1. Stage 1 – *Preparation of the project plan*. In this phase, project application was prepared, detailed task and assignment roster was created, partner contracts were prepared, financing application was drafted and project plan was agreed between all stakeholders.

2. Stage 2 – *Preparation of algorithms to set up SNA network and individual analytical algorithms.* In this stage, various algorithms that create general SNA network were created. They were prepared for various Use-Cases:

- Churn Prevention
  - Probability calculation & Detection of churn-prone customers
  - Leaders / Influencers identification
  - Churn Prevention Lift Analysis
- Campaign Management (SNA based)
  - Early Adopters detection
  - Spinners identification
  - Retention campaigns
  - Viral Marketing & Acquisition Campaigns
  - Value segmentation (Low ARPU subscribers with high RPU connections)
- Household Identification – Family Identification
  - Customer segmentation
  - Location / Time of call Detection

3. Stage 3 – *Development of the prototype.* In this stage, a platform for development of the complex solution was set up. Architectural components of the solution and possibilities of their interconnection were defined. Finally, development system was set up. Some parts of the system were functioning in a virtual environment (Big Data Cloudera servers, Oracle database with Oracle Advanced Analytics), and application server for GUI. This prototype was also defined and

documented according to best practices and set up for further development activities.

4. Stage 4 – *Check of the quality and the functioning of the algorithms*. In this phase, prototypes were integrated with the database, and connected with parameter entry tables. Error checking was also completed. Various calculations were checked (depending on the parameter set) against the expected results based on algorithms. End results was that the best parameter sets were selected for SNA network and various Use-Case calculations (parameters giving the best results are detected).

5. Stage 5 – *Set up of the test infrastructure similar to production environment*. In this stage, three main groups of activities were performed. Firstly, integration services were developed, with end result being the defined infrastructure base and all solution components similar to quantity and capacity of data processing to the production environment. Module set for data input, transfer and transformation to a form suitable for calculations and export was also completed. Secondly, GUI (Graphical User Interface) for visualization and data management was developed. This module is used to integrate parameter setting, data input and export, log analysis and user and rights management into a single console.

6. Stage 6 – *Generation of large data sets similar to production data.* As a part of this activity, program modules that are not a part of the solution (external utilities) were developed and used to generate CDR files, but also other data necessary for solution testing. These utilities have to closely emulate logical data sets used by the mobile operators.

7. Stage 7 – *Testing of large data set processing and system adjustment.* In the final project phase, model parameters for SNA network and various Use-Case analysis were tested and optimized, depending on the processing speed, amount of processed data and expected results. Also, load, stress, integration and analytic tests were performed.

IV. NEOS SNA FOR TELCO PROJECT RESULTS

During the project preparation, several project risks were identified. During the project execution they were successfully managed.

The first possible group of identified risks were technological risks. SNA uses a number of connected platforms, used as infrastructural solutions. This risk was managed by the selection of best-of-breed platform and its modules. Algorithms were prepared based on mathematical theories, which require high level of quantitative knowledge. This particular risk was mitigated by the inclusion of the research team that possessed significant experience in the above mentioned field, especially in the field of mathematical theories.

The second groups of identified risks were market risks. Namely, it was possible that operators are not adequately interested in advanced analytical solutions. Before the project, the level of innovation and market interest was tested. The level of innovation was acknowledged by winning the "Oracle Innovation Award for Big Data & Analytics" on the level of Eastern Central Europe [6]. Furthermore, some initial contacts with several mobile telephony operators, who expressed their interest in the above mentioned solution, were made.

All anticipated risks were successfully managed during the project and did not have a negative impact on the final results.

A set of standard project software documentation was created during the project execution that comprised of the following components:

1. SNA System Technical Architecture,
2. SNA System Algorithms,
3. SNA System Description,
4. SNA System UI Description, and
5. SNA - Final Presentation.

Oracle BDA is cluster of servers as a standard configuration, and is used in identical manner as in a prototype environment.

Oracle Database is clustered with common storage infrastructure. Real Application Clusters option (RAC) is used for smart cluster environment infrastructure. Specific options can be used if needed.

Clustered application server environment is recommended for load balancing, high-availability application environment. Apache Tomcat or Oracle Glassfish servers are clustered with common http server in front.

Oracle Linux 6 is used as an operating system for all mentioned servers.

Recommendation for production infrastructure was to use Oracle BDA, as it was used in the product prototype. But to ensure scalability and robustness of the production environment, it was advisable to use clustering environment. This clustering environment is shown in detail in the following Figure 4.

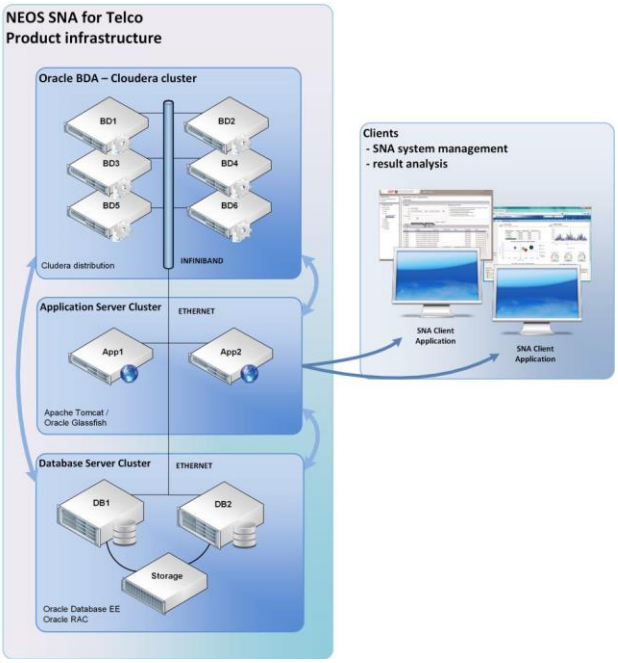

Figure 4. NEOS SNA for Telco Product Infrastructure [7]

In the final product, CDR generator was created as a module of the SNA application. Its generation was based on templates, meaning that it is parameterized and users are able to customize output. Files are stored on the Glass Server and they can be automatically transferred to the BDA Landing Area.

SNA visualization is a tool of the overall SNA application framework that provides insight into Node Ego Network. It combines communication data with SNA metric results available in the table to the system operator. SNA visualization can be altered to show adjustable levels of display (1-3).

Calculation repository contains a set of database objects (tables, views, sequences and triggers). It was designed to facilitate calculations and provide connections between input data, input parameters and results. RStudio Server was used as integrated development environment (IDE) for R development. Access is achieved through web browser and its implementation achieved movement of the computation closer to the data. R code is executed directly from the source editor.

A significant effort was undertaken in order to ensure big data security, which is of utmost importance to mobile operators, and especially with the emergence of the new GDPR regulation [8]. HDFS security was used in order to ensure security on the folder level, while Sentry was used for the Hive security. Various layers of big data security are shown in Figure 5 [9].

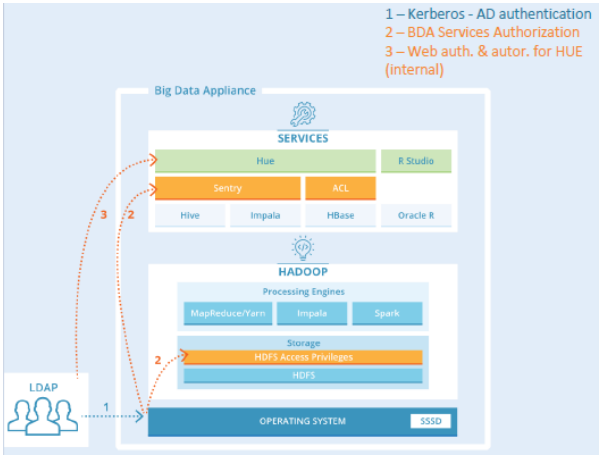

Figure 5. Neos SNA big data security [9]

Cluster was fully integrated with LDAP, so it does not use any local users, thus further increasing the simplicity of the security management. Kerberos authentication is used along with HUE SSO integration that is also LDAP integrated.

V. PREREQUISITES FOR SNA INTRODUCTION IN PCS

While being actively involved in development of described SNA project for mobile telephony operators, the authors came to realization that similar SNA engine might be modified to be deployed in Port Community Systems, for two separate proposed purposes:

1. *The Port authority* could utilize SNA to analyse connections between various other stakeholders involved in cargo attraction to a certain port. There is a recent paper dealing with similar topic, but it used SNA approach to analyse research trends related to ports. This paper is in fact a cross-sectional longitudinal study of various other researches in period between 1985 and 2015. A number of studies and contained keywords were analysed with main goal being to obtain degree centrality and betweenness centrality that would point to identification of research trends related to port competition [10]. This is in fact a form of meta-research.

2. *Customs authorities and ministry of interior (Maritime Border Police)* could use SNA to analyse connections between various stakeholders using documents and data available to Customs and Police during cargo processing. One prerequisite for full-scale implementation of such system is the deployment of e-Manifest information system [11]. Considering that in early 2016 the European Maritime Safety Agency, together with some other agencies and bodies has launched the e-Manifest pilot project,

preliminary data availability should not be a significant issue.

In both cases, it is important to understand that overemphasis on nodes tends to disregard "space" between the nodes, and in this case, ports. By analysing only ports and cargo being trafficked between ports, underlying connections are being largely disregarded. However, ports in a network cannot be separated from the very fabric that creates such networks like a mesh of other players in the logistics chain: railway and truck terminals or even airports. So, utilization of SNA analysis imposed over the port community should be carefully constructed in order not to give too big of an emphasis to certain nodes, and completely disregard how those nodes "came to being".

VI. PROPOSAL OF APPLICATION OF SNA TO PCS

In case of mobile telephony operators, they are usually data owners so it is reasonably simple to gain access to data and create SNA models. However, in the case of PCS, the situation is much more diverse and more complicated. While the PCS might contain all necessary data that could be entered into the SNA model, the PCS itself is formed around commercial management of the cargo and administrative ship management during its arrival, stay and departure from the port. Therefore, PCS will inevitably have to be at a significant level of development in order to aggregate all data from commercial operators in the port and their Terminal Operating Systems (TOS).

The authors are proposing the following path for adoption of SNA in PCS:

1. Definition and research of exact technologies required to develop the project. While the technologies are already tested and proven during the development of SNA for mobile operators, the level of complexity of cargo logistics might require alterations of the existing technological setup.

2. Development of SNA for PCS prototype, including infrastructure (equipment, operation systems, Big Data layer, additional modules), development tools and background services, calculation, user interface modules etc.

3. Creation of development infrastructure similar to production infrastructure.

4. Setting up modules that will be used to generate input data (similar to CDR generators) for PCS. Considering that PCS are systems based around exchange of messages between various stakeholders, and that XML schemes should be readily available, it should not pose a problem to reverse engineer the message creation and create a workable set of production data.

5. Development of configuration and parameter repository used for calculations, validations and storage of system-specific statistical data.

6. Programming the module used to import data into the system (Big Data layer)

7. Creation of background-ran modules with various calculations that process data in the Big Data system (for example, Hive), while parameters for calculations and validations are stored in a separate repository in a relational database that is also used for storage of static data related to every individual calculation and validation process.

8. Envisaging and creating a module used for graphical visualization of the calculation (applicable to SNA network and connections, and calculated metrics).

Entire process is finalized by creation of the module for end result export. This phase can be especially important for a large or complex PCS with large traffic volumes, because data export is typically more important for them than data visualization, which is typically used as just an auxiliary tool.

VII. CONCLUSION

After 1950s, research of networks became a separate topic of interest in sociology, but also in financial theory and in practice – banking. In the last decades with the rise of social networks, it became a topic of interest in the field of technology and communications. One such project was developed in a period between 2015 and 2017 in Croatia, and was funded by Croatian Agency for SMEs, Innovations and Investments. It was developed in 18 months by the company Neos Ltd. from Zagreb, Croatia and the Faculty of Electrical Engineering and Computing from the University of Zagreb, Croatia.

This particular SNA application is adjusted for use by mobile telephony operators who can create custom analysis of the networks comprised of their users and subscribers, calculate the network, identify relative importance of network members and their impact to other members. It can also be easily adjusted for usage by banks and financial institutions in order to evaluate networks created by their customers, but also to evaluate how risky are some customers spending habits and other financial habits. SNA application was based mostly on Oracle and some other enterprise-level open source technologies.

Considering that maritime cargo logistics is also effectively a network created by the main stakeholders,

the authors propose the implementation of SNA also in conjunction with the PCS information systems. Main steps to be undertaken to adjust SNA methodology for usage in PCS are identified, along with two most viable purposes: risk assessment of customs office and police, and connection between remote and domicile ports, which can be used to evaluate the possibilities of additional cargo attraction, thus increasing the competitiveness of seaports and the whole trade route.

Further research of this topic, at least in Republic of Croatia, relies on impeding implementation of national PCS that will commence mid-2018., and introduction of NSW (National Single Window) for maritime traffic.

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GDPR and the Reuse of Personal Data in Scientific Research

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ABSTRACT - Impact of EU data protection reform on reuse (secondary use) of personal data in scientific research has been largely ignored by the scientific community when compared to other effects and consequences of new legislative framework on various business and governmental activities and general use of personal data in social processes. The new legislative framework contains distinct new mechanisms and provisions concerning reuse of personal data for research purposes and will foster new practices and facilitate a more efficient and economic approach to various fields of research. Research institutions, libraries and archives recognized as data controllers need to comply with the new regulation. This paper will discuss selected topics from the field of new data protection regulation, especially organizational practices in order to ensure information security and accountability of these organisations.

Keywords: GDPR, data protection, libraries, digital archives, privacy

I. Introduction

When the new General Data Protection Regulation officially goes into effect in May later this year, it will mark a turning point in almost a quarter of a century of data protection development in the European Union. [1]

A lot has changed since the first adoption of data protection rules on the European level in the early 1990's through the provisions of the Data Protection Directive. [2]

Rapid technological development, particularly of electronic communications, the Internet, search engines, social networks, new information society services and postindustrial data economy, especially in the online content industries, have brought around new and unforeseen challenges for the protection of personal data of EU citizens and all other physicial persons residing or travelling through EU. The scale, the speed and the ubiquity of processing have increased dramatically.

What has also changed is the legal status of personal data protection in the EU legal system. The Treaty on the Functioning of the EU establishes personal data protection as a right available to all individuals in the EU. [3]

Article 8 of the Charter of Fundamental Rights of the EU enshrines personal data protection as a distinct fundamental right under Title II of the Charter, equivalent to right to liberty and security, respect for private and family life (privacy), freedom of thought, expression, assembly etc.[4]

Regulating how personal data is obtained, processed and retained, the new Regulation will affect organizations from EU and abroad that make use of personal data obtained from physical persons in the EU.

Twenty three years after enacting the Data Protection Directive, a milestone in legal development of personal data protection in 1995, and almost six and and a half years after the first regulation proposal, and following two years of *vacatio legis* period left for Member Countries to prepare for its application, the General Data Protection Regulation is now ready to come into effect bringing both evolutionary and revolutionary mechanisms to protect individual's rights concerning their personal data.

II. From Directive To Regulation

Replacing the earlier Data Protection Directive and the national laws it was transposed into, as the new source of the EU material rules concerning data protection principles, users rights and protection mechanisms the Regulation has several main goals.

One of them is to ensure adequate protection of the fundamental data protection principles and rights of individuals subjected to personal data processing such as the right to be informed about data processing, right to access own personal data, right to erase or transfer personal data to another data controller etc.

The Regulation contains mechanisms to ensure adherence to basic principles of data protection such as lawfulness, fairnes and transparency of processing, purpose limitation, data minimisation, accuracy, storage limitation, preservation of integrity and confidentiality and especially, to make sure the controller remains responsible and is able to demonstrate compliance through the principle of accountability.

Another is to update the existing framework that has not kept proper pace with the evolving technology landscape

that has progressed immensely over the last quarter of the century. The advent of technologies allowing cheap and quick DNA sequencing, detailed biometry readings and other technologies that reveal sensitive health may potentially lead to abuses and discrimination of affected individuals.

The choice of the delivery method, a Regulation instead of a Directive, reveals the need to improve uniformness and adherence to data protection standards across the 28 Member States.

By direct application rather than having each Member State decide how its requirements are to be transposed into nation law, the Regulation will help enforce common EU standards of data protection regardless of the legal system, state or supervisory body that interprets it.

The Regulation however leaves some room Member States to regulate their specific supervisory system, provide additional rules alongside or over the standards of the GDPR and clarify potentially unclear concepts such as legitimate interest as the legal basis of processing, required data protection officer skillset and expertise, privacy impact assessment methodology, liability of persons responsible for data controllers actions, provisions regarding collective redress after a data breach and so on.

As of the moment of writing, only five of the Member States have adopted national laws accompanying the GDPR while additional fifteen have produced draft proposals. [5]

The draft of the new Croatian Law on Implementation of the GDPR is currently available to the public. It does not contain provisions regarding the exceptions, safeguards and derogations relating to processing for scientific research purposes as regulated by the Article 89. of the GDPR.

III. KEY CONCEPTS AND DEFINITIONS

There has been much discussion regarding the key definitions of terms regarding data processing in relation to existing laws and the Data Protection Directive. Some authors point out to more elaborate definitions concluding that their scope has expanded. Some claim the scope has not changed.

One of the most important ones is the definition of personal data. The Data Protection Directive used to define personal data as any information relating to an identified or identifiable natural person, an identifiable person is one who can be identified, directly or indirectly, in particular by reference to an identification number or to one or more factors specific to his physical, physiological, mental, economic, cultural or social identity [6]. We can find similar provisions in a host of national laws such as the Article 2 of the Croatian Personal Data Protection Act [7].

The GDPR expands the definition referencing identifiers such as a name, an identification number, location data, an online identifier or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person, but does not broaden it – the original definition has always implied that any information relating to an identified or identifiable natural person represents personal data, regardless of whether categories of such information have been explicitly named by the relevant laws or not.

Similarly, with regard to the definition of special categories of personal data, especially health data, there is still some confusion whether biometric and genetic data, now explicitly defined by the GDPR, represent an extension of existing special categories of data. They do not – they represent of course data pertaining to health of data subjects, and such data is already recognized as special category of personal data by existing regulation. What is new is special reference to biometric data with the purpose of uniquely identifying a natural person.

IV. SPECIAL CATHEGORIES OF PERSONAL DATA

The GDPR recitals commenting on the Article 9 of the GDPR state that Member States should be allowed to maintain or introduce further conditions, including limitations with regard to processing of genetic data, biometric data or health data in general while not hampering the free flow of personal data within the Union should those provisions apply to cross-border processing of such data. [8]

The draft of the Croatian GDPR implementing law contains four articles concerning genetic and biometric data, providing additional safeguards regarding use of genetic data in life insurance contracts, use of biometric data by public and private sector authorities for the purposes of protection of persons, property, classified or business secrets [9]

In addition to principles of data protection recognized by the previous generation of laws starting with the Data Protection Directive, the Regulation now explicitly regulates the need to ensure the integrity and confidentiality of personal data during the collection, processing, use and retention.

These principles are easily recognized by information security experts as two of three founding principles of information security, the CIA triad of confidentiality, integrity and availability. [10]

From the perspective of research organisations, libraries and archives, the main changes for these organisations include requirement to implement adequate procedures for responding to user request in connection with their rights as data subjects, implement privacy by design and privacy by default measures, technical and organisational measures to reduce risk, conduct privacy impact assessments, develop adequate incident reporting procedures and regulate the position and responsibilities of the data protection officers.

While most organisations are aware of the Regulation's very strict fines, very few are aware of the reinforced liability for damages in case of data breaches in the context of possible collective redress and the personal liability of management and board members as regulated by national laws.

IV. REUSE OF PERSONAL DATA IN THE CONTEXT OF RESEARCH

Information systems of various research organisations these days contain a wealth of personal information that could be reused and lead to important discoveries in all fields of science. Use of this data potentially could allow researchers to uncover new knowledge concerning today's medical, social and economical challenges.

In general, Article 5 of the GDPR regulating the principles relating to processing of personal data allows the retention of personal data longer than necessary for the

purposes of for which the personal data was originally collected and processed if needed for archiving purposes, scientific and historical research purposes or statistical purposes and if appropriate technical and organisational measures are applied. This abrogation of the principle of storage limitation is further regulated by the Article 89 and several recitals. [11]

The Regulation considers the reuse of personal data collected in various situations where the purpose of initial collection does not cover the possible use in research.

Recital 50 of the Regulation considers the use of personal data for purposes different than those at the time of initial collection, stating that further processing for archiving purposes in the public interest, scientific or historical research purposes or statistical purposes should be considered to be compatible lawful processing operations meaning that these uses do not represent a change in purpose of processing that would require a separate legal basis.

Furthermore, Recital 156 of the GDPR, reflecting on the provisions of Article 89 comments the obligation to ensure appropriate safeguards – technical and organisational measures – to ensure the rights and freedoms of data subjects in the case of reuse of data for purposes of archiving in public interest, scientific and historical research purposes or statistical purposes.

Article 89 regulates that processing for archiving purposes in the public interest, scientific or historical research purposes or statistical purposes, shall be subject to appropriate safeguards, in accordance with this Regulation, for the rights and freedoms of the data subject. What these appropriate measures are, the Regulation does not specify above a passing comment on the possibility of use of pseudonymisation techniques.

Instead, general obligation is put forth that data controllers need to implement technical and organisational measures to ensure respect for the principle of data minimisation and anonymize data if secondary processing no longer requires the identification of data subjects.

Article 89 is also interesting as it leaves to the Union and Member States manouvering room to implement serious derogations from the data subject rights regulated in Articles 15, 16, 18 and 21 of the GDPR – right of access, rectification, restriction of processing and the right to object to (automated) data processing and profiling. How will these derogations look and function in practice, remains to be seen if and when they are adopted in the next generation of Member States data protection laws.

Another way research institutions, libraries and archives can further process personal data for research purposes is through obtaining a valid consent as the legal basis for processing.

Under the GDPR, rules for obtaining consent are more detailed and demand that consent be given by a clear, affirmative act by an individual informed specifically on the categories of data and their use.

The request for consent needs to be presented in a separate form and manner distinguishable from other contract matter and presented in a clear and plain language that informs the data subject of his rights.

Finally, the controllers need to be able to demonstrate how, when and what has data subject consented to with regard to processing of their personal data. [12]

V. DPO AND DPIA: KEY MECHANISMS TO SAFEGUARD DATA SUBJECT RIGHTS

One of the key new features of the GDPR is a risk-based approach to data protection activities directing data controllers to put into practice technical and organizational measures to protect personal data according to the percieved level of risk. [13]

The Regulation differentiates between three levels of risk and corresponding obligations for the controllers as regulated by the GDPR: high, normal or intermediate and low risk.

A high-risk processing activity requires that organizations engaging in such activity conduct data protection impact assessments. Should a personal data breach occur that could result in a high risk to the rights and freedoms of natural persons, the controller has an obligation to communicate the data breach to the data subject without undue delay.

Most of personal data processing activities will not fall under the high-risk category. For these activities, the controller should adopt measures appropriate to the perceived level of risk.

Finally, some of the activities will present minimal risk towards the rights of data subjects and in these situations controllers are relieved from obligations to notify supervisory authorities or data subjects in case of a data breach.

Research institutions, libraries and archives should assess their legal basis for processing personal data and record processing activities inline with the provisions of the Article 30 of the GDPR. Establishing a record of processing activities, categories of personal data collected, their use and possible exports, categories of individuals, identifying information systems containing personal data and assessing risks to individuals and their rights are the first steps in a compliance program.

The DPIA is a process aimed at assessing the likelihood and severity of risk of a data processing activity from the perspective of individuals rights and freedoms and suggesting mitigation measures to lower risk. It is designed to describe the processingm assess its necessity and proportionality and help manage risks. DPIA represents an important tool for demonstrating accountability and compliance with the Regulation. [14]

While carrying out a DPIA is not mandatory for every processing operation, Article 35 of the GDPR determins the situations where data controllers are mandated to implement a data protection impact assessment (DPIA) of one or more of their data processing activities.

The Regulation mandates conducting DPIAs where new technologies are used, for example in biotechnology, genome sequencing, complex personal data profiling and data set combining, where systematic and extensive processing of special categories of personal data is being performed and where there is a systematic monitoring of a publicly accessible area on a large scale.

From the perspective of research institutions, libraries and archives, all these situations may already account for significant amount of their personal data processing. While the national supervisory authorities are expected to establish and make public a list of the kind of processing operations which are subject to the requirement for a data protection

impact assessment, they may also establish and publish a list of the kind of processing operations for which no data protection impact assessment is required. A typical situation concerning research data where DPIA is likely to be required is archiving pseudonymised personal sensitive data such as data concerning vulnerable data subjects of research projects or clinical trials.[15]

The DPIA process is not a once in a process life-cycle procedure but instead a continuing activity that controllers need to perform when conditions and circumstances of processing change, especially concerning the risk to individual's rights and freedoms.

At the same time, under the GDPR, the regulation of the position, roles and duties of data protection officer has been significantly enhanced. Article 37 of the GDPR regulates the situations where appointment of data protection officer is mandatory, emphasizing the processing done by public authorities or bodies and controllers whose core activities consist of processing operations that require regular and systematic monitoring of data subjects on a large scale or processing on a rage scale of special categories of data and personal data relating to criminal convictions and offences.

While the concept of DPO in itself is not unfamiliar to data protection regulation, Data Protection Directive did not require organisations to appoint a DPO. The practice of appointing the DPO has developed in national legal systems of Member States over the last fifteen years.

Regarding the data protection officer's required professional qualities and expert knowledge, Article 37.5 of the Regulation states that the data protection officer shall be designated on the basis of professional qualities and, in particular, expert knowledge of data protection law and practices.

The DPO has to be able to fulfil the tasks set by the Article 39 of the Regulation, especially to inform and advise the controller or the processor and the employees who carry out processing of their data processing obligations.

The DPO also needs to monitor compliance with the GDPR and other Union and national laws and with the policies of the controller or processor in relation of the protection of personal data. He or she will participate in awareness-raising and training of staff involved in processing operations and the related audits, provide advice where requested as regards the data protection impact assessment and monitor its performance, cooperate with the supervisory authority and act as the contact point for the supervisory authority on issues relating to processing while paying due care to the risk associated with processing operations, taking into account the nature, scope, context and purposes of processing. [16]

VI. Practical Implications On Research Institutions

Research institutions, libraries and archives by definition collect and use substantial amount of data that may contain personal data.

While the Regulation confirms and explicitely protects data subject rights, it also states that right to protection of personal data is not an absolute right and that it has to be considered in relation to its function in society and be balanced against other fundamental rights in accordance with the principle of proportionality, i.e. in the case of balancing against rights regulated by the Articles 9 and 10 of the Charter of Fundamental Rights of the EU.

With already mentioned provisions of Art. 89 and Recital 153 of the GDPR, the Member States are allowed to develop specific solutions to the balancing between these rights. [17]

Unlike the earlier data protection laws, the GDPR now applies not only to research institutions, libraries and archives in the EU, but also to organizations established elsewhere provided that they collect and use personal data or monitor data subjects residing in the EU.

Even though GDPR expands the possibility of research institutions to reuse personal data, the research organizations, just like any other data controllers or processors need to meet the new regulatory obligations.

In practice, this means several key efforts inluding education, personal data maintenance and discovery, compliance (gap) analysis and implementation of adequate technical and organisational measures.

Education should include not only researchers and other key personnel handling personal data, but also management and data protection officers if they have been appointed. Data protection is still not widely accepted as a mandatory part of legal education in most European universities and is even less present in other professions and higher education programs.

In order to satisfy regulatory requirements all organisations subject to the GDPR need to conduct activities to adopt or modify their data usage, security and privacy policies.

In order to do so, they need to have an informed overview of personal data processing activities and ensure adequate protection measure and establish clear and practical procedures concerning users' rights requests, data breach incident response and reporting procedures, data protection impact analysis etc.

Research organisations, libraries and archives may in the course of their activities use outside resources or outsource some of the data processing to third parties. If personal data is also processed in this manner then special care needs to be observed when dealing with data processors and ensuring that obligations regulated by the Article 28 of the GDPR are observed by the data controller and the processor. This means a thorough review of procedures and contracts governing these activites.

This review should include an information system and information security audit both of the data controller's systems and those of the processors.

After concluding the analysis of the existing state of data protection, the data controllers should implement measures to adapt their processing to GDPR requirements starting from deletion of redundant and superfluous data, risk analysis of current and planned processing operations, appointment of the data protection officer and his proper positioning in the organisational structure with regard to provisions of Article 38 as well as the issues concerning possible conflict of interest etc.

VII. Open Questions

From the perspective of research institutions and libraries, there are still a few uncertainties left before the Regulation enters into effect.

One of them concerns the data library systems use to globally exchange data on newly published books and other publications, which usually contain personal data on authors and other individuals and require export of data into third countries and international organizations that will not meet the future adequacy decision requirements as regulated by the Chapter V of the GDPR.

Second issue concerns the efforts to reconcile the rules that govern freedom of expression, including journalistic, academic, artistic and or literary expression with the right to the protection of personal data.

The Regulation states that processing of personal data solely for journalistic purposes, or for the purposes of academic, artistic or literary expression should be subject to appropriate derogations or exemptions if there is a need to reconcile the right to the protection of personal data with the right to freedom of expression and information as regulated by the EU Charter of Fundamental Rights.

The Regulation Recitals specifically refer to the issue of processing of personal data in the audiovisual files and in the the news and press libraries and archives, requiring Member States to adopt adequate provisions to allow exemptions and derogations required to balance these fundamental rights.

An issue that is already present in the provision of Article 39 concerns the possibility of bringing a collective redress action against the data controller, as recommended by the European Commission in 2013.

The provision allows data subjects to collectively assign a non-profit institution to file a complaint and pursue rights from Articles 77, 78 and 79 of the GDPR including a right to an effective judicial remedy against a supervisory authority and a right to an effective judicial remedy against a controller or a processor as well as the right to compensation from Article 82 of the GDPR potentially bringing about lawsuits with damages far exceeding much discussed administrative fines. [18]

VIII. Conclusion

The new EU legal framework of data protection has already been percieved, especially outside of the Union, as strict, creating additional administrative overhead and numerous new obligations for data controllers especially concerning appropriate technical and organisational protection measures.

From the perspective of research institutions, libraries and archives however, the new Regulation creates exemptions and opportunities to reuse personal data potentially facilitating vibrant landscape of secondary use of collected personal data.

Personal data has become a vital digital asset and resource, and the EU lawmakers hope the new Regulation will foster research and development of new innovative services and products.

In order to make use of this provisions, as well as to fulfill obligations set by the GDPR, research institutions and other organizations need to assess their personal data use. In practice, this means they need to create and regularly update records of processing, review their organisational and technical protection measures and conduct other activities mandated by the Regulation.

If their activities meet the Regulation criteria regarding mandatory designation of data protection officers, they need to carefully choose and appoint experts with appropriate skills.

Regulating limitations of users rights, especially concerning the retention of data and allowing processing for secondary use new provisions may allow researchers to process and use data that would have been legally inacessible in the current framework, enabling the development of new information society services and products as well as fostering more efficient research.

At this point, it remains somewhat unclear on how exactly will the limitations and exceptions regarding secondary use of research data containing personal data look from the perspective of organizations established in different Member States after they adopt companion national legislation.

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The Impact of HTTP/2 on the Service Efficiency of E-commerce Websites

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***Abstract* – Web page download times are important for e-commerce as they affect several business metrics, such as brand perception and conversion. A responsive web service is also desirable for search engine optimization. The widely used HTTP/1.1 protocol does not operate optimally in existing web environments because it suffers from problems such as bloated headers and ineffective use of TCP connections. Therefore, some e-commerce operators have already introduced the latest version of HTTP, which is called HTTP/2. However, a large number of e-commerce operators are still considering if HTTP/2 can produce significant benefits over HTTP/1.1. The HTTP/2 performance has been explored through a number of general-type studies focusing on all types of web sites. Some studies even present that HTTP/2 not necessarily significantly reduce the download times of web pages. In this study, we focus solely on e-commerce sites because e-commerce has better than average access to the benefits of HTTP/2. In addition to the download times of web pages, we investigate HTTP/2's impact on network traffic volumes and server service efficiency. We found that the current method of exploiting HTTP/2 is unable to reduce significantly page download times. The server service capability was also at the same level in both versions.**

Keywords* – HTTP/2*; e-commerce

I. INTRODUCTION

Web performance engineering is primarily dealing with a challenge to minimize the download times of web pages to maximize user experience. Several studies emphasize that it is important for organizations to verify the load times of their web pages. This is particularly important for the e-commerce sector because fast websites achieve profitability. Page speed has a measurable impact on several business metrics, such as brand perception, conversion, revenue, shopping cart abandonments, and page views [1]. Reference [2] presents that the fast download speed of a website promotes visitor loyalty and user satisfaction.

A responsive web service is also desirable for search engine optimization. Google has adopted site speed as part of its search ranking algorithm. This means that the fast site obtains a higher ranking in Google's search listings. Web performance engineers also seek to minimize the amount of data travelling across the Internet. This cuts the energy consumption of the Internet promoting the Green Internet ideology [3][4]. Reduced data transfer volumes are also beneficial for users with slow Internet connections, such as mobile device users.

The widely used HTTP/1.1 protocol (Hypertext Transfer Protocol) does not operate optimally in existing web environments because it suffers from problems such as bloated headers and ineffective use of TCP (Transmission Control Protocol) connections. With the aim of reducing the amount of network traffic and speeding up the download times of web pages, IETF has released a new version of the HTTP protocol called HTTP/2. Because this new version maintains the HTTP semantics, its deployment is easy without requiring any mandatory changes to the existing web page structures. As inspired by this, some e-commerce operators have introduced this new version alongside the old one. However, a large number of e-commerce operators are still considering if HTTP/2 can produce significant benefits over HTTP/1.1.

The HTTP/2 performance has been explored through a number of general-type studies that have focused on all types of web sites. In this study, we focus solely on e-commerce sites. E-commerce has better than average access to the benefits of HTTP/2, because e-commerce utilizes a lot of cookies and downloads relatively more resources from the main site. The previous findings have suggested that the introduction of HTTP/2 should not necessarily significantly reduce the download times of web pages. Because of this, the advantages should also be found on other metrics. In addition to the download times of web pages, we investigate HTTP/2's impact on network traffic volumes and server service efficiency.

The paper is organized as follows. Section 2 describes the backgrounds for HTTP based performance optimization. Section 3 presents our experimental test results. Section 4 draws conclusions from these results.

II. BACKGROUNDS

Over the years, the web has evolved from simple text content from one server to a complex ecosystem with different types of content from multiple servers under different administrative domains [5]. This development has set performance challenges for traditional data transfer protocols and called for their features to be upgraded.

A. Performance Meters

Rendering a web page consist of fetching several varying types of files, often from many different servers. A typical web page includes HTML, CSS, JavaScript, and image files. These files can be called the resources of a

web page. The performance of a website can be evaluated by a variety of meters [6][7]. The number of bytes or the number of files fetched to render a web page can be measured. The number of TCP connections needed to download the resources of the page can also taken into account in the efficiency evaluation. Performance can also be defined as the capability of executing a number of operations within a unit of time. With websites, this means that how many concurrent users the website can serve. However, the most user-centered meter regarding to the performance of a web page is the time it takes to load a page.

The Navigation Timing API [8] provides many performance timings of web page loading. For example, the domContentLoaded event fires after the DOM and CSSOM trees are both ready indicating that the render tree can be constructed. This event does not necessarily require that all images have been loaded. Instead, the domComplete event fire after all of the resources on the page have been fully downloaded even if some of the resources can still be downloaded afterwards in an asynchronous way.

These technical indicators are not always capable of expressing how users experience page downloads. Therefore, analytical tools often offer their own indicators. In this study, we use the following indicators. The Start Render time indicates the moment when something is displayed to the screen. This does not necessarily mean that the user see the relevant content of the page, but it is at least a sign that that the page loading is progressing. The Document Complete time tolerably corresponds with the above-mentioned domComplete event. The term of Fully Loaded are used to the time when all the asynchronous resources are also completely fetched.

B. Drawbacks of HTTP/1.1

In terms of performance, HTTP/1.1 has its limitations [9]. The two main limitations of HTTP/1.1 are ineffective transferred protocol control information and the ineffective use of TCP connections. With extensive use of HTTP, HTTP 1.1 has evolved into a protocol that communicates with a wealth of metadata in its request and response headers to enable to exchange the necessary control information between the client and the server. The headers of HTTP/1.1 are always transferred in plaintext format to maintain compatibility with previous versions of HTTP. In the worst cases, these uncompressed plaintext headers may generate multiple kilobytes of protocol overhead for each HTTP message. In the context of e-commerce, the situation is worse than average because the e-commerce sector utilizes a lot of cookies in its operations. HTTP cookies are massively used for re-marketing, session management, personalization, and web analytics purposes.

HTTP/1.1 is unable to multiplex resources over the same TCP connection. If the browser fetches several resources from the same server, these resources have to be delivered sequentially over the established TCP connection. Efficiency is further reduced by the fact that the client must refrain from sending a new request to the same TCP connection until the reply to the previous request arrives. It is possible to overcome this drawback by using the so-called HTTP pipelining technique but its utilization has remained very limited despite its benefits.

Because of the above factors, the total load time of the resources over the same TCP connection is roughly equivalent to the number of fetched resources multiplied by the round-trip time of the connection. In order to avoid delays caused by this, browsers establish multiple parallel TCP connections to the same server. This solution improves user experience but uses resources in an inefficient way. Opening a new TCP connection consumes network resources especially if TLS (Transport Layer Security) encryption is used, as it is often the case with e-commerce. The server must also maintain state information for each TCP socket. There is always a browser specific upper limit on the number of these parallel TCP connections. This limitation can be circumvented by domain sharding technology, which can distribute the content between multiple host names. In the extreme case, the whole artificially distributed content can still be located behind a single IP address. This workaround consumes the resources of the Domain Name System. There are also a number of other ways to optimize HTTP/1.1 activities related to header inefficiency and the use of TCP connections, including concatenation, spriting, and resource inlining techniques [7].

C. HTTP/2

Since HTTP/1.1 has its limitations, IETF decided to develop the new version of HTTP with the aim of lower application delays and better utilization of the network resources. HTTP/2 was announced in 2015 as an additional binary framing layer between the transport layer and the HTTP plaintext layer [10]. This means that any existing website or application can be delivered over HTTP/2 without modifications. Although with small changes, performance can be somewhat improved since some existing HTTP/1.1 performance optimizations can hamper HTTP/2 performance.

HTTP/2 attempts to minimize the amount of network traffic generated by HTTP control information. Firstly, as the name implies, the new binary framing layer of HTTP/2 works on a binary basis enabling efficient transfer of its own control information. Secondly, HTTP/2 uses a HPACK mechanism to reduce the bit stream of the redundant HTTP headers. The HPACK mechanism uses two tables to reduce the bit stream. A static table involves the cache for the commonly used HTTP request and response header names. A dynamic table references other headers used in the current session. These tables reduces HTTP header sizes by sending integer based cache indexes to the existing cache entries instead of the string literals themselves. In addition, the effective HTTP-specific Huffman encoding of string literals reduces the amount of network traffic.

The new binary framing layer of HTTP/2 enables full request and response multiplexing using only a single TCP connection. Once a TCP connection is established between the server and the client, it can accomplish multiple resource fetches. Each resource fetch forms a

new stream with its unique stream identifier. HTTP/2 is capable of breaking down the HTTP messages of this steam into independent frames. The frames of different streams can be interleaved and maintaining the transmission order between the streams is not required.

In addition to the aforementioned commonly used enhancements, HTTP/2 also offers some other enhancements whose use will become more common in the future. A server push feature allows the server to push useful data to the client without the client's explicit request for it. A priority mechanism makes it possible to the client to specify a certain ranking among concurrent streams on a single TCP connection.

D. Related works

Previous studies have indicated both improvement and degradation in web page load times when comparing HTTP/2 with HTTP/1.1. Reference [11] compared HTTP/2's performance with HTTP/1.1 under various network delay, bandwidth, and loss conditions by cloning the top 20 Alexa websites. In typical circumstances where packet losses are rare and round-trip times are relatively short, they found that HTTP/2 cut page load times only about 20 percent even though they had placed all the cloned web site resources on a single server, omitting domain sharding. Reference [12] took into account the impact of domain sharding by splitting the web resources across the multiple domains. They cloned six typical websites to their multi domain test environment. They found that HTTP/2 did not provide better performance on any of these tested web sites. Due to the limitations of their study, they did not, however, claim that that HTTP/2 lead to the performance degradation in terms of page load time in general.

Reference [13] presents the measurement results of a large number of different types of sites. They found that 80 percent of websites supporting HTTP/2 experience a decrease in page load time compared with HTTP/1.1, and the decrease grows in mobile networks. The average page load time reduction of 500 ms was discovered with the fiber connection and 1.6 s with the mobile connection. The remaining 20 percent see an average page load time increase of 1 s with the fiber connection and 1.4 s with the mobile connection. Reference [14] presents, despite their somewhat limited research, that HTTP/2 is not enough on its own to improve web page load times. They suggest that web sites must be designed with HTTP/2 features in mind in order to fully take advantage of HTTP/2's benefits.

As indicated above, previous research results are some contradictory. However, the studies have provided indications that the benefits of HTTP/2 are most noticeable in mobile environments where data rates are small and packet losses are rare. However, if packet losses are common, HTTP/1.1 usually outperforms HTTP/2 [11][12][15] .

III. PERFORMANCE TESTS AND RESULTS

The performance of HTTP/2 has been explored mainly by general-type studies focusing on all types of web sites. We focus solely on e-commerce sites. In addition to the download times of web pages, we investigate HTTP/2's impact on network traffic volumes and server' service efficiency. This section presents our measurement results.

A. Download times of web pages

In this section, we compare the page load times of HTTP/2 and HTTP/1.1 to each other. The objective was to find out if HTTP/2 could reduce the download times to the extent that users could also detect a better user experience. We selected 15 e-commerce web sites supporting the HTTP/2 protocol as a test set. Supporting the HTTP/2 protocol means that the site can respond to the service requests of both HTTP versions. In order to facilitate the maintenance of web pages, HTTP/2 capable servers usually provide identical web resources for both HTTP versions. At this time, it makes sense to optimize the resources for HTTP/1.1, because HTTP/1.1 is currently the most widely used version.

When choosing these web sites, we tried to create a set that corresponds well with the typical site distribution of a regular user. Due to this, most of the selected sites were major international and national e-commerce sites, but there were also small sites. Since the test situations mimicked normal browsing events, the round-trip times of the TCP connections also corresponded to typical situations. We measured only the download times of the landing pages. When the browser cache was empty, the number of HTTP requests needed to download the web resources of the web page ranged from 38 to 180.

We used the WebPageTest-software [16] to test page download times. It is a free software to execute website speed tests from multiple locations around the globe using real browsers. We used the software version where the test generator was installed on the local workstation. This computer was connected to the web via a high-speed wired LAN connection and, therefore, the loaded page versions were intended for desktop users. The browser version was Google Chrome. The download times of the pages were tested when the browser cache was both enabled and disabled. To get correct results, each test case was repeated five times and the presented test results are the average of these test cases.

Fig. 1 shows the download time comparisons between HTTP/2 and HTTP/1.1. The figure presents the results as a ratio of the page load time of HTTP/2 and HTTP/1.1. If the ratio falls below 1, it means that HTTP/2 performs better than HTTP/1.1. When calculating the ratio, the Start Render, Document Complete, and Fully Loaded times were taken into account. This ratio was 0.97 when the browser cache was empty when downloading the pages. In this case, HTTP/2 managed slightly to shorten the download times. Instead, the download times were somewhat longer when utilizing the browser cache. In this case, the ratio was 1.03.

The test results show that, in general, the current way of applying HTTP/2 is not capable to reduce download times to the extent that it would have a significant positive impact on user experience. Instead, HTTP/2 was able to reduce the number of open TCP connections clearly in all cases. On average, the number of TCP connections decreased by 25 percent when considering the results without caching. As a result, HTTP/2 utilizied opened

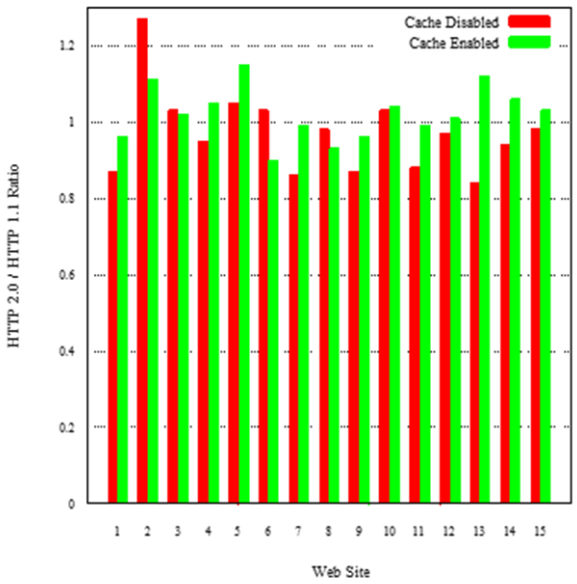

Figure 1. Download time comparisons between HTTP/2 and HTTP/1.1

TCP connections more efficiently than HTTP/1.1. HTTP/2 transmitted 3.4 resource requests via one TCP connection when the corresponding averaged value for HTTP/1.1 was 2.7. Table 1 summarizes the average number of request messages and TCP connections.

B. Network traffic volumes and the service efficiency of servers

In this section, we presents the impact of HTTP/2 on network traffic volumes and server service efficiency. We created an e-commerce based web page for our measurements. The page consisted of 25 resource files.

TABLE I. AVERAGE NUMBER OF REQUEST MESSAGES AND TCP CONNECTIONS

	Number of requests	Number of TCP connections	Requests per Connection
HTTP/2 (no cache)	106	31	3.4
HTTP/1.1 (no cache)	107	40	2.7
HTTP/2 (cache)	46	23	2.1
HTTP/1.1 (cache)	45	25	1.8

These resources were housed on the same server. The processing power of this server was deliberately low so that we could push the server to the limits of its service capability.

We used the Load Impact-tool [17] to generate service requests for our test server. The Load Impact-tool helps determine the capability of handling a certain amount of users on a website. In this study, the amount of concurrent users increased evenly from 1 to 40 during the 8-minute test. We used the collectd-tool to collect metric data. Collectd [18] is a daemon, which collects system and application performance metrics periodically.

Fig. 2 shows the test results. The figure presents the way in which HTTP/2 and HTTP/1.1 increase the network traffic volumes and the CPU utilization rates of the server when the number of simultaneous users on the server increases steadily. The measurement results indicate that there are no significant differences between these two HTTP versions in the network traffic volumes and the CPU utilization rates.

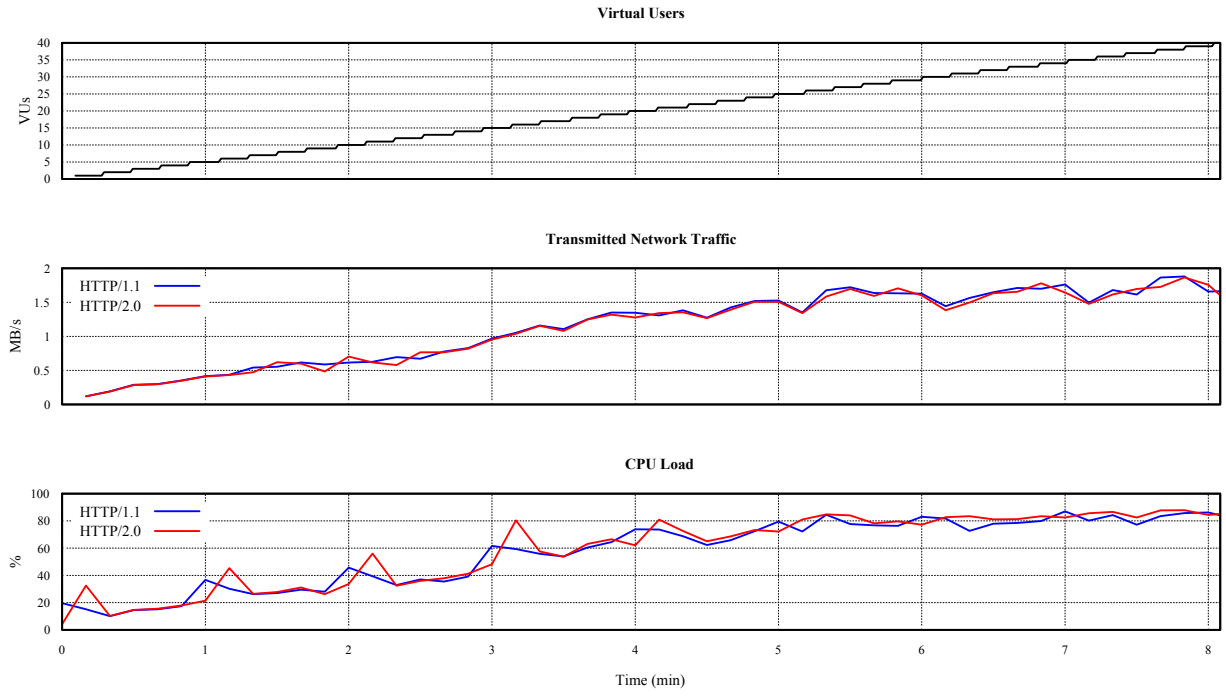

Figure 2. Network traffic volumes and the CPU utilization rates of the server

HTTP/2 is unable to reduce significantly traffic volumes because volumes associated with the protocol control functions are ultimately low compared to the application data transfer. In addition, some HTTP/2 properties affect traffic volumes in the opposite way. Less traffic is needed to open TCP connections. The HPACK-algorithm also reduces the amount of data to be transferred. On the other hand, HTTP/2's own control information adds the number of bits to be transferred. These same factors also explain why the service efficiency of the server is almost identical with both versions. The HPACK-algorithm and the new binary framing layer of HTTP/2 increase the processing load. A lower number of TCP connections reduces the need for processing.

IV. CONLUSION

This study indicates that, in general, the current way of applying HTTP/2 is not capable to reduce the download times of e-commerce web pages to the extent that it would have a significant positive impact on user experience. The existing browsers are able to keep the download times of HTTP/1.1 competitive with HTTP/2 by opening several parallel simultaneous TCP connections to the same server. Therefore, research results like this are always dependent on the browser version used because the maximum number of simultaneous connections varies between browsers. According to the results, the HTTP version used does not have a significant effect on server service efficiency. We can conclude that e-commerce operators do not necessarily have to rush to deploy HTTP/2, but the introduction of HTTP/2 is justified due to the reasons below.

The tested web pages were not optimized for HTTP/2 but rather for HTTP/1.1. This was indicated by the fact that the downloaded pages consisted of the same amount of resource files despite the protocol version used. This implies that e-commerce operators currently offer the same page structure for both HTTP versions. The optimization techniques of HTTP/1.1 may even be detrimental to HTTP/2. In addition, utilizing the server push function will enable HTTP/2 to streamline its operations in the future. It should also be mentioned that this study focused solely on the service efficiency of servers. Introducing HTTP/2 will slightly reduce the load on routers. For example, routers need to make fewer routing decisions because traffic related to opening TCP/TLS connections reduces.

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ERA Metamodel of the Analytical Hierarchy Process and Risk Matrix

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Abstract – This paper has been motivated by the project *Ivanscica for a better tomorrow* which was supported by the European Commission funds. The main goal of the project was to build a dialogue between the City of Zlatar and the City of Ivanec. To achieve that, several alternatives were proposed, and decision has been made by using the AHP. To successfully implement the decision, risk analysis was done. This integrated approach applied on the project became a trigger to propose general framework of integration of those two methods – which is the main goal of this paper. In general, after a specific strategic decision has been made, the process of its implementation starts. However, before the implementation of the strategic decision, it is recommended to conduct a risk analysis. First, this is necessary for predicting possible risks, that is, situations or events that might threaten the process of implementation and the decision effects. Second, the classification of risks in terms of two variables must be done. Those two variables are the probability of risk occurrence and the strength of the risk's negative effect on the implementation process. Last, the activities of risk management must be defined. In this paper, after providing a theoretical background, we present an entity-relationships-attributes (ERA) model of two complementary methods: the analytical hierarchy process (AHP) method (used for strategic multi-criteria decision-making) and a risk matrix (used for risk management). In the practical part, we provide an overview of how those two methods have been used in the case mentioned project.

Keywords - AHP, risk matrix, ERA, local government unit

I. INTRODUCTION

Information and communication technology (ICT)-supported decision making offers great possibilities, but unfortunately, it is seldom used in decision making in the public sector. This should change because decisions made in the public sector are financed by taxpayers' funds and have far-reaching consequences. Further, the advanced usage of ICT in Croatian self-government units are rare [1]. Some examples of possible ICT usage in the public sector are found in paper [2].

One of the few examples of decision making supported by ICT in Croatian local self-government units is the project *Ivanscica for a Better Tomorrow,* the main goal of which was to build a dialogue between the City of Zlatar and the City of Ivanec. The purpose of the established cooperation was to define the strategic development of the mountain Ivanscica and the activities that take place there. The project was funded by European Union (EU) funds from the Youth in Action program and was launched by the Zlatar Youth Association (ZUM). The project was implemented by young people from both Zlatar and Ivanec (ZUM and the Youth Council of the City of Ivanec) and the decision makers in these two local self-government units (the City of Zlatar and the City of Ivanec) [3].

The mountain Ivanscica represents a natural border between the two cities (Zlatar and Ivanca) and between the two counties (Krapina-Zagorje County and Varazdin County). Although the potential for tourism development is unquestionably present, tourist attractions on Ivanscica are underdeveloped. Given the divisions of ownership over Ivanscica, which in the past has caused conflict, and due to the limited resources of the two cities separately, the cities need to develop the tourist offerings through joint efforts.

The youth representatives from both cities decided to encourage a solution to this problem through the project *Ivanscica for a Better Tomorrow*, with which they wanted to create a basis for the future development of tourist offerings on Ivanscica. Through three three-day meetings over a period of four months, they analyzed the problem, identified the tourism potential of Ivanscica, and suggested the first step in addressing the problem: defining the forms of cooperation between the two cities using the analytical hierarchy process (AHP) method. Before this, local authorities had not used the AHP method [3]. In the paper [3], the implementation of the AHP method in the project is described in detail.

In this paper, we present an overview of the application of the risk matrix method, which was implemented after the application of the AHP method, with respect to the chosen alternative. Based on the practical example, we will show how the AHP and risk matrix methods are compatible, and a common entity-relationships-attributes (ERA) metamodel will be provided based on the two methods. The proposed ERA metamodel can, through the appropriate software application, become a useful tool for decision making and performing a risk analysis of implementing the decision in the public sector. This kind of application can then generally be applied, independently of the project or decision problem.

The second section of the paper presents the steps of AHP method application. In the third section, the risk matrix application will be explained, while the fourth section presents the details of the ERA metamodel. The benefits of the ERA metamodel are explained in the conclusion.

II. AHP METHOD

The AHP method is one of the best-known methods for decision making and the scientific analysis of scenarios by consistently evaluating a hierarchy, the elements of which are goal(s), criteria, sub-criteria, and alternatives. It has been widely used in management, resource allocation, and distribution [3].

In terms of the decision-making level, the AHP is mainly used for making strategic decisions, followed by making tactical decisions (such as in big organizations). It is rarely used for making short-term operative decisions. Strategic decisions influence a whole organization; they are long-term and expensive. Also, the implementation of strategic decisions often requires many resources, including human and financial decisions and hardware and software.

The application of the AHP can be described in four main steps [4], [5]:

1. Decision-making problem structuring. The problem must be structured in the form of a hierarchy, with a goal at the top, criteria and their sub-criteria at a lower level, and finally, alternatives at the bottom.
2. Pairwise comparisons. At each level of the hierarchy, elements are pairwise compared with respect to the higher-level element. Criteria are compared with respect to the goal, sub-criteria are compared with respect to the criteria, and alternatives are compared with respect to the sub-criteria. In the pairwise comparison process, the Saaty scale of relative importance is used, which consists of nine degrees.
3. Global priorities. Based on pairwise comparisons from the previous step, criteria weights and local priorities of alternatives have been calculated. Criteria weights and local priorities are then synthesized into global priorities. The alternative with the highest priorities becomes a candidate to be a final decision.
4. Sensitivity analysis. In this step, an analysis of results stability is done. Decision makers examine how changes in criteria weights (+-5%) influence the alternatives' rankings.

III. RISK MATRIX

Risk is defined as a possible uncertain situation in the future that can have a positive or negative impact. Decision making within risk conditions is a situation that occurs when decision makers know the consequences of the alternatives that are expected for each situation (or event), but do not have information about the probabilities of these risks occurring [7]. Paying attention to the risks of the project is important. The basic idea of risk management is to anticipate the future, identify the problems that may arise, and define activities that can successfully solve these problems. Therefore, successful project managers today develop different models for the future, in which they anticipate the projected risk impacts and undertake preventive actions and activities accordingly. Risk management benefits can be divided into two groups [8]:

- Hard benefits: producing reliable plans and budgets to achieve a more detailed project

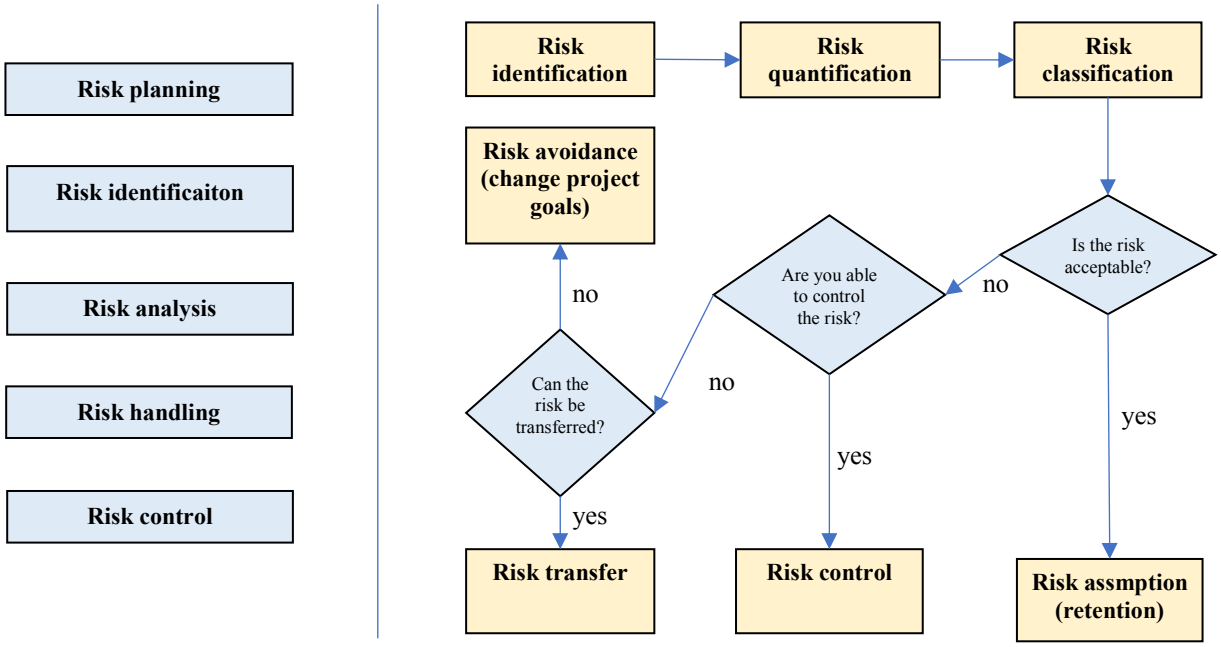

Figure 1. Risk management

analysis; increasing the probability of meeting the deadlines and budgets; allowing a more objective comparison of alternatives; reducing the probability of carrying out unprofitable or cost-ineffective activities.

- Soft benefits: improving communication; improving the understanding of project participants; fostering teamwork.

Two main risk components in terms of risk quantification include the following [7], [8]:

- Risk probability
- Risk impact

Depending on the project, data on risk components are collected by the analysis of historical data in similar situations and through various simulations and models for predicting the risk and impact of the project. Also, experts in the problem area may be helpful in defining risk components.

Risk management can be defined as the continuous and disciplined process of planning, assessing, processing, and controlling risks. It is important to start risk management on a project as early as possible and to implement it throughout the project's lifetime. The risk management implementation steps are described in the left side of the diagram appearing in Fig. 1 (above) [8]:

1. In the first phase, risk planning, strategies and methods for identifying risks, analyzing risks, developing a risk management plan, and monitoring risks are developed and adopted.
2. The second and third phases, those of the identification and analysis of risks (risk assessment), incorporate the operational execution of the risk management plan. Here, decision makers identify the risks that are threatening the enterprise, determine to what extent (probability) they threaten, and establish what the possible consequences (impacts) are.
3. In the risk handling phase, decision makers choose a risk reduction strategy that mitigates the risk to an acceptable level according to the risk management plan.
4. In the risk control phase, we monitor the success of the chosen strategy and, if necessary, determine additional activities that will reduce the risk impact to the acceptable level.

Risk planning is not a single activity; the plan is revised some time into the process due to specific changes in the environment as well as the results of plan to mitigate risk. Once the risk has been identified, the steps of risk management plan, from the analysis to the control, continues until the risk is resolved. The right side of Fig. 1 (above) presents a slightly different view of risk management. There are four main strategies decision makers can use when reducing risk [8]:

1. Risk assumption, risk retention: This strategy is used when decision makers are aware of a risk and its consequences but feel that they can cope with these consequences. Therefore, they do not take any specific action in the direction of risk resolution.
2. Risk control: In this situation, decision makers are aware of the risk and its consequences and feel that the consequences can be detrimental and that a reaction is required. In this strategy, decision makers feel that they can solve this risk alone, so they do not look for any help. The essential part of this strategy is to oversee the risk measures taken and to continuously measure the probability and impacts of the risk on the project.
3. Risk transfer: In this strategy, decision makers are aware of the existence of the risk and the strong negative impact of the risk's consequences but are not able to deal with the risk alone. They must, therefore, look for partners to help them deal with the risk by decreasing or eliminating the negative impact of the risk on the project.
4. Risk avoidance: In this strategy, decision makers are aware of the existence of the risk and its estimated severity, but it would be too expensive to either fight it alone or to seek help. As such, decision makers change the project's goals instead of dealing with the risk.

It is important to note that some authors use a different definition of *risk avoidance*, referring to it as a situation in which decision makers are aware of the risk, its consequences, and the dangers it brings, but choose not to do anything. They do not change the project goals, seek help, or transfer the risk, instead continuing to proceed with the project no matter what might happen in the future. Simply, they take the risk. This strategy is also called *risk ignorance*, and it differs from risk assumption (or risk retention) because decision makers know in advance that the risk is not acceptable and that its consequences can have a high negative impact on the project.

Because risks are not equally dangerous to an organization, they therefore need to be classified according to their potential impact. Depending on the risk consequences, there are several different risk types [8]:

- High risk: the consequences of the risk have a high impact on the realization and results of the project.
- Moderate (medium) risk: the consequences of the risk have a moderate impact on the project.
- Low risk: the consequences of the risk have a low impact on the project

Risk classification into the above categories can be completed based on the two previously mentioned risk components: the impact of the risk on project realization (i.e., the consequences of the risk) and the probability of

risk occurrence. Based on the experience of project managers, the risks are classified into the three categories, as presented in Table 1. In addition to this, it is possible to classify risks more precisely using five categories (Very Low, Low, Moderate, High, and Very High [7]) or even more [9].

Values 1, 2, and 3 in Table 1 are related to the intuitive scale of each of two variables. For the specific situation, the assessment of impact and probability must be given by the problem area experts. This method is one of the simplest methods for risk assessment. More complex methods used in risk management are Monte Carlo simulation, decision trees, and sensitivity analyses. Tools that can be used to support this method include TreePlan,[1] @RISK,[2] and SensIt.[3]

TABLE I. RISK MATRIX [7], [8]

		Impact of risk on the project		
		1	2	3
Probability of risk occurrence	1	Low	Low	Moderate
	2	Low	Moderate	High
	3	Moderate	High	High

IV. APPLICATION OF AHP-RISK MATRIX INTEGRATION ON THE PROJECT IVANSCICA FOR A BETTER TOMORROW

A strategic decision related to the project *Ivanscica for a Better Tomorrow* is already presented in [6]: two cities had to decide on the type of collaboration that should be conducted to revitalize the mountain Ivanscica, which is currently undeveloped, but has huge tourism potential. The two cities needed to collaborate because the mountain is placed between them, with the top of the mountain being a natural border. Three possible types of collaboration were *considered: the establishment of the Ivanscica Foundation, town* twinning, and the creation of a Cooperation agreement between the two cities. The AHP method suggested that a cooperation agreement should be established.

This solution was presented to the units of local self-governments, and the City of Zlatar and the City of Ivanec accepted the proposed solution and decided to implement it. This was a step forward in the cooperation between the two cities. To increase the chances of the successful implementation of the decision, a risk analysis was performed.

When we discuss the *Ivanscica for a Better Tomorrow* project, the identified risks are related to the realization of the project continuation, meaning the implementation of the cooperation agreement. The identified risks are presented in Table 2, together with the corresponding estimations of risk probabilities and risk impacts on the project continuation. Table 2 also contains the proposed risk management activities. Some of the risk management activities in Table 2 were implemented in advance through the provisions of the cooperation agreement. Some risk management activities are only planned to be implemented when the related risks occur during the implementation of the agreement.

Finally, some situations have been identified as potential risks, but no real risk management activities have been assigned to them. Such risks arise mainly in relation to the characteristics of the decision makers and the public administration system. Namely, decision makers in public administration (especially in the local government unit) are often very passive and, in the end, are not interested in implementing the decisions that have been made. The main idea of risk management is also to overcome this passivity and to implement the agreement; however, further problems arise when there is passivity about implementing the risk matrix results. This is a disadvantage of a risk management system in which the same people implement the decision as control the implementation process.

V. ERA METAMODEL OF THE AHP AND RISK MATRIX

During the project implementation, it was concluded that the two methods can easily be integrated. The integration contributed to achieving the project goals because the whole context was analyzed more in detail. This became a trigger to propose general framework of integration of those two methods. Any other multiple-criteria decision can benefit from risk analysis integrated with applied multiple-criteria decision-making method.

The AHP method can be used as a part of risk management in three ways:

1. For the prioritization of risks (for an example, see [10]),
2. As a prediction-assessment tool used to determine the probability of a risky situation,
3. For prioritizing activities that can be used to influence a specific risky situation.

In this paper, we propose a slightly different approach for connecting the AHP and risk management. Some multiple-criteria decision-making problems can be solved by the AHP, and when the decision is ready to be implemented, a risk analysis can be done. This is a sequence of two methods that are applied separately (even though the AHP can be additionally applied as a part of risk management in the sequence, which is recommended if the situation is complex).

There are different tools and apps that can be used to apply the AHP and to create the risk matrix, but these require that the two steps be done separately. The idea of this paper is to propose the integration of the two methods into one software application. One of the first steps in software development is the creation of an ERA model. The proposed ERA model describes how data about the decision-making problem, as well as data about the implementation of two methods, will be designed,

[1] Webpage: http://treeplan.com/
[2] Webpage: http://www.palisade.com/risk/
[3] Webpage: http://tornadocharts.com/

TABLE 2. RISK MANAGEMENT IN THE PROJECT *IVANSCICA FOR BETTER TOMORROW*

Risk	Classification	Risk management activities
Lack of interest of the Committee members for the performance of their duties (since it is a voluntary work)	Low risk	No action is required.
	Medium risk	The superiors to the Committee members should talk to them and motivate them to complete their assumed tasks.
	High risk	The usage of an employment instrument created by the Croatian government which encourages one-year training of young people without the commencement of employment. Those trainees would be in charge of implementing the continuation of project co-operation.
Lack of knowledge of the Committee members about creating application forms for NGOs to apply on the tender	Low risk	No action is required.
	Medium risk	The project participants have developed templates for the application forms and listed the criteria for the evaluation of applications. These should be given to the Committee members so they could check them and potentially use.
	High risk	Use the existing templates to create forms, such as the templates proposed by Office for Cooperation with NGOs, Government of the Republic of Croatia.
Lack of interest for the tender application among the potential applicants	Low risk	Organization of the exemplary activity on the top of the mountain within the third project meeting so the potential applicants would understand that nothing difficult is expected from them Creating a project brochure with detailed descriptions that will be send to potential applicants Promotional activities for the tender
	Medium risk	Promotional activities for the tender. Sending letters to potential applicants.
	High risk	Reallocation of funds which are usually intended for associations in the budgets of local self-government units, into this tender so the potential applicants would be motivated to apply due to less money available for their usual way of financing
Lack of knowledge among the potential applicants about completing the application forms	Low risk	An example of the filled application form should be made available on the web.
	Medium risk	Organizing workshops about the tender, discussions on the potential topics for application and workshops about forms filling
	High risk	Along with workshops, ensuring the expert assistance in tender application (possibly also through recruiting a young person for training)
Inability to connect with a potential applicant from another city since it is mandatory that the applicants come from two different cities	Low risk	The brochure of the initial project contains a list of associations that make up the largest group of potential partners in the future projects
	Medium risk	Creating a web site (web 2.0) for the purpose of establishing contacts with other associations, discussing potential partnerships, and the like
	High risk	Organizing additional new events at the top of the mountain (similar to the third project meeting) by the two cities.
Lack of funding for project implementation since the tender provides only 50% of the required funds	Low risk	No action is required.
	Medium risk	Organization of workshops about financial planning, sponsorship opportunities and application for other available tenders
	High risk	Increase of co-financing to 75%
Incomplete documentation (at first deadline)	Low risk	No action is required.
	Medium risk	Allow documentation to be added after the submission deadline (applies only to the first cycle)
	High risk	
Lack of final report after project implementation	Low risk	No action is required.
	Medium risk	By e-mail remind organizations which implement project on the obligation to submit the final report and all the necessary attachments before expiry of the submission deadline
	High risk	Along with an e-mail reminder of the final report submission, remind the organization that in the absence of reporting, they will no longer be considered for any funding from the local government unit in which they operate, and the premises that they may got for usage from the local government unit, will be given to another organization
Reduced revenues in the budgets of local self-government units which can result in reduced funds available for tender	Low risk	No action is required.
	Medium risk	Reallocation of funds which are usually intended for associations in the budgets of local self-government units, into this tender so the annual amount for tender would not be reduced
	High risk	With an attempt to implement the activity from the upper cell, look for the available tenders for local self-government units to finance activities that would otherwise be funded by the local self-government's budget so that the money could be redirected to the project continuation (e.g., designing a project for the EU program " Youth in Action "or" Erasmus + "- there are subtypes in these programs on which self-government units may apply and some of their regular activities finance from such projects – e.g., employee salaries, different representational and dissemination costs for celebration of the city day, etc.)
Incomprehensible withdrawal of local self-government units from participating in the implementation of the project "Ivanscica for a Better Tomorrow"	Low risk	Continually reminding on the ultimate goal - a joint application of two cities to EU funds with the aim of developing infrastructure and content on Ivanscica
	Medium risk	Discussions with decision-makers about the continuation of cooperation
	High risk	Point out to the decision makers on negative media publicity that might arise in the event of withdrawal from the project's continuation. They might be called for not wanting to do what they themselves signed, even though it only costs 30,000 HRK a year and can bring a lot of good things. In addition, by withdrawal the leaders of the local self-government units would show how they treat young people who initiated and led the project.

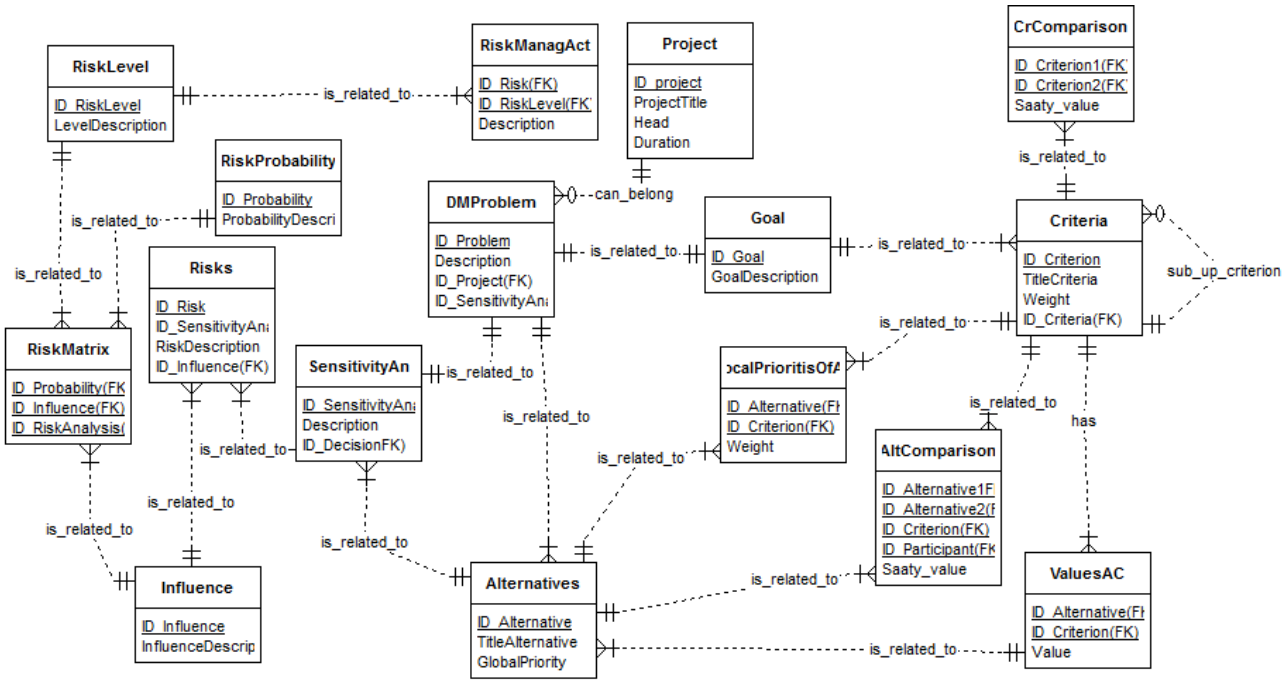

Figure 2. ERA model of AHP and risk matrix

connected, and stored. The initial ERA model consists of tables in which the decision-making problems are described, through alternatives, criteria and subcriteria, goals, pairwise comparisons, consequences, and risks and their impacts and probabilities. The proposed ERA metamodel for AHP–risk matrix integration is given in Fig. 2.

The integration of these two methods can improve both the methods for two reasons: (1) when the AHP is used, historical data from risk analyses can influence the criteria in the decision-making problem and, accordingly, the final decision, and (2) when the risk matrix is applied and the risk management activities are brainstormed, they can be gathered from AHP data, which contains descriptions of all the alternatives.

CONCLUSION

The application of the integrated AHP-Risk Matrix approach on the project *Ivanscica for a Better tomorrow* brought benefits to the project (when compared to applying the AHP only). The decision-making problem was much more deeply analyzed which increased the prepareness of the decision to be implemented.

We concluded that this approach can be successful in other situations as well – not only on this project, especially in the area of local governments where many strategic decisions are made.

We proposed an ERA model for possible software application that would support such integration and increase the quality of decisions and prepare them for the implementation process.

ACKNOWLEDGMENT

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Smart-City- Awareness amongst Croatian citizens

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***Abstract* - Globally, the concept of smart-cities is imposed as one of the crucial elements of the development of local government. There are a few examples of smart-city initiatives in the Republic of Croatia and an insignificant number of formal certification. By using widely standardized indicators we shall introduce citizens with the indicators for developing smart-cities. The aim of this paper is to detect the smart -city awareness of Croatian citizens in terms of its importance and their initiative towards local government. According to the research results, the paper will recommend methods and their implementation into the key segments for achieving real assessment of ICT infrastructure, and therefore approach the development of a self-sufficient Croatian smart city model.**

Keywords - smart-city; globally standardized indicators; local government; open governance; Republic of Croatia

I. INTRODUCTION

Today, in the Republic of Croatia (further: Croatia), there are no smart-cities, such as defined in the smart-city key indicators within the Horizon 2020 Programme named "CITYkeys indicators for smart city projects and smart cities", co-funded by the European Commission (used both as a guide and a tool for writing this paper). [1] Usually, key indicators aim to facilitate and enable stakeholders to invest in projects for smart-city implementation, cities to learn from one another, and to monitor progress, by means of integrated performance. The framework for smart-cities should be carried out in a way to implement tangible elements which are expected to support smart-city development and to achieve environmentally friendly, economically viable and socially desirable urban environments. Technologies are playing an important role in sustainable and smart transformation of any existing city into an intelligent city or when the smart-city is developed from the ground up, it's crucial that it to meets varied people's expectations. The choice of technologies, platforms, tools, and methodologies is crucial for the intended success of smart city projects in any part of the world. [2]

A 'smart city' is a city where investments are focused towards smart citizens who use renewable energy resources wisely and widespread technological networks to combine sustainable economic growth whilst improving the quality of life, through the open government model by the interaction of all stakeholders. [3]

Due to the importance of developing the smart city elements in Croatian cities, the goal of this paper is to detect the smart-city awareness of Croatian citizens in terms of its importance and their initiative towards local government, their familiarity with the meaning and the elements of a smart-city compared to the key indicators from the *supra* mentioned study.

II. METHODOLOGY

Different EU cities confirmed that the implementation of smart-city elements and solutions are high on their agenda, due to the fact that they expect great amount of benefits when they 'become smart', included: sustainability, efficiency, better participation of citizens in the work of local governments and an increase of quality of life in general [1]. Since Croatian cities are still not primarily oriented towards implementing smart-city methods and elements in their cities, we have decided to examine opinions of Croatian citizens on their standpoints regarding implementation of smart-city elements into Croatian cities. We have also compared the responses of citizens who responded to the questionnaire on the crucial elements of smart-cities.

For conducting this research, we have opted for a questionnaire as a tool for collecting data. The data was collected by Web-Assisted Interviewing [4]. Specifically, data was collected from 23rd of January until 31st of January 2018 and the questionnaire was provided in an Internet-only version via Google Forms. The questionnaire was provided to a certain number of participants using Social Media (Facebook, Twitter). We are also very aware of the limitations of this research, due to the fact that only citizens with Internet and social media networks access could have participated in the questionnaire. The value of the questionnaire is limited because the knowledge that we can give depends on the integrity of the respondents and their ability to answer the questions asked. However, this questionnaire can be used as an example of a larger scale project for local self-governments when implementing the elements of a smart city. For this kind of research, the most important is to have a credible random sample of respondents in the questionnaire, where the numbers of respondents in the qualitative research isn't limited with the highest number of respondents.

Participants were introduced with the purpose and objectives of the questionnaire before answering the questions. The questionnaire was conducted for Croatian citizens only, therefore, Croatian language was used.

The reasoning behind using the web questionnaire in Google Forms is the following: the provision to potential participants was conducted without expenses, it offered anonymity and the authors concluded it was optimal for a certain number of respondents [5].

The questionnaire contained twelve (12) questions. The first three (3) were related to defining the participants by several categories authors deemed important (gender, age and the size of the city participants live in). The fourth question asked the participants if they know what the term smart-city means.

The following two (2) questions (with an option for participants to also propose their own answers) offered the participants to select from multiple answers. The fifth question was: "Which of the following are the elements of the smart-city term?", and the sixth question was: "Which of the following elements of the Smart-city are already provided in the city you live in?"

The areas in which cities need indicators to measure their smart city performance are: energy, greenhouse gas emissions, traffic and transport, digital infrastructure and E-services, resource management, citizens' participation, competitiveness, economy, environment, quality of life etc. We have categorized the answers into the five (5) basic categories which the smart-city consist of: Smart governance, Smart living, Smart mobility, Smart environment and Smart people. Some answers belong into the two (2) categories. The selection of indicators for the evaluation framework was based on an inventory of the needs of cities and citizens, the CITYkeys working definitions and the structure of the evaluation framework, and the categorization made by S. Kondepudi and R. Kondepudi [6]. Additionally, some of the answers were not elements of a smart-city (not grouped in any of the above-mentioned categories). False answers served as "red-flags" to indicate if the participants who stated they know what a smart-city is, really understood what constitutes a smart-city in practice. Two other possible answers were "None of the above" and "I am not familiar with the term smart-city". The answers provided are presented in Figure 1 *infra*.

The seventh question offered identical elements and asked the participants to rate each element on a scale from 1 to 5 - one (1) indicating that the element is not necessary in the city participants live in, while five (5) meaning the element is (reasonably) needed in the city participants live in.

Smart governance	**Smart liviing**	**Smart mobility**	**Smart environment**	**Smart people**	**Uncategorized/ false**
Citizen-government interconnection	Smart security system	Smart parking	Energy-efficient facades	Smart education and health care	Shared drives with a personal vehichle (carpooling)
Automated collection of data regarding citizen habits		Smart traffic lights	Smart waste disposal		Quality of life reduction
		Smart public transportation	Smart energy savings		Usage of non-renewable energy sources
					Free Wi-fi in bars
					Smart benches

Figure 1: Categorized answers (Questions 5 and 6).

The set of questions from eight (8) to eleven (11) asked participants the following: "Question 8: Does the introduction of smart-city elements increase the quality of your lives"; "Question 9: Are you familiar with any initiatives your local government is facilitating regarding smart-city elements"; "Question 10: When do you expect your city will implement some elements of a smart-city?; "Question 11: Would you participate in a digital platform which would provide an opportunity for joint decision making on projects relevant to the development of your city?".

The twelfth (final) question was open-ended, and participants were asked whether they think the city they live in is "smart". Participants were asked to write and explain their answer on the above question.

III. ANALYSIS OF THE RESULTS

The questionnaire was completed by a total of 673 respondents, out of which: 28.4% are from 18 to 30 years of age; 31.1% are from 31 to 40 years of age; 28.7% are from 41 to 50 years of age; 9.1% are from 51 to 60 years of age; and 2.8% of the respondents are older than 60 years of age. Out of the total, 59% of participants were male and 41% were female respondents. 67.8% respondents answered they live in cities larger than 35.000 inhabitants, 16.9% live in cities from 10.001 to 35.000 inhabitants, while 15.3% participants live in cities with less than 10.000 inhabitants.

The reason why we grouped respondents in this manner is based on the definitions from the Act on Local and Regional Self-Government, [7] which provides the terms of municipalities, towns and big towns (cities)[1].

According to the research conducted by the United Nations in 2014 more people live in urban areas than in rural areas globally. In 1950, 70% of people worldwide lived in rural settlements and less than 30% in urban settlements. In 2014, 54% of the world's population is urban. The urban population is expected to continually grow, so by 2050, the world will be 1/3 rural and 2/3 urban. Roughly, the population will reverse in comparison to what we had during the 1950s'. 73% of European population already lives in urban areas. The United Nations' research predicts that over 80% of Europe's population will be living in urban areas by 2050. [8] Therefore, the information that more than 2/3 of the respondents live in cities larger than 35.000 inhabitants; is in line with UN's data.

Out of the 466 respondents that stated they are familiar with the term smart-city, 69.1% live in cities larger than 35.000 inhabitants, 17.2% live in cities between 10.001

[1] Croatian Act on Local and Regional Self-Government defines municipalities as units of local self-government (usually) below 10.000 inhabitants, towns as units of local self-government with (usually) more than 10.000 inhabitants, while big towns (cities) are units of local self-government which have more than 35.000 inhabitants.

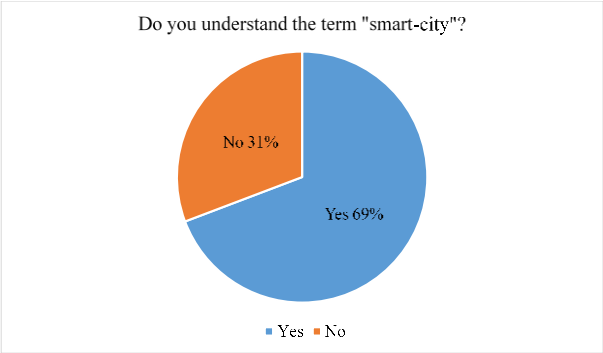

Figure 2: Question 4: Do you understand the term "smart-city"?

and 35.000 inhabitants and only 13.7% live in cities with less than 10.000 inhabitants. Out of the 466 who stated they understand the term smart-city, 39% are female respondents, and 61% male. As for the 207 participants who stated they did not understand the term smart-city, 18.8% live in cities with less than 10.000 inhabitants, 16.5% live in cities with between 10.001 and 35.000 inhabitants, while 64.7% live in cities with the population larger than 35.000. 45.9% are female and 54.1% are male. It can be concluded that mainly inhabitants of big towns (cities) do understand the term smart-city, and roughly equally women and men in an equal percentage.

Respondents correctly noticed some of the elements of the smart-city, such as: citizen-government interconnection (66.1%), energy-efficient facades (39.1%), smart parking (55.7%), smart traffic lights (64.6%), smart public transportation (70.9%), smart energy savings (72.1%), smart security system (62.7%), smart waste disposal (74%), smart education and health care (60.5%), and automated collection of data regarding citizen habits (34.8%), indicating that more than 50% of respondents are familiar with the most smart-city elements. When describing how does the smart-city look like, most of the citizens agreed that a smart-city uses digital technology, combines energy, mobility and infrastructure, increases efficiency, increases citizens participation, enables innovation and improves both social and economic value of the city. These answers again seemingly point out that respondents are familiar with the smart-city topic.

It is interesting to notice that 52% of respondents identified smart benches, 20.2% of them identified free Wi-Fi in bars and 33.1% of them identified shared drives

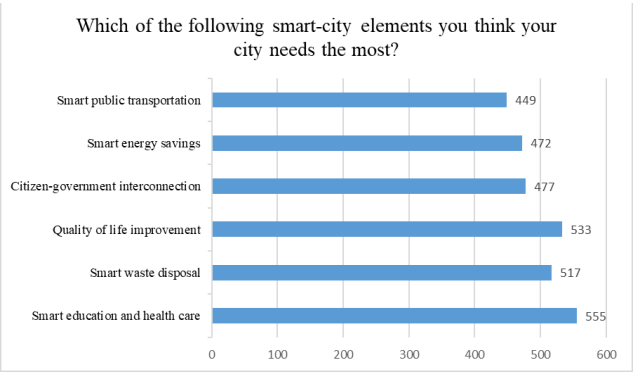

Figure 3: Question 7: Which of the following smart-city elements you think your city needs the most?

(carpooling) as the elements of the smart-city (all of which are false answers). Therefore, it's important to notice that more than half of the respondents are, to some extent, unsure of the term smart-city.

Out of the 350 respondents which selected Smart benches as an element of a smart-city, 76% answered they know what a smart-city is. Also, 72% who selected free Wi-Fi in bars also thought they knew what the smart-city is. Similar percentage is evident in the third false answer: where 79% of respondents who selected shared drives (carpooling) said they knew what the term smart-city means. So, seemingly it looked like the respondents understood the elements of smart-city, but for these non elements they answered incorrectly.

In the question number 6: "Which of the following elements of the smart-city are already provided in the city you live in?" the respondents concluded that 24.8% don't have any of the above elements implemented in their city. 41.5% of respondents stated they have smart benches and 49.9% stated they have free Wi-Fi in bars, which are incorrect answers.

Question seven (7): "Which of the following smart-city elements you think your city needs the most?" represents the opinions of respondents on the smart-city elements needed in their city. The most respondents concluded they primarily need: smart education and healthcare, better citizen-government interconnection, and quality of life improvement, roughly around 80%. (shown in Figure 3). The result suggests that the local self-governments need to educate citizens considerably on the topic because citizens are eager to learn about smart-city methodology.

Question eight (8) was: "Does the introduction of smart-city elements increase the quality of your lives?" Out of the 673 respondents, only 1.5% think that implementing smart-city elements will not improve their quality of life, in comparison to 93.5% who answered positively, while the rest answered: "I don't know". Out of 10 respondents which answered negatively, all of them stated in the final open-ended question that their city is not "smart".

Question nine (9): "Are you familiar with any initiatives your local government is facilitating regarding smart-city elements?" is perhaps the most important question for our research (See Figure 4). The answers indicate that only 19.3% of all the respondents actually knew what their local government is doing regarding smart-city implementation projects. Such a low percentage may indicate one or more of the following:

a) Croatian local governments are not transparent and they are closed to the public;

b) Croatian local governments do not have any plans and/or resources to implement smart-city solutions;

c) Croatian citizens do not have any instruments to inquire or participate in implementing smart-city solutions;

d) Croatian citizens are not interested in local politics and improving the city they live in.

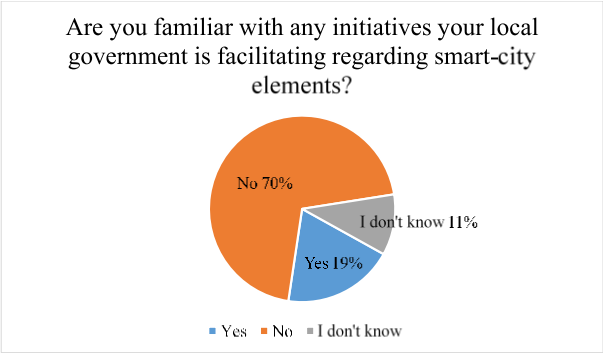

Figure 4: Question 9: Are you familiar with any initiatives your local government is facilitating regarding smart-city elements?

Answers on Question number ten (10): "When do you expect your city will implement some elements of a smart-city?" provide following results: 51% of respondents think that their city will either never implement, or it will take more than 10 years to implement smart-city elements in the city they live in. Only 6% think that it will take less than three years for their local government to implement smart-city elements. The result indicates that people are untrustworthy towards the local governments in Croatia and/or the resources are insufficient for the implementation of smart-city elements (See Figure 5). The reason for this might be that many of the challenges faced by smart cities surpass the capacities, capabilities, and reaches of their traditional institutions and their classical processes of governing, and therefore require new and innovative forms of governance [9].

Surprisingly, a significant percentage of respondents (72%) answered that that they would actively participate in joint decision making within a digital platform on projects relevant to the development of their city. In addition, 26% of them answered that they would participate passively (i.e. following announcements). Therefore, we conclude that Croatian citizens are very interested in participating in local projects, since only 2% of the respondents answered that they would not participate in the (co)decision making processes (See Figure 6).

There are a few succesful cities in Europe (Barcelona and Amsterdam), which developed systems where citizens and companies can easily interact on solving key issues with 'smart' solutions. Barcelona's project "BCN Open Challenge" set out six challenges for businesses and

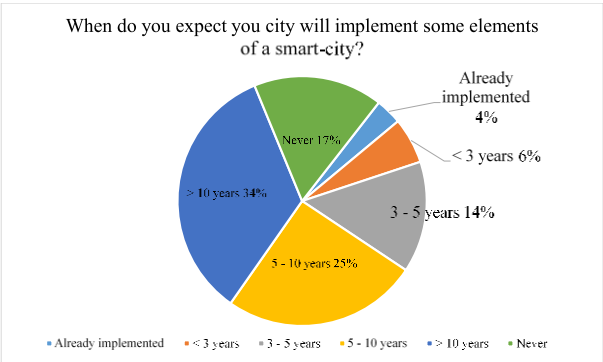

Figure 5: Question 10: When do you expect you city will implement some elements of a smart-city?

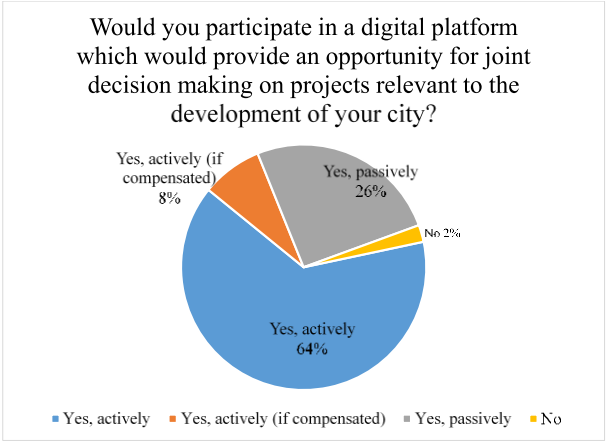

Figure 6: Question 11: Would you participate in a digital platform which would provide an opportunity for joint decision making on projects relevant to the development of your city?

entrepreneurs to provide solutions for transforming public spaces and services. [10] Similarly, Amsterdam Smart City is an online platform which connects all interested parties in one goal: dealing with 'smart city' problems and solutions [11] aiming to improve the functioning infrastructure, access to resources, and safety and security for the population [12].

Croatia needs a fundamental shift, when we think of Croatian cities and about urban development in the near future. Citizen participation reduces government corruption by expanding public insight and decentralizing government power [13] by giving them the ultimate decision in the adoption of the city's services. Building smart-cities through the concession agreements and public procurement models are necessary for the development of all mentioned smart-city elements and improvement of local governments, by helping them become more competent and transparent when awarding concessions and performing public procurement contracts.

The twelfth (final) question: "Do you think the city you live in is "smart" and explain why? was included as an open-ended question. Respondents could freely write and explain their answer. Out of the 673 participants, 589 answered that their city is not "smart" (negative); 22 answered that their city is "smart" (positive); 56 respondents answered answers such as "partly, somewhat, better than the rest, it has potential" (categorized as partly yes); and six (6) respondents did not provide any identifiable answer (Unidentified), as provided in the Figure 7 below. The results indicate that 88% of the respondents' state that their city is not "smart" and needs

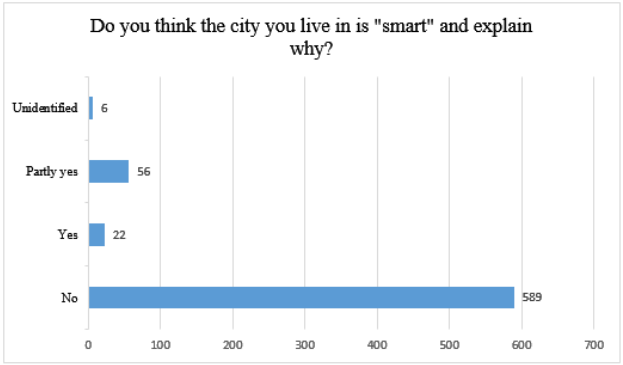

Figure 7: Question 12: Do you think the city you live in is "smart" and explain why?

improvements.

IV. CONCLUSION

The idea behind this paper was to explore Croatian citizens' view towards implementation of smart-city elements into Croatian cities and to use the results of this questionnaire in future practice. There are a few notable limitations in this questionnaire; first, the respondents are coming from different cities of different sizes and from different parts of the country. The questionnaire is intended for the population of Croatia, but the citizens are not related specifically to any region. Therefore, we cannot rule out the possibility that such differences influenced the results.

Secondly, all the questions (except Question 12) were posed as closed-ended. Close-ended questions require respondents to choose from a set of provided response-options. There are also possibilities to use open-ended questions, which we did not use in this questionnaire, (except the last question), since the usage of mixed questions is not suitable for this kind of random sample. Furthermore, Oudejans and Christian (2010) found respondents more likely to respond to narrative open-ended questions when they were interested in the topic of the questionnaire. [14] Also, there are some positive aspects when using the closed-ended questions; answering closed-ended questions is easier as well. Respondents do not have to formulate an answer in their own words. Instead, they only have to check the response option that applies to their answer, making the answering process much easier and less demanding, resulting in better response rates to closed-ended questions. [15]

From the answers of the respondents, it's evident and it can be concluded that the citizens are not familiar with the work and public policies of their local governments. Citizens are highly interested in participating and joint decision making but they are not acquainted with instruments for partaking in local governments decision making processes, due to the fact that local governments don't have and/or don't provide citizens with the plans and/or resources for adopting the elements of smart-cities. Since citizens are not provided with any instruments for joint decision making with the local governments (such as digital platforms mentioned above), we highly recommend adoption of a national-level strategy for better citizen inclusion in joint decision-making processes regarding the implementation of smart-city elements, such as mentioned successful cases from Europe.

There are, however, a few examples of Croatian cities with smart-city technologies. For examples, city of Koprivnica which has implemented smart waste system, E-governance system, electronic bill presentment and payment service (ISO Standard 37120:2014 Sustainable development of communities - Indicators for city services and quality of life) and some other small projects towards becoming a smart-city. [16] In Croatian city of Rijeka, citizens have two smart bus stops offering information which provides a better and more relevant service to citizens and tourists traveling by bus. The bus stops provide users the information on the current locations of the buses and access up to twelve (12) city cameras. [17]

The research has also shown that the Croatian cities need new models of transparent policy making and project performance. Those models should be based on using concession contracts public private partnerships, and innovation partnerships within the public procurement regulations [3].

The significance of this research is to demonstrate citizens' interest regarding possibilities of implementing elements of the smart-city and their active participation towards using models which have proven to be successful in practice. Successful practices, mainly, used concession contracts, public procurement and public private partnership models, which are already available to Croatian local governments, but still underused. This paper should encourage Croatian local governments in using this models in order to boost growth of smart-cities in Croatia.

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Attitudes to and usage of Internet and e-services by citizens in Croatia: general population vs. business population

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Abstract - This paper investigates the usage of Internet and e services by citizens in Croatia. The focus of research is to resolve, if any significant difference in use of e-services and the Internet for private purposes exists between: 1) the general population of citizens (representative sample of 2 county HRs) and 2) citizens who are employed and who are using e-services and the Internet for business purposes. The first sample includes adults from two north-west counties in Croatia (N=427), and the second one includes employees in Croatian small, middle-sized and large companies (N=436). Survey results showed significant differences in using Internet and e services for almost all activities that have been in focus of this research: information search, education, communication, social networking, entertainment, financial activities, commercial activities and participation in civil activities (petitions, discussions). Non-significant differences were found only for participating in political activities.

Keywords - ICT, e-services, benefits of ICT

I. INTRODUCTION

Most people would agree that the ability to use information and communications technology (ICT) and Internet is a prerequisite for living in information society. The benefits of usage of ICT and Internet are usually reflected in improved outcomes in education which is finally positively reflected in simpler and better employment, improved outcomes concerning the health care, increase in efficiency and savings in public services, savings in time, simpler and cheaper communication and networking and potential advantages for consumers due to the possibility of cheaper purchase of products and services.

In this research, the benefits that ICT and the Internet offer for general population and business population are categorized into economic, social and individual benefits. These benefits would occurred for Internet and e-service users that are in focus of this research and presented by two populations. One include citizens in general population and second citizens that are employed and use Internet and e services at workplace.

Research question is, does significant difference exist in frequency of usage of Internet and e-services between those two groups when they use them in private purposes.

II. BENEFITS OF ICT

The benefits that ICT brings can be categorized into economic, social and individual benefits.

A. Economic benefits

From the standpoint of individuals who use ICT, the common opinion is that people are able to find better jobs, earn higher incomes, and provide a better life for themselves and their families [1-4]. Slightly discouraging fact is, according to the OECD study for 2013 that only 39% of individuals in the EU labour force judged their computer skills to be sufficient to look for a job or change a job within a year [5, p. 88].

ICT and the Internet expand the number of consumers and increase their opportunities in the electronic marketplace, thus stimulate digital economy and contribute to the overall economic growth [6]. An interesting trend, which is associated with e-inclusion, is the increasing importance of corporate social responsibility. E inclusion contributes to more effective use of limited resources for both companies and government, multiplying the reach of experts and professionals beyond their normal geographic area of influence. Implemented e-inclusion projects in the field of e government, which encourage governments to develop advanced online services, make public administration more efficient and cost acceptable, and for the citizens more accessible [7]. E-inclusion can influence the reduction of costs of social and care systems [8].

Promoting e-inclusion brings significant benefits and opportunities, especially in the ICT sector market. It is confirmed that the industries closely connected to e-inclusion such as telecommunications (Nokia, Ericsson, and Siemens), media and online services, directly contribute to economic growth [9]. The European Commission also clearly emphasizes the economic benefits of e-inclusion, "the impact on European industry is clearly positive: apart from civil work for networks which has a direct impact on local employment, sales of network equipment will also benefit global European suppliers, as well as telecoms or satellite operators, and areas with advanced broadband connections will see an increase in demand for products and services" [10]. The initial estimates indicate that benefits from e-inclusion in the countries of the EU could be in the order of €35 to €85 billion over 5 years [11]. In addition, broadband Internet

connection is expected to create 1 million jobs and boost the EU's economy by €850 billion between 2006 and 2015 [12]. To take full advantage of the economic benefits that e inclusion offers, countries must be led by governments that recognize ICT and the Internet as a major driver of growth, innovation and economic development.

B. Social benefits

The society is becoming increasingly networked and ICT and the Internet serve as one of the primary and critical forces for shaping society structures. Therefore, social power in today's digital era is increasingly related to the abilities to use new forms of ICT [13]. On the other hand, inequality in the use and application of ICT and the Internet is a potentially significant new driver of social exclusion, which can accelerate existing social divides and create new ones [6]. In countries where the policy initiatives were designed to promote e-inclusion, the risk of social exclusion is replaced by social cohesion that stems from active citizenship and a strong culture participation [14]. The use of ICT and the Internet allows people simpler, easier and cheaper way to create and maintain contact with communities, family and friends and thereby prevent or reduce the risk of isolation and social exclusion. It also contributes to an increase of social capital [15, 16], which is important for all people, but mainly for the disabled and people with special needs by providing tools for overcoming the motoric, perceptual or cognitive difficulties that make this participation difficult [17]. The benefit from the use of ICT and the Internet are characterized as leading to social and self-understanding benefits, interaction benefits and task-orientated goals [13]. Under self-understanding benefits increase access to ongoing social and political affairs or health information, interaction benefits increase connectivity and social support, while under task-orientated benefits are entailed to financial management, telework, travel, shopping etc.

Active participation in the information society for people would result in improvement of social relationships, improvement of job possibilities and, in general, in active participation in all other spheres of society.

C. Individual benefits

Individual benefits of e-inclusion can be classified into several categories [6, 9]: (1) improved access to information and dissemination of information; (2) improved opportunities for education; (3) facilitation of employment, improvement of working conditions and salary prospects; (4) improved opportunities for social interaction and communication; (5) improved supply of commercial and public goods and services; (6) improved opportunities for saving time and money; (7) improved opportunities for entertainment and leisure; (8) improved opportunities for identity formation and psychological development; (9) improved opportunities in health and social care; (10) improved opportunities for cultural understanding. In terms of access to information and the dissemination of information, e-inclusion brings users opportunities to be constantly up-to-date and informed, rapidly and efficiently reach all the contents needed in a given moment and at a given place - at home, at work, on the move.

Research in this area proves that people are often more motivated by e-learning and encouraged to conduct greater independent study. A growing array of educational software applications and the use of social media applications offer opportunities for lessons to be individually adjusted to the student's needs in ways that the classic way of teaching never could [18]. The usage of ICT and the Internet has positive effects on learning and cognitive development through interactive learning styles, by supporting new multimedial ways of presenting information [19]. A major role in employment play the necessary skills that one must possess for the use of ICT, the so-called e-skills or digital skills. For individuals, lack of e-skills and low digital literacy can affect life chances including educational and employment opportunities [20]. According to research of Department for Education and Skills (2002), 60% of existing and 90% of new jobs require ICT skills [21]. People, who are ICT-literate, in principle, stand a better chance in the job market. In turn, job vacancies are increasingly advertised on the Internet. In this respect, European e-skills forum (2004) emphasizes that e-Inclusion is crucial and to a large extent can help each individual realise their full potential by empowering them [22]. The extent to which an individual is able to establish diverse social connections (like Facebook, Twitter, LinkedIn etc.) can be an important factor in their successful incorporation into the labour market [9, 23]. Enhanced employability and salary prospects could include greater self-sufficiency from the state, improved financial security and greater quality of life for an individual. Slightly discouraging is that, regardless of the number of strategies adopted by EU countries related to the acquisition of ICT and digital skills, according to the study of OECD for 2013, more than 60% of the EU labour force reported their computer skills as being insufficient to apply for a new job [24].

Social relations are very important for the functioning of individuals and society as a whole. ICT and the Internet also play a considerable role in simplifying interactions between citizens and public authorities thanks to the digitalisation and automatisation of many processes. The overall share of citizens that use ICT and the Internet to perform administrative procedures has increased in recent years. However, still not sufficiently, which is confirmed by the OECD report for 2014 that states that, on average, only 35% of users in OECD countries use e-government services [24]. In order to satisfy the wishes and needs for products and services, e-inclusion provides great benefits for consumers. Research conducted by the OECD shows that today, on average, 47% of customers in OECD countries decide to buy products or services online, up from 30% in 2007. It is expected that in future this trend will continue because at the present time this way of purchase already replaced traditional distribution channels for some categories of products and services [24].

One of the main goals of ICT and Internet services nowadays is to satisfy the necessity of people for entertainment. For the purpose of entertainment various forms of services and tools are available, from on-line gaming, portable consoles, MP3 players, social networking (YouTube, Facebook, SecondLife) to watching movies, listening to music, sharing and trading pictures, stories,

drawings, software, music, videos, visiting museums, watching theatrical performances, searching for travel destinations, visiting forums in order to collectively practice hobbies etc.

One of the most outstanding benefits of e-inclusion is in the field of health and social care. Doctors can remotely assist or monitor vital parameters of patients anywhere and anytime. The so-called assistive technologies, supported by ICT and the Internet, play an important role in health care [26]. Many studies have researched the benefits of ICT and assistive technologies for the elderly, disabled people and for people with special needs. Such technologies enable such groups to reach autonomy, dignity and opportunities for independent living [27-29]. All these opportunities are also excellent responses to the social challenge of inclusion, which contributes to minimizing person isolation from the society through e-inclusion mechanisms.

III. RESEARCH DESIGN AND METHODOLOGY

With the aim to investigate the use of Internet and electronic services by citizens in Croatia, which include e learning, e employment, e communication, e government, e commerce, e entertainment, e culture and e health services, a survey on two representative samples were made. The first sample includes adults from two north-west counties in Croatia (N=427), and the second one includes employees in Croatian small, middle-sized and large companies (N=436).

Before any survey, on these two samples, extensive literature review has been done and validation of measuring instrument was performed in pilot study online.

As the first step, a new research measuring instrument (a questionnaire) has been developed, with 78 items related to digital economy (25 items), e-learning (6 items), e-health (17 items), e-government (15 items), e-culture, e-communication and e-entertainment (15 items). The questionnaire items were accompanied by two types of five-point Likert's scales (from ”1-strongly disagree“ to ”5-strongly agree“; from ”1-not at all“ to ”5-very frequently“). These 78 items were supplemented with socio-demographic indicators: questions regarding participants' age, gender, place of residence, employment and infrastructure. In the next step, the research was continued with content validation of the measuring instrument in which a panel of experts from Croatia and Austria participated. In qualitative content validity analysis, experts' recommendations are adopted on observing grammar, using appropriate and correct words, applying correct and proper order of words in items and indicators. For quantitative content validation by two empirical indicators are used: Content Validity Ratio (CVR) and average value of relative importance. In order to additionally reduce the number of items, as well as for the purpose of preliminary determination of the number of factors in the remaining set of items, factor analysis was performed. In order to collect the data for the possibility of implementing factor analysis a pilot study on a convenient sample of respondents was conducted. An online questionnaire was designed for data collection. To contact potential respondents electronic mail, social network (Facebook) and e learning system of Faculty of Organisation and Informatics were used. The data collection period via an online survey lasted three months, i.e. from June to September 2014. The Kaiser-Meyer-Olkin (KMO) test of sampling adequacy and Bartlett's test of sphericity were examined to check that the requirements for factor extraction were met (for more see Hutcheson and Sofroniou, 1999) [30]. For the extraction of factor, the factor analysis method here applied is ”maximum likelihood“ with orthogonal Varimax rotation method and Keiser normalisation. Also to assess the fit of the model the percentage of non-redundant residuals with absolute values grater then 0.05 was examined independent (more about factor analysis see Cureton, D'Agostino, 2009) [31]. To approximate the reliability of a measuring instrument, its degree of internal consistency should be determined. This study employed Cronbach's Alpha reliability coefficient for measuring internal consistency of extracted factors.

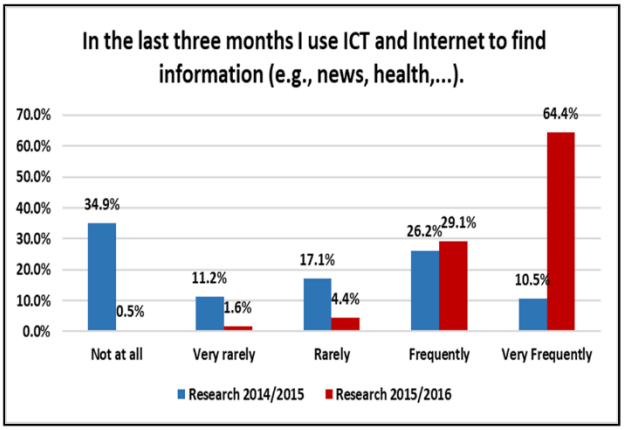
The main part of the research, for first population (citizens in general population) was conducted on a representative sample, which was developed with help of the Croatian Bureau of Statistics. Instrument included 35 items from initially defined 78 items, reduced and modified after validation of measuring instrument in pilot study. The sample was comprised of adults in two counties in Croatia (Varaždin and Međimurje County), according to a defined address sample taken from the Census of Population, Households and Dwellings in the Croatia in 2011. Representative sample Fieldwork for the research was conducted via face-to-face oral interviews during December 2014 and January 2015. Eleven qualified interviewers conducted the interviewing. The number of adults (18+) who participated in the survey and have properly filled out the questionnaire is 427.

After the first research on (general population) in 2014/2015 the second survey was also made but this time on citizens that work as employees in Croatian small, middle-sized and large companies (business population) with the same 35 survey items. Research was conducted in the period end of 2015 beginning of 2016 through online questionnaire. The questionnaire was sent to the 23,805 e-mail addresses of SMEs and large companies, whereby 436 properly completed surveys were collected. During the survey, company contacts in the Republic of Croatia were collected through the database of Croatian Chamber of Economy called BIZNET (2017) [32] according to the county centers including the city of Zagreb. Sample was made from 151.445 active companies in Croatia according to two criteria: a) size of company and b) availability of contact or e-mail address. Total of the active companies in December 2015 was 151.445 companies, from which, by size and availability of mail contact, in the sample was taken total of 23,805 enterprises i.e. the sample makes 15.71% of the population. In this sample, the return of properly completed surveys was 436 i.e. 1.83% of the sample.

IV. RESULTS OF DATA ANALYSIS AND DISCUSSION

After survey conducted on general population of examinees in Međimurje and Varaždin County (research 2014/2015, N=427) and second survey conducted on the population of subjects employed in Croatian small, middle-sized and big companies (research 2015/2016, N=436), a

detailed analysis of the research results acquired is presented in the continuation, as well as of the results of variance analysis conducted on the two sets of subjects aforementioned.



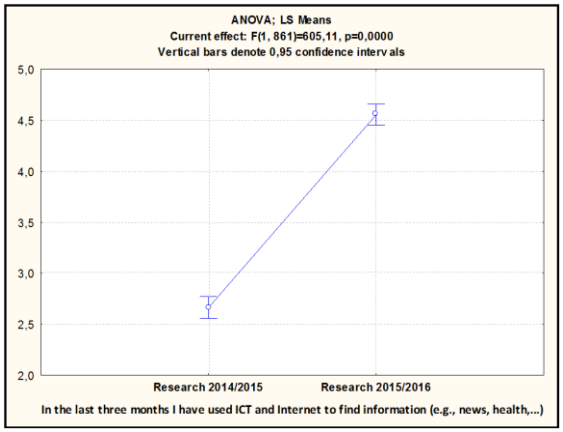
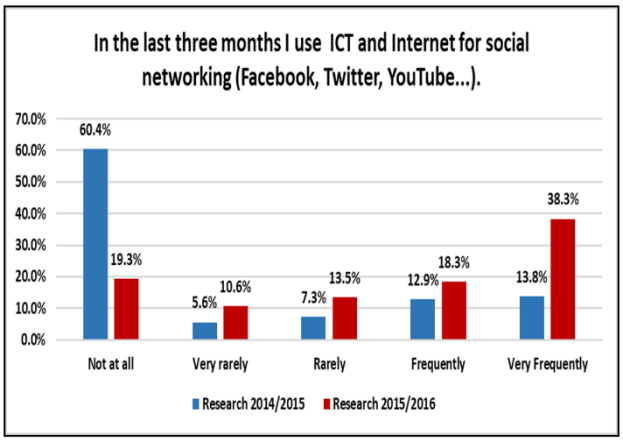


Figure 1. The use of ICT and the Internet for information search

Figure 1 clearly shows that subjects who use ICT and the Internet in their business activities on everyday basis (research 2015/2016) tend to do the same when they do their private searches (ex. news, health care…), since 93.05% stated they do that "often" or "very often", unlike general population (research 2014/2015), where only 36.7% claimed they do it "often" or "very often". The conducted variance analysis confirms a significant difference between the two given sets of examinees (df=1, df2=861 F=605,111, p=0.000).

ICT and the Internet for educational purposes are also used significantly more by subjects who do the same for their everyday business activities. 65.9% claimed they do it "often" or "very often", while the research conducted on the general population presents surprising data where 63.2% of subjects said they do not use ICT or the Internet for educational purposes at all. Significant difference between these two researches was confirmed here as well (df1=1, df2=861 F=542,991, p=0.000).

When researching the use of ICT and the Internet from the aspect of communication, one can notice that subjects of the research conducted in 2015/2016 use it greatly, due to the fact that 96.6% of examinees claimed they use ICT and the Internet for such purpose "often" or "very often", unlike the examinees from 2014/2015, where there are only 38.6% of them in Varaždin and Međimurje county. Significant differences among the subjects were confirmed in this case, too (df1=1, df2=861, F=16997.63, p=0.000).



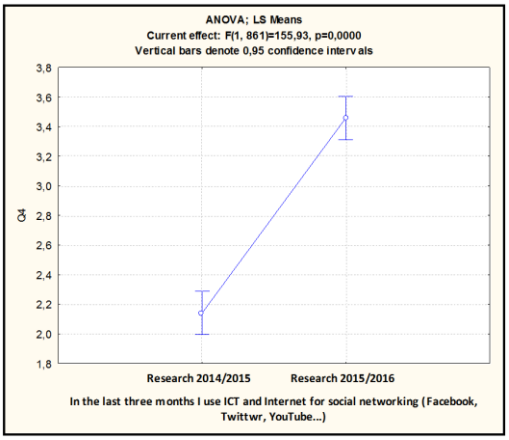
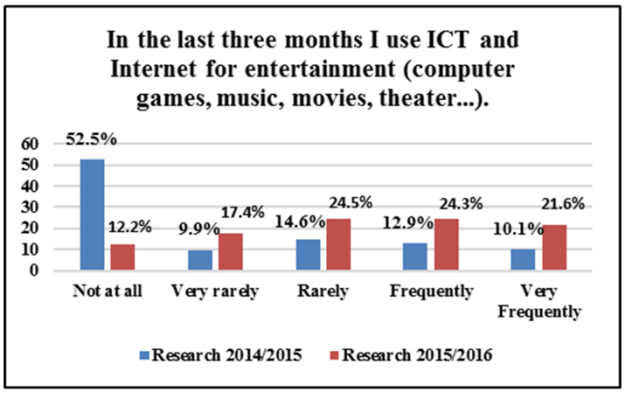


Figure 2. The use of ICT and the Internet for social networking

Examinees from Varaždin and Međimurje County do not prefer connecting via social networks (2014/2015); over 70% of them declared they do not do it at all, "very rarely" or "rarely" (Figure 2). Over 55% of employees who use ICT and the Internet in their everyday business activities (research 2015/2016) do that "often" or "very often". Significant difference was clear between these two groups of examinees (df1=1, df2=86, F=155.932, p=0.000).



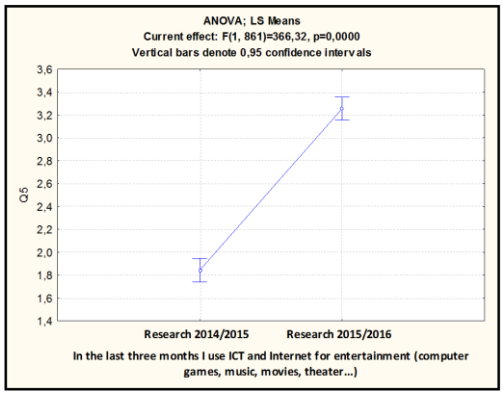
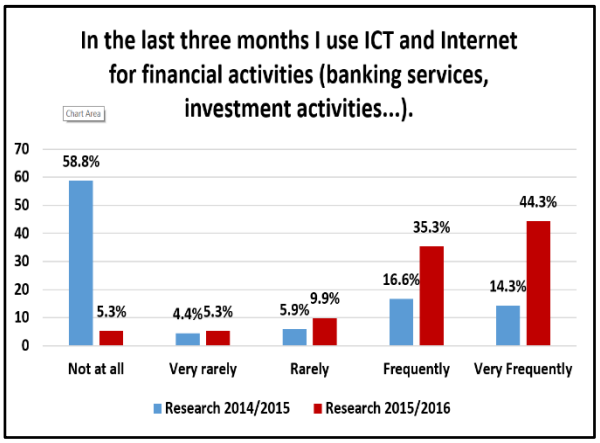


Figure 3. The use of ICT and the Internet for entertainment

While observing the use of ICT and the Internet from the aspect of entertainment, such as listening to music, watching films or playing computer games, data analysis indicates that both groups use it rarely (Figure 3). On the one hand, 77% of subjects from the research conducted in 2014/2015 said they do not use ICT and the Internet for such purpose at all, "very rarely" or "rarely", while on the other hand, 12.2% of examinees from the research conducted in 2015/2016 do not use it at all, while only 21.6% use it "very often" but nevertheless, significant differences were confirmed here as well (df1=1, df2= 861, F=366.315, p=0.000).

Figure 4 allows observation that the share of subjects using ICT and the Internet for everyday business activities use the same greatly for commercial activities, too. No less than 68.9% declared themselves as doing the same "often" or "very often", unlike general population (research 2014/2015), where it is only 21.5% of them. Concerning the issue of commercial activities, significant difference was also confirmed between the two researches (df1=1, df2=861, F=367.046, p=0.000).



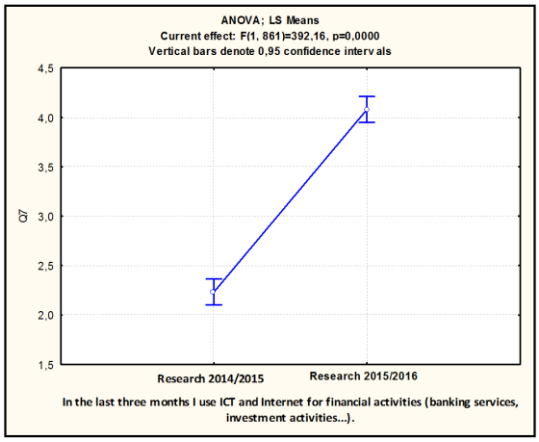


Figure 4. The use of ICT and the Internet for financial activities

Equally as with commercial activities, the same trend of use was noted with financial activities. Everyday use of ICT and the Internet for business activities has positive influence on active use of the same for, for instance, financial activities, confirmed by the data presented in figure 4, where one can take note of the fact that a group of examinees from the research conducted in 2015/2016, no less than 79.6%, use ICT and the which is Internet for such purposes "often" or "very often", while a very low percentage of general population (research 2014/2015), only 30.09% out of total number of examinees (N=427), said they use it "often" or "very often", but the fact that is most surprising is that no less than 58.8% of examinees claimed they do not use ICT or the Internet for financial activities. A significant difference was confirmed in this case, too (df1=1, df2=861, F=382.18, p=0.000). Taking part in certain activities, such as signing petitions, voting or discussions, is not customary via ICT and the Internet, which can be noticed with both groups of subjects (Figure 5). Such a way of using ICT and the Internet is not done at all by no less than 89.9% of examinees in the research conducted in two Croatian counties in 2014/2015, as well as with the group of subjects in the research of employees' population from 2015/2016. Variance analysis once again confirmed significant difference (df1=1, df2=816 F=677,876, p=0.000).

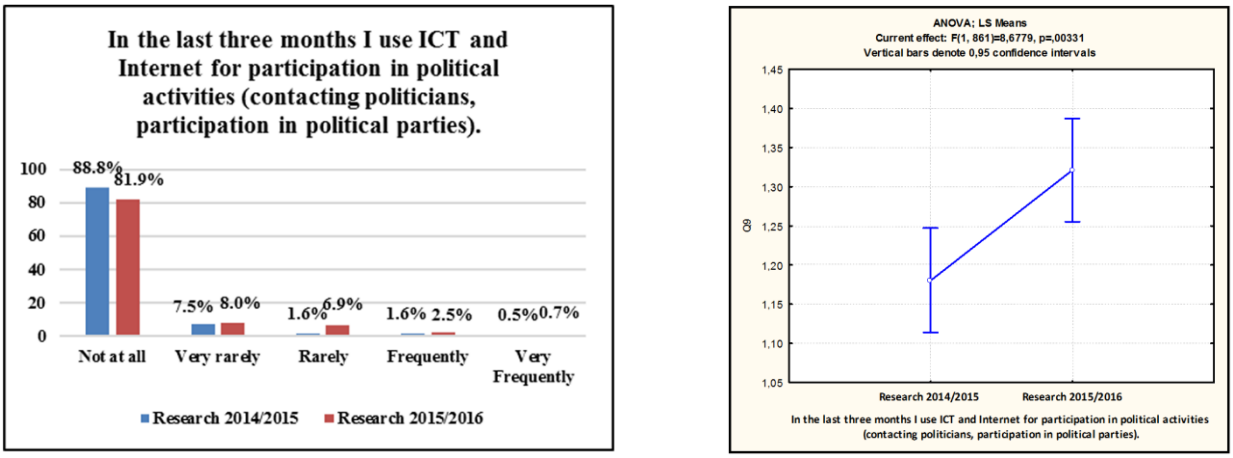


Figure 5. The use of ICT and the Internet for political activities

Croatian citizens' lack of interest for taking part politically speaking is visible in times of election, hence the fact that subjects in both researches do not use ICT and the Internet for purposes of political participation, or use it "rarely" or "very rarely". 97.9% of examinees in the research conducted in 2014/2015 do not use ICT and the Internet, or use it "rarely" or "very rarely", while insignificantly smaller difference (96.8%; ANOVA df1=1, df2= 361, F=8.678, p=0.00331) can be noticed with subjects using ICT and the Internet for business activities on everyday basis (research 2015/2016).

Figure 6 makes it clear that a significantly larger percentage of subjects in research conducted in 2015/2016 declared themselves that using ICT and the Internet has become their daily routine, no less than 90.8% of them, unlike the general population in two Croatian counties (Međimurje and Varaždin), where only 45.2% said the use has become a daily routine for them. Variance analysis showed significant differences for these two groups of examinees (df1=1, df2=861, F=325.033, p=0.000000).

Examinees (research 2015/2016) using ICT and the Internet for business activities on a daily basis show more concern for Internet safety, manipulating and gathering personal information, as well as for confidentiality of personal data than general population, where only 60% express great concern. A significant fact concerning the research conducted on general population (research 2014/2015) is that almost 40% remain indifferent, ie have no attitude towards the topic.

Concerning this, variance analysis confirmed significant difference between these two sets of examinees (df1=1, df2=861, F=56.275, p=0.000000 and df1=1, df2=861, F=58,059, p=0.000000).

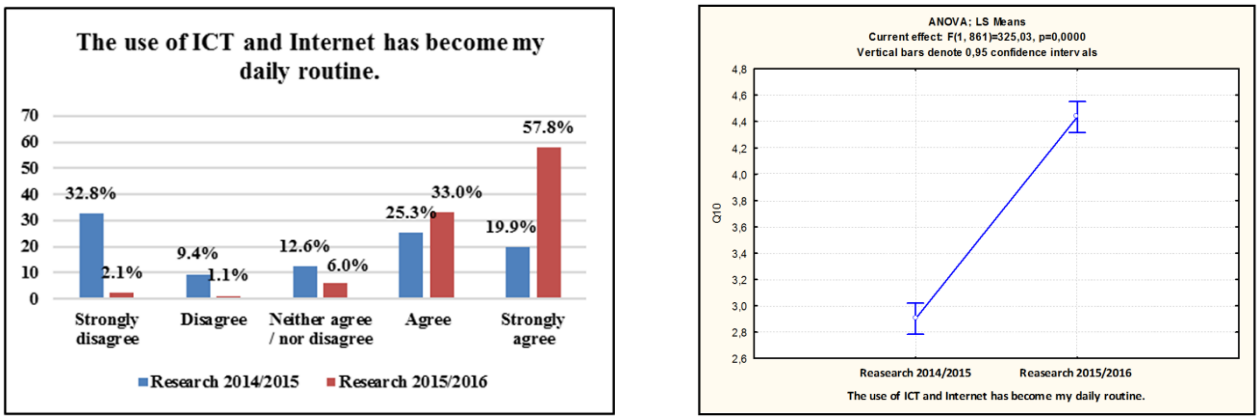
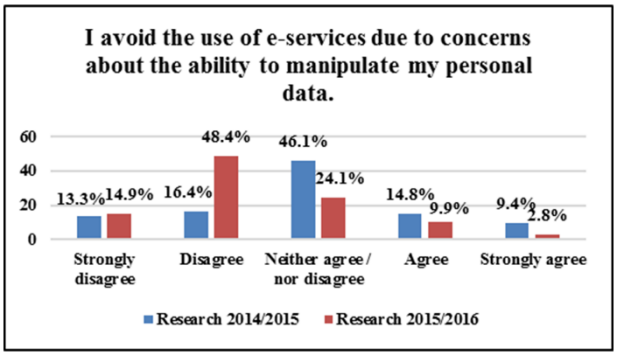


Figure 6. The use of ICT and the Internet on daily basis

An interesting notion that can be observed from Figure 7, connected to Internet safety, is that whether or not examinees using ICT and the Internet for business activities on a daily basis are more concerned about Internet safety, this is not the actual reason for their avoiding e-services (63.3%). One can thus conclude they are more inclined towards using e-services, regardless of their attitude concerning Internet safety. As with the previous picture, one can also realise that a great percentage of subjects in general population (research 2014/2015) do not express their attitude towards the topic (46.1%). Concerning the matter, variance analysis confirmed significant difference between these two sets of subjects (df1=1, df2=861, F=35.380, p=0.000000).



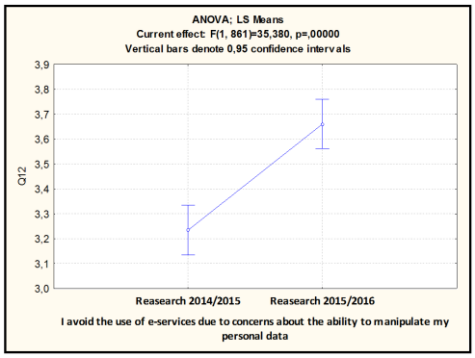


Figure 7. Attitudes related to the use of e-Services and Internet Security

V. CONCLUSION

The objectives of this research was to investigate the use of Internet and e services by citizens for private purposes in Croatia on two population: first include citizens in general population (general population) and second citizens that are employed and use Internet and e services at workplace (business population). Among other things, the purpose of the research was also to determine whether there are significant differences in the use of Internet and e-services between these two populations. The presented results show that a significant difference in the use of Internet and e services between the general and business population exists in almost all activities except in the political and that the use of ICT and the Internet is considerably higher in the business population of citizens than in the general population of citizens..

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Examining Digital Government and Public Service Provision: The Case of Finland

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***Abstract* - Finland is one country that has long embraced technology in many aspects of her existence. To understand the present outlook of digital government and public service provision in Finland, an evaluation is necessary. This paper explores the successes and challenges of digital government in relation to public service provision through relevant reports and by focusing on policy strategies, implementations, and innovativeness. The case of Finland revealed that digital government via the e-government framework is vital in the areas of democracy and decision-making, health care, education, integration, security, land survey and social services provision. Areas that require improvements are collaboration, coordination, partnership building between stakeholders, funding, fiscal policies, expertise, literacy, and acceptance. In addition, is addressing the problems of data deluge and ethical dilemmas (trust), and inequality questions.**

Keywords - Digital Government; egovernment; public sector; public service provision; Finland

I. INTRODUCTION

Digital government is part of the broader change management and new public management reform ideas. Change management is often referred to as the general strategy adopted in teaching and helping institutions, governments, groups, societies and individuals to pursue and realize change. Formulating change and implementing change in administration are two different things with unique challenges, though the latter is said to be more complex than the former (Brunsson 2009). Technological innovations of various kinds have made governance more modernized and accessible to more people at different levels (local, national and global). Growth in digital technologies such as internet services has changed the traditional models of governance. The modernizations have mainly manifested in the delivery of public services and expansion in the geographical and demographic reaches of governance.

Examining how digital government shapes public governance (formulation and implementation of public service) is evaluating the definition and principles of action, mission statement, guideline or regulatory framework (do´s and don´ts), administrative and implementation aspects of tools, results, successes, challenges, and prospects. A contemporary perspective on examining the relationship that exists between citizens and governments/institutions would include ways of providing citizens with better, satisfactory, and secured services with the most comfortable costs. In addition, is examining the future of public governance (e.g. the roles of artificial intelligence in future public sectors). Finland is one the countries that have embraced technology in many aspects of their endeavors. In the past two decades, the government of Finland has invested massively in technology and innovations at both national and local levels of administration. The massive investments have mainly concerned the formulation and implementation of public policies and services through the digital government or ICT strategies. The policies of digitalization in Finland have yielded mixed outcomes. Digital government in relation to public service provision has been successful in most contexts and aspects and faced challenges in other aspects and contexts; thereby, needing improvements. According to University of Vaasa (2018), the ICT sector in Finland suffers from human capacity limitation (labor shortages), which has been identified as a major hindrance to Finland´s economic growth and the development of digitalization of the Finnish society; to be specific the software industry has labor shortages of thousands of experts nationwide. Figure 1 is a representation of objective and focus of this paper.

Digitalization is using and welcoming things that have been transformed to digital forms; the digital transformation part concerns the effect(s) of digitization (Khan (2016). According to the World Economic Forum (2017), the digital revolution has transformed the traditional ways of doing things in our modern world. This transformation has also been witnessed in the areas of governance, which is now called digital government. Figure 1 is a representation of the objective outlook.

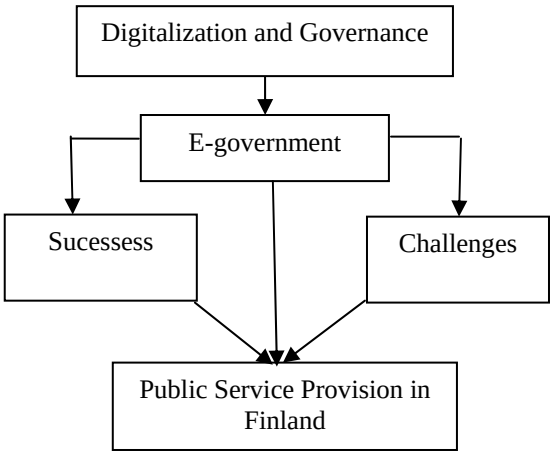

Figure1: Overview of Objective

Digital government is a more recent and broader concept in comparison to the e-government concept. The strategies of digital government and e-government are similar. However, in reviewing the concept of digital government in relation to public service provision, the e-government framework is more encouraged, because of the availability of real cases and experience.

The key aim of this paper is to examine the contemporary outlook of digital government and public service provision in Finland via the e-government framework. The successes and challenges in Finland are explored through policy strategies, implementations, and innovativeness. The case study uses information/data from different national and international reports (desk research) as justification for analysis and evaluation of e-government outlook in Finland. This represents the broader outlook of digital government and public service provision in Finland.

II. REFORMS AND DIGITALIZATION IN PUBLIC SECTOR.

Dimensions to understand the relationships between reforms and digitalization in the public sector are numerous. The popular dimensions are political and administrative dimension, economic dimension, social dimension, anti-corruption dimension, exponential technologies dimension, energy transition dimension etc. From the political and administrative dimension, we understand/study the provision of public services and ways governments and institutions relate with their citizens, because it is proven that technology is an essential part of good governance. From the economic dimension, we study/understand how human and capital growth are affected; one key question to ask in this regard could related to what is the contribution of the informal sector or activities of criminal organizations to the GDP. (OECD 2016; & European Police Office 2017.) According to Global Security (2017), criminal networks in Italy for example contribute 20-27% to the Italian GDP. Social dimension helps us to study/understand interactions between different individuals and groups/institutions. The anti-corruption dimension helps to study/understand how digital tools could enhance or serve as solution to corrupt activities (e.g. fraud). According to Tickner (2015: 1-8), technology plays a crucial role in the fight against corruption and other unethical activities. From the exponential technology dimension, we study/understand the relevance of emerging technologies (e.g. artificial intelligence) in the future of human existence and public sector. From the energy transition dimension, we study/understand the nature, relevance and future of energy in our world (OECD 2016; & European Police Office 2017).

Digitalization is highly reflected in all the models of New Public Management (NPM) reform ideas, which are the Market Model, Flexible Government Model, Deregulating Government Model, Participatory State Model and E-Governance Model. The market model stipulates that the assumptions of private sector model are the best ways of managing the public sector, where digital tools enhance efficiency. The participatory state model focuses on the need for democratic and collective mechanisms to be key features in governance by understanding what the public wants and finding ways toward fulfilling them; digital tools help in the realization of this objective. The flexible government model stresses the need for government and its agencies to make appropriate policy responses to environmental changes rather than just responding in their habitual ways to what are inherently novel changes; digitalization is an essential part of the change. The permanence of government, both for individual and public organisations is generally regarded as inimical to growth. At a more basic level, a flexible government is simply one that is capable of responding effectively to new challenges and of surviving in the face of changes. Deregulating government model emphasises the need for the reduction of formalised rules and regulations and the elimination of rules that would cause delay to public service functions. Therefore, the public service workers would be less controlled in carrying out the public business, because *Administrative discretion* becomes a relevant tool for the public service worker in the day-to-day dealings under this model.

Digital tools are vital here in helping public officers to become more flexible. E–Governance model of reform is quite a new approach in reforming the public sector. This model emphasises the adoption information and communication technologies (ICTs) in the management of public service to make it more functional by increasing growth and reducing unnecessary delay (red tape). (Simon 1997; Peters 2001; & Riley 2003.) According to Peters (2001), the values that have informed the need for change in the management of public sectors include that of modernization, internationalization and societal/cultural advancements.

A. *Definition of Digital Government and Roles in Public Service Provision*

Digital government is an idea and pattern of guaranteeing accountability and effective organization through digital procedures. Digital government has different definitions and interpretations, but central to all is the one relating to dissemination and generation of services and information within institutions/government from one perspective and between institutions/government and citizens or public from another perspective through the adoption of ICT strategies. According to Fountain (2004), digital government can be summarized as the production and delivery of services and information inside government and between government and the public, in order to formulate and implement government/public responsibilities; the two natures of government relationships that exist within this framework is government-to-citizen and government-to-government relationships. According to OECD (2016), governments in most developed countries have been urged to develop and implement digital government strategies in order to realize digital transformation; this became imperative, because of the key contribution of digital technologies as a strategic enhancer in creating open, participatory and trustworthy public sectors in improving social inclusiveness and governmental accountability, and to connect government and non-government actors and develop new approaches to add to national development and long-term sustainable growth.

The Digital government ideas have mostly manifested through the e-government framework. It is through the e-government framework that strategies relating to digital government have been experimented in many countries. The e-government framework is most suitable, because the issue is not to introduce digital technologies into public administration (digitalization), but to integrate the use of digital technologies into public sector modernization efforts (transformative digital government) (OECD 2016:7). According to Gunter (2006), e-government is a modernized form of government that uses solid and reliable information and communication technologies (ICT) in the provision of public services to citizens (G2C), institutions, and other relevant stakeholders. E-government is not only relevant to the public sector, but also the business sector from the angles of corporate governance, hybridity and service efficiency. According to Johnson (2002), Government to Business (G2B) services has good benefits for companies in areas of cost cutting. Through the e-government framework, relevant tools (software, hardware, applications etc.) are adopted or used to provide the relevant services; some of these tools include social media, internet and other computer and mobile technologies/applications such as e-voting and e-participation tools. Special arears of public services that the e-government tools have been tested in different countries include educations services, social care and protection services, health care service, integration services, security service etc. The tools of digital government in general play different good roles in the society, but also have their unique challenges; the social media for example is good platform for information sharing between individuals and groups, but it is also an avenue through which evil, unethical and corrupt activities are executed by bad individuals/groups. Labor and financial challenges have limited the efficiency and effectiveness of digital public service provision in many nations and useful solutions are being sourced to tackle these challenges (Johnson 2007).

III. THE CASE OF FINLAND

Like in many countries, digital government through the e-government framework is about the provision of public services to citizens, institutions and other stakeholders in Finland. Digital government in Finland has a long history, the pioneering policies are traceable to the 1970s when ICT was considered as an essential part of good governance. However, the 1990s was considered the golden era when Finland became one of the leading information technology countries. In the 1990s, Finland was ranked topmost in internet connections per capital and technological innovations development. Numerous e-government projects were initiated and implemented in Finland in the 1990s and the country became one of the international best practices and case study for other nations. Public service provision in Finland through the e-government framework has been implemented in different sector. According to the Finnish Prime Minister (Mr Juha Sipilä), digitalization is high on the government program, because public services shall be developed primarily as digital; in May 2015, Finland published its National Action Plan, which is the 100th National Action Plan published under the Open Government Partnership since its creation in 2011. This being the 2nd Action Plan for Finland, the aim was to commit the country in making online services more market oriented and focusing on the Youth participation in Government and Open Data. (OECD 2003; & European Commission 2015.)

Key areas that digitalization has been adopted in public service provision are health care provision, social service provision, security service provision, integration service provision, and election and citizen participation services (e.g. e-voting, e-democracy, and e-participation). However, different arguments, results and prospects have followed digitalization and public service provision in Finland and to understand these more clearly, the policy successes and challenges are explored through its strategies, implementations, and innovativeness.

The strategic breakdown of digitalization into different operational areas has enhanced the effectiveness and focus in respective sectors. At the beginning of digital government policy formulation in Finland, a clear directive was issued by the Finnish Government on the need to separate digitalization between the public sector and private sector. The open government action plan has

been another strategic success in Finland, because online services have become more citizen-friendly and youth participation in government is at the highest point. Official data of state has become more accessible to citizens/public with the inclusion of good public service provision through the government to citizens (G2C) initiatives. The successes of the policy dichotomy and open government action plan have been enhanced by the legal and ethical frameworks availability and viability. The implementations of digital government policy through the e-government framework have been successful through the development of digital tools at central, regional and local governments and institutional levels. (Ministry of Finance 2009; European Commission 2015; OECD 2003; OECD 2016; & OECD 2017.) Table 1 shows the success outlook.

Table 1: The Success Outlook

Digital Government and Public Service Provision	Key Areas of Success
Strategy	- Breakdown of digitalization into different operational areas. - Open government action plan and government to citizen G2C initiatives - Legal and ethical frameworks backup
Implementation	- Development of digital tools at central, regional, and local governments and institutional levels - Voting and participation services - Health care and educational service provisions - Security and integration service provisions - Social care provision and land survey activities
Innovativeness	- Broadening of scope

Sources: Ministry of Finance (2009); European Commission (2015); OECD (2003); OECD (2016); & OECD (2017)

The development of digital tools at different levels in Finland has helped Finnish citizens to participate in democracy and decision-making through e-voting and e-participation services; in addition, health care (e-archiving and e-prescription), education (clouding), integration, security, social care, and land survey activities have been made more accessible, transparent, convenient, effective and efficient to citizens and other stakeholders in Finland. The success of digital government policy in Finland is also characterized by its innovativeness in relation to scope broadening, because the Finnish government is presently switching to digital innovations in every sector (e.g. energy transition) and questions of artificial intelligence as part of future public sector is being answered. (Ministry of Finance 2009; European Commission 2015; OECD 2003; OECD 2016; & OECD 2017.)

The statistical breakdown of the successes of e-government in Finland are represented in the Eurostat (2018) evaluation report. Figure 2 is a representation of people in Finland using internet to interact with public authorities

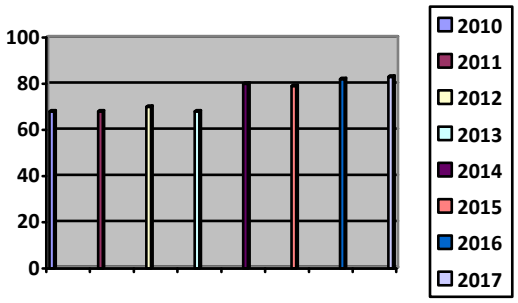

Figure 2: Individuals using the internet for interacting with public authorities (Eurostat 2018).

According to the Eurostat (2018) report, the percentage of people using the internet to interact with public authorities in Finland has grown from 68% in 2010 to 83% in 2017. Other statistical data to evaluate the successes of e-government in Finland is derivable from the European Commission (2015: 6) report. The report shows that the percentage of people who use the internet to obtain information from public authorities in Finland has grown from 61% in 2010 to 74% in 2015; the percentage of individuals using the internet for downloading official forms from public authorities in Finland has grown from 49% in 2010 to 63% in 2015; and the percentage of individuals using the internet for sending filled forms to public authorities in Finland has grown from 39% in 2010 to 59% in 2015. In enhancing more, the success of e-government in Finland according to the European Commission (2015: 8) report, the Ministry of Finance and Population Register Centre have launched the Data Exchange Layer on November 18, 2015, which is premised on the Estonian X-Road model and software. The Data Exchange Layer would help to

standardize the mode of exchanging information between public sector organizations and national datasets and in the future enables the use of other services developed in the National Architecture for Digital Services program. According to the Ministry of Finance (2009), the program on electronic service and democracy (SADe) in Finland considers the experiences of end-users of all e-services and the gap that exists between national government and municipalities. However, Challenges exist in relevant areas of e-government and public service provision. Table 2 is a representation of some of the key challenges:

Table 2: The Challenge Outlook

Digital Government and Public Service Provision	Key Areas of Challenge
Strategy	- Collaboration, coordination and partnership building limitations
Implementation	- Financial and fiscal limitations - Expertise/labor limitations - Illiteracy and Acceptance - Data deluge and ethical dilemmas (professional ethics, anonymity/privacy, security, secrecy, & trust issues)
Innovativeness	- The inequality question

Sources: Ministry of Finance (2009); European Commission (2015); OECD (2003); OECD (2016); & OECD (2017).

A key strategic challenge of digital government policy in Finland is related to the issues of collaboration, coordination, and partnership building limitations. According to OECD (2016) and European Commission (2015: 26), the nature of autonomy that exist between the different levels of administration in Finland is a key challenge to e-government policies formulation in Finland. The local governments/administrations, municipalities and regional governments in Finland enjoy a high level of autonomy in both administrative and financial senses. The administrative and financial autonomies make the formulation and updating of general digital government policies in Finland challenging, because different authorities could have different interests at the same time. According to the OECD (2016: 50-51), local governments collects a high share of the general government revenues in Finland, compared to other OECD countries, which is also reflected in the distribution of general government spending. This largely helps them to determine the direction and speed of digitalization of governance, though the act on Information Management Governance in Public Administration allows that the Ministry of Finance has to be consulted when it comes to huge or significant ICT procurement (European Commission 2016: 20).

For the implementation of digital government in relation to public service provision in Finland, finance/money is still a key challenge. The financial and economic crisis has negatively affected the efficiency and effectiveness of e-government implementation in Finland. The implementation challenge is supported by unfriendly and not very transparent fiscal policies and objectives in Finland that often do not put the long run and interest of every stakeholder into consideration. (European Commission 2015 & OECD 2016.) The inadequate technical expertise that exists in Finland is another challenge to the implementation of digital government in relation to public service provision in Finland. According to University of Vaasa (2018), the ICT sector in Finland suffers from human capacity limitation (labor shortages), which has affected e-government implementation. The issue of digital literacy is another challenge to the implementation of digital government in relation public service provision in Finland. According to Eurostat (2018: 4-7), about 7% of the Finnish population have difficulties in using e-government tools such as the internet and social media. The problem of digital illiteracy also affects the acceptance of e-government tools at both individual and institutional levels. The challenge of “data deluge” is another challenge that limit e-government implementation in Finland. According to OECD (2016: 35-37), healthcare provision in Nordic states including Finland is affected by data deluge or explosion, because of the huge gap that exists between service supply and feedback from one perspective and management of big or public data from another perspective. The challenge of ethical dilemma in relation professional ethics, anonymity/privacy, security, secrecy, and trust also affect negatively the implementation of e-government tools; especially, in the areas of democracy and health care provision in Finland (European Commission 2015 & OECD 2016).

The innovativeness of digital government policy in Finland has not adequately addressed the inequality question that exists in Finland. According to the European Commission (2015: 18-19), the “Government Information Society Programme” has a key objectives of boosting competitiveness and productivity, and promoting social and regional equality through effective utilization of information and communications technologies throughout the society. The value differences that exist between different generations (X, Y

and Z) at work must be included in future modifications of e-government strategies and implementation in Finland (OECD 2016).

IV. CONLUSION

Digital government as part of public service provision and good governance requirements in Finland has been largely successful; especially, through the e-government framework. Digital government has been defined as part of broader change management and new public management reform ideas in the public sector. Change remains a constant in life and this philosophy has manifested in different perspectives in contemporary administration. Digital government can be summarized as the production and delivery of services and information within government or institution and between government, institution and the public, in order to formulate and implement government/public responsibilities; the two natures of government relationships that exist within this framework are government-to-citizen and government-to-government relationships. The formulation and implementation of public policies and services in Finland have been strongly affected by the growth and use of technological tools. The significance of technology in contemporary administration and governance cannot be overemphasized; especially, as it concerns public institutions and citizens; institutions and execution of public services; and other economic and societal relevance. The case of Finland has revealed from the various reports studied that digital government through the framework of e-government has a good strategic breakdown, action plans and backups.

E-government in Finland is vital to the participation of citizens in aspects of democracy and decision-making; in addition, is helping in health care, education, integration, security, land survey, and social services provision. The implementation of e-government have been enhanced by the development of digital tools at central, regional and municipal governments and institutional levels. The innovativeness of digital government in relation to public service provision essentially concerns scope broadening such as the energy transition. However, after a careful review of different reports on the case of Finland, areas of improvement are still numerous such as improving collaboration, coordination, partnership building between stakeholders, funding, fiscal policies, expertise (labor shortages), literacy level, individual and institutional acceptances. In addition, is addressing the problem of data deluge or explosion and issues relating to ethical dilemmas (e.g. trust and security). Finally, plans relating to future innovations must include ways to address the general inequality questions that exist in Finland.

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A New Concept of a Smart City: Utilizing the Analysis of Existing Concepts and Comparative Solutions

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***Abstract* - The accelerated rate of urbanization leads to numerous detrimental effects such as overpopulation, air pollution, light pollution and traffic jams. The city authorities all over the world are aided by various technologies in tackling these issues. The application of technologies such as IoT and BigData and their integration via numerous open-source solutions enables the creation of various smart solutions and environments.**

The purpose of this paper is to present a smart city concept with reference to already tested and successful projects. The focus of the paper is the analysis of implemented solutions in major cities worldwide as well as the entire process leading up to the final implementation. Furthermore, the paper will discuss the kinds of adaptations at various levels which are necessary to implement in order to create an adequate concept.

Research methods such as analysis and description as well as secondary data processing will be utilized to analyse the finalized projects, all of which include the application of technologies to create smart solutions and environments.

The paper suggests a new model of a smart city based on the use of ICT technologies and smart solutions aimed at the enhancement of the living conditions in large metropolitan areas.

Keywords - Io T, BigData, open-source, technologies,

I. INTRODUCTION

ICT solutions were instrumental in effecting numerous changes in user groups everyday activities, ever since the first applications of such methods to this day. However, the introduction of ICT solutions into every pore of society brings about changes on a much larger scale than ever before. Although the solutions display a high variability, they are not uniform and every society or community utilizes the ICT solutions in accordance with their needs. However, it is impossible to account for all areas of ICT application (required for every system) using available examples in order to ensure a successful application.

II. CONCEPTS OF A SMART CITY

A successful implementation of smart technologies in cities is greatly contingent upon the readiness to accept such technologies. Only when new technologies are implemented in such a manner as to act in synergy, and as such contribute to the quality of life, the contours of a smart city begin to emerge. A general definition of a smart city (one that everybody can agree upon) is still not available for several reasons. One such reason is that every community applies different solutions in their areas, depending on their needs. Therefore, some definitions include solely the implementation of new technologies and sustainability as key reference points to designate a certain place as a smart city. Other definitions, for example, emphasize that it is necessary to include elements such as the intertwining of numerous levels of authorities in their coordinated efforts to realize better efficiency of city management [1]. However, all definitions available for analysis point in the same direction: the focus is on the user. After all, the user stands at the very core of all systems oriented towards technological and innovative solutions. The system is dependent upon the user and the success of every project depends on the users themselves.

A well-known example of a planned and directional development of a smart city is Amsterdam, Netherlands. The project of developing smart solutions targeted issues such as the reduction of CO2 gas emissions. The project consisted of five phases and they included [2]:

- An initial phase where all partners participating in the project present clear goals
- The planning phase where clear guidelines are formulated, pertaining to the accomplishment of goals
- The project development (generating project ideas etc.)
- Monitoring and evaluation

The final, rather uncommon, phase for such projects is communication, namely all information about the success and further steps are made available publicly in order to

enable other large metropolitan areas and cities to apply the proposed project structure. This final step can be construed as an initiative to define guidelines globally regarding the projects whose goal it is to provide suggestions for the smart solutions implementation [3].

As early as 2004, Seoul Special City, the capital of South Korea, has attempted to implement ICT solutions within the existing infrastructure in order to strengthen its competitive advantages. However, the City approach was limited to the enhancement of the existing services and new solutions were neither sought nor applied. Bearing this in mind, the results of this project were positive regarding the improvement of traditional services. However, smart solutions demand incorporation of multiple systems, thus creating new services and integrating several already existing. The Smart Seoul Project 2015 superseded the previous project in the City. The focus of this project was more user -oriented, the holistic dimension is more pronounced and the solutions were not applied merely to improve certain services but to integrate several of such services, thus creating a collaborative environment [4].

The notion discussed above, that the implementation of smart solutions varies from city to city and consequently demands different frameworks, vividly demonstrates the dynamism of smart solutions implementation. The Smart Seoul project has produced three ‘’axioms’’ which served as the guidelines in development of proposed solutions [5]. Proactive approach is advocated, namely the ICT infrastructure is considered in a long-term perspective. The solutions that were to be implemented have to be as new as possible, always bearing in mind the long-term requirements of the city.

A major study authored by Juan M. Barrionuevo, Pascual Berrone and Joan E. Ricart [6] has defined a planned, three-phase process of building a smart city. Since our proposal includes only the initial phase of a smart city project, we will refer here to this phase alone. The process of planning and execution a smart city project can be time consuming that can stretch over decades. The first phase includes the assessment of the current situation. Or to put it in another word, it is necessary to ascertain the key areas where the implementation of smart solutions would achieve the most positive effect. Available data is also used in the initial phase as well as benchmarking with other cities which implemented smart solutions. The rationale is that the solutions already applied were proven successful before the decision has been made to implement them in a new context.

III. Definitions Of A Smart City: Discussion

The problematics of defining a smart city stems, as discussed above, from the varying nature of projects and the area of application process of innovative technological solutions. The ACIMER group project attempted to produce a working definition of a smart city [7]:

> *“A Smart City is an integrated system in which human and social capital interact, using technology-based solutions. It aims to efficiently achieve sustainable and resilient development and a high quality of life on the basis of a multi-stakeholder, municipality-based partnership.”*

This definition clearly focuses on various forms of humans-related capital i.e. what constitutes a frame of reference in a certain community. Furthermore, these forms of capital are placed in the context of an integrated, technology-based system in order to enhance the quality of life as well as working conditions by increasing the number of involved stakeholders in a certain area.

The following definition designates clear spheres of action which is implied in [8]:

> *„A Smart City is a city well performing in a forward-looking way in these six characteristics, built on the ‘smart’ combination of endowments and activities of self-decisive, independent and aware citizens”*

A definition proposed by V. Albino, U. Berardi and R. M. Dangelico in the Smart Cities, Definitions, Dimensions, Performance, and Initiatives, determines a smart city as an environment where all available resources, together with technology, are integrated in a manner to contribute to the general wellbeing and sustainability of an area.

To quote the authors directly [9]:

> *„Being a smart city means using all available technology and resources in an intelligent and coordinated manner to develop urban centres’ that are at once integrated, habitable and sustainable.”*

IV. Smart Cities: Technology And The Market

The uninhibited functioning of devices and applications requires a thoughtful deliberation on ICT solutions in smart cities. Open source solutions offer interoperability and an added impetus to develop new and innovative products. The investments such as production facilities and the rights for using the source code are unnecessary in this context. The markets regarding smart cites solutions grow exponentially and the structure of market leaders is changing as well.

The data compiled in the Navigant research leaderboard report [10], depicts predicted growth of markets (by world regions and in millions of US dollars) involving solutions for smart cities. It is apparent that progressive growth causes the doubling of incomes in less than a decade, approximately every five years. The strongest growth is predicted in Latin American markets. One of the main reasons for such an expansive market growth is the entrance of an ever-larger number of technological giants in the field of smart solutions development. As data compiled by Eric Woods and Noah Goldstein

demonstrates, the leaders in the solutions market are companies such as Cisco and IBM [11]. It is a well-known fact and practically a matter of common knowledge that These companies presented their solutions in the computer network niche for decades now.

The communication between sensors and server locations and data processing applications must be flawless. The protocols used by sensors at locations where smart solutions are utilized, must be developed in a manner to insure the maximum flow of information at minimal costs. **LoRa** LPWAN protocol is a solution that conforms to such demands [12]. This protocol offers low costs and large coverage area. The connectivity range is larger than any existing protocol for wireless communication. Further advantage of this protocol lies in the fact that separated network parts or communication channels are available, thus the traffic effected by wireless network users does not interfere with the traffic from sensor to the transmission point.

V. NEW CONCEPT – COMPARATIVE SOLUTION

Following the discussion on successful application of smart solutions in various projects, this section will elaborate a concept of multiple solutions application in order to create a productivity effect with the citizens and users in a certain environment.

The application of the concept is demonstrated in Fig. 1 using booking services for the tourist season. The future guest forms a decision to visit a certain place in a smart city environment. The guests book their accommodations via any online platform available, such as booking.com. This system sends the booking information to the establishment owner and the information also reaches the national system where all visits are recorded. The central computer system receives the information on a weekly basis on potential visitors, the duration of their visit etc. (the system is restricted to meta information only; the personal information is not available in the system as it is restricted to booking application chosen by the visitor) The main computer system processes the information and, using an algorithm, provides a certain output on the number of potential visitors and the country of origin. The commo needs are patterns etc.

The central system sends the information to eMarket which is then used for market control. The eMarket system can, based on the inputs on user increase, define future demand and react in a timely and adequate manner. Accordingly Fig 2. , the eMarket system sends the prices information in the opposite direction in order to prevent market instability, the constitution of cartels etc. Up to this point, infrastructural thus defined as well as behaviour interventions are completely unnecessary (except perhaps when the infrastructure demands improvements). The financing of this part of the project will be secured through private funds or through state subsidies. The

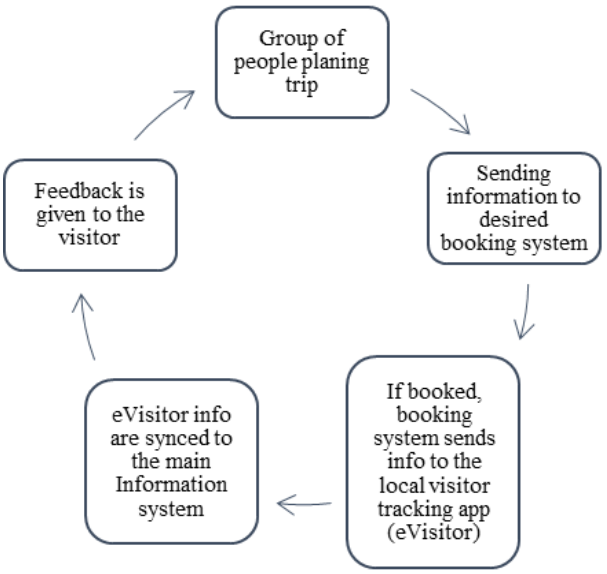

Figure 1 Model of the smart city: First phase, Getting the information (source: author)

suppliers of staple goods stand to benefit greatly from such a system as they will be in a position to receive precise information on future demand of goods and thus minimize the potentially excessive costs of supply, storage etc. The main computer system sends the information to eInfrastrucure system Fig 3. The goal of this system is to prevent excessive overload of all infrastructural components in a certain area (roads, water consumption,

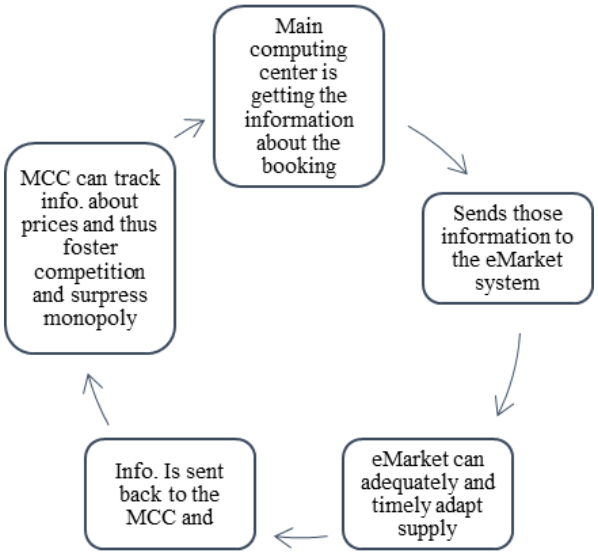

Figure 2 Model of the smart city: Second phase, MCC and eMarket interaction (source: author)

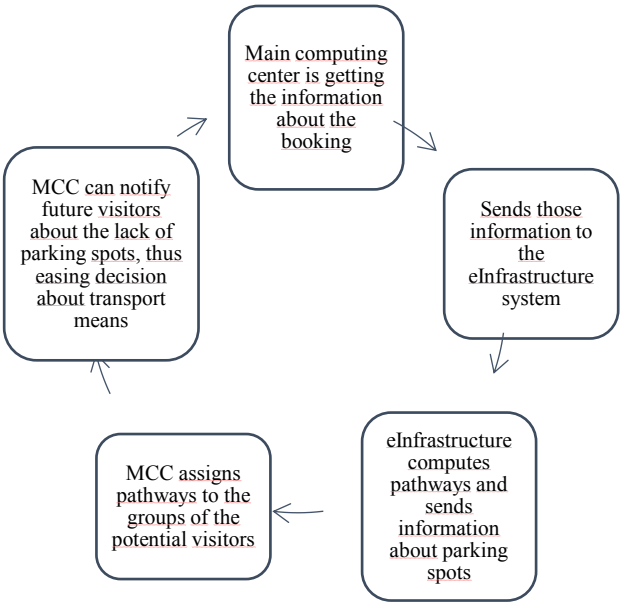

Figure 3 Model of the smart city: Third phase, MCC and eInfrastructure interaction (source: author)

parking etc.). Based on the received information, the eInfrastructure system defines and groups potential visitors and assigns an ideal path to the destination, segmented according to time, road tolls and arrival date. The same system compares the number of available parking spots in the city and conducts a simulation of an overall roads jamming. Accordingly, the information is passed on to the main system where information on infrastructural overload is stored. The main system compares the received meta data and additional options available at the booking phase. The information is thus available to booking systems as a means of optimization. This part of the concept application demands the implementation of sensors at all parking zones, the roads equipped with traffic density sensors, pollution etc. In the case where the building of these elements is required, the project can be financed from the state budget, residential taxes and excise duties on motor vehicles. The final application of the smart system refers to every visitor of certain attractions and destinations, whether tourists or the local inhabitants. The possession of the application enables all users to access the information on current and potential visitors. The model proposed here tracks the overload of attractions and enables the reduction of visitor number and reorganization of visitor activities by appropriate redistribution of visitors to various attractions in each destination. This part of the model, named eCapaCity, emphasizes the contribution of the entire system to the enhancement of living conditions, both for the tourists and visitors to certain attractions in a certain destination. The carrying capacity of a certain destination or attraction is the main variable taken into account. eCapaCity enables the users to rationally use their leisure time in conditions of an accelerated life rhythm. The unnecessary delays and loss of time is avoided and various forms of pollution are decreased.

VI. Required Infrastructure And Layered Design

The proposed implementation of smart solutions does not require numerous interventions in the environment of a particular place. It does, however, require fundamental restructuring of tasks performed by the employees on an everyday basis. The system contributes to the elimination of uncertainty upon the definition of business plans, thereby contributing to the market stability and minimizing the need to perform trend analysis because the actual data is available in real time. The implementation or the integration of various systems must consider the overload of each system. For instance, the first phase of the concept, which includes the acquisition of information on visitors who booked their accommodation through online services, requires a definition of interrelationship between all stakeholders involved. The information on visitors is highly sensitive and it is imperative to identify exactly which information will be passed on to the central system within the destination.

The accommodation providers will still receive complete information from the online accommodation booking services. When the accommodation providers receive the information, they can be included in the system, either automatically or through an intervention by the accommodation providers. After the information is entered in the overnights record system, the data is synchronized in the main system (MCC). The Fig 4 implicates that only part of information is sent and the rest is coded, precisely for the purpose of protecting the personal information. Afterwards Fig 5, the MCC segments the data in discrete groups, depending on the system the information is sent to. Hence, the eMarket system receives only the information on age structure and the country of origin. The advantage of a layered design is the reduction of overload in each component involved. The MCC, as the central system, carries the greatest workload in data processing and segmenting. While the MCC carries the greatest workload, the remaining systems receive ready-made data which can be utilized in analytics and return the results back to the MCC.

The layered design improves the capacity to sustain computer attacks as well as the data processing problems. For example, if the data received from the eInfrastructure

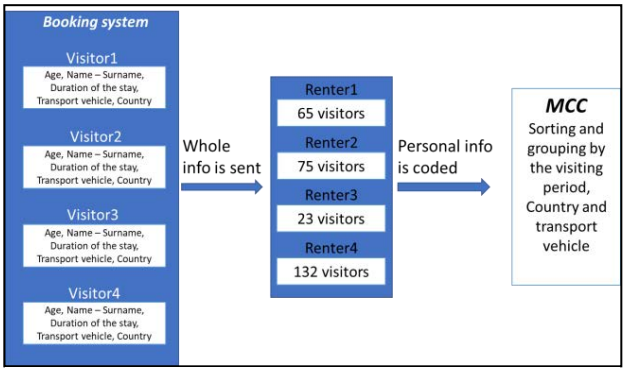

Figure 4 Model of the smart city: Data flow and data privacy (source: author)

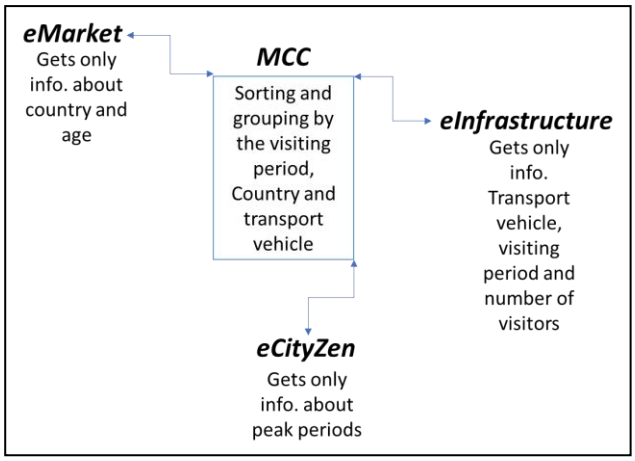

Figure 5 Model of the smart city: Data flow between information systems (source: author)

are for some reason corrupted, the problem is easily identifiable by first isolating and then analyzing the eInfrastructure system. In the eventuality that the problem is not found in the first layer i.e. in the eInfrastructure layer, the problem can be escalated to the MCC system, and then, if necessary, to troubleshoot other layers in the system.

VII. Benefits Of The Model And Further Research

The benefits of this model of a smart city concept go well beyond the concept of the smart city itself. The model of central data processing system provides a means to unburden all the other systems included in the concept. Thus, the investment is reduced to a single, central object, while other systems can be facilitated by other tools such as cloud virtualizations/solutions etc. Tourism, as the most progressive factor in any destination, has a great impact on all spheres of life. The implementation of this system would unburden the infrastructure while potential visitors would receive precise instructions from the system which is placed in the destination itself. Both the inhabitants and the visitors can receive information on traffic jams in a timely manner and how to avoid them efficiently. All of these solutions only grow in power as the system is complemented by other smart cities and innovative solutions. The system proposed here is, in fact, a skeleton upon which additional traits are built necessary for precise benefits. For example, users are in a position to receive real-time information provided that multiple cities and systems are attached to the central system. Pre-planned routes from eInfrastructure system can be redefined as visitors move towards the destination, thereby enhancing the feeling of satisfaction and the experience of the voyage to the destination itself. Precise drafting and the definition of actions within the system is quite necessary to define, as well as the communication between the systems. The various frameworks of user data utilization have to be considered seriously and consistently. The system such as the one proposed in this paper should not be viewed from the technological point alone because the end users are at the core of the system. The structure is replete with users who are well versed in new technology but lacking in professional terminology. In that case it would be ideal to provide double designations for the entire system, services and applications used on one hand, and separate designations for professionals and expert teams who will create and maintain the system itself, on the other.

The chart demonstrates some of the benefits provided by discrete systems developed in this paper Fig 6

eInfrastructure	Better experience of the trip for the visitors. Better informing about the parking spots
eMarket	Suppressing price overgrowth. Benefits for the long-term storage for the markets
eCapaCity	Timely notification about traffic jams. Allows timely preparation during peak periods

Figure 6 Model of the smart city: Benefits of the system (source: author)

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Emerging trends in e-logistics

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***Abstract* - In the recent years technological trends behind logistics processes haves evolved significantly, from traditional logistics to widespread use of e-logistics. This transition is of crucial importance for the competitiveness within the logistics market. Internet of Things and Internet of Everything have a strong influence on the logistics itself, though it may not be entirely visible to the end user. Supply chain management changes and evolves, just as much as 3rd-party logistics and 4th-party logistics expand towards 5th-party logistics. E-Logistics develops various disciplines in which cloud-based operations, m-logistics, as well as Mobile Supply Chain Management and augmented reality are important segments in the future of logistics. There are no visible limits to aforementioned development; we are witnessing a completely new paradigm of logistics and supply chain management.**

Keywords* - *e-logistics; future logistics; cloud logistics; supply chain management

I. INTRODUCTION

Information and communication technologies (ICT) are of key importance for development of the competitiveness of logistics enterprises. Traditional businesses, not enhanced by ICT, will find it difficult to respond to the needs of the modern market. The e-commerce has become very important because of its speed, cost-effectiveness, transparency, green orientation and the way in which it analyses and processes data. In parallel, logistics is evolving into e-logistics.

There are various definitions of e-logistics, but one all-encompassing is that e-logistics is actually a transformation of the classic tools used for logistics processes in a modern way, and backed-up by Internet based technologies. However, the use of the Internet technologies in logistics processes does not mean that logistics becomes „electronic". E-logistics is essentially a complex entity (system), which includes manufacturers (distributors), logistics centres, resellers, carriers, consumers among which there is an electronic exchange of data via Internet or dedicated electronic networks with the help of mobile (wireless) and wired communication technologies with the aim to reduce data errors and improve efficiency in decision-making and more [1].

Figure 1 shows four logistics development scenarios [2], with the greatest potential for development.

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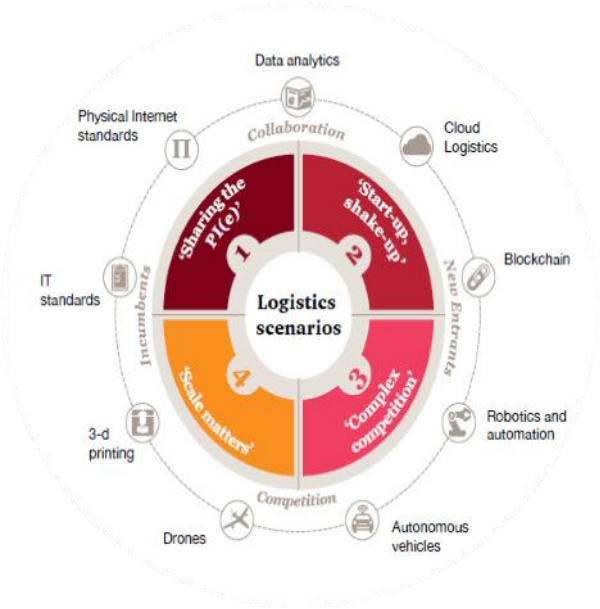

Figure 1. Logistics scenarios [2]

Some of these areas, such as cloud computing, robotics, automation and implementation and compliance with current ICT standards, are already largely implemented in logistics. For instance, the 'sharing' concept is currently thriving in logistics – from Uber-style approaches and last-mile delivery to more formal joint ventures and partnerships at the corporate level, the whole sector is redefining collaboration. But much of this is hampered by inconsistencies in for example shipment sizes, processes or IT systems. The Physical Internet promises great things for the sector, coming along with increased standardization in logistics operations [3].

II. E-LOGISTICS IN USE

In the next few chapters, some of the most used e-logistics tools or e-logistics sectors will be described and some examples of their use will be provided.

A. Cloud in logistics

Cloud computing is a term used to describe the usage of the Internet to access data, information or software. The idea behind this form of computing is that the user is no longer dependent on his PC (Personal computer), but (s)he can input and receive data independently of his

current location and distance from office and PC. This way all the information is accessible to the user regardless of used device, as long as the user is able to connect to the Internet (by laptop, smartphone, tablet etc.).

The most significant advantage of cloud computing is that it enables new platform-based business models and increases efficiency. On the other hand, cloud computing disadvantages are that the projection of costs can be unclear since once a certain scale is reached, physical data centers still tend to be cheaper for a larger company with massive demands. Also, a potential problem could be data security [4].

B. Mobile logistics

Smartphones have gained their popularity due to convenience and the possibility that the user is available everywhere and can attend to the tasks immediately. Smartphones enable product browsing, selection and shopping on-the-go. Similar to individual consumers, industrial customers expect to get shipments faster, with more flexibility and transparency at a lower price [5].

When someone, for example, buys a product through an online shop, they can track the entire course of the shipment starting from order, to warehousing, transportation, and final delivery at the door (last-mile delivery). The idea that private and corporate buyers want to keep track of what is happening with their shipment is not surprising. Such level of transparency and availability of information is required at B2B (Business to Business) and B2C (Business to Client) levels.

Mobile Solutions for Logistics offer the following features [6]:

- Mobile Warehouse Management Solutions: Know your warehouse in and out
- Door Delivery Mobile Solutions: Speed-up your door delivery services
- Mobile Asset Tracking Solutions: Know the location of every shipment
- Mobile Fleet Management Solutions: Get the most from your fleets
- Customer Servicing Solutions: Meet the needs of the modern-day customer

These features are recognized by some of the world's leading logistics companies that have offered their Android applications on Google Play (Figure 2: Transportation applications and Figure 3: Shippers' applications). The majority of applications are also available for the iOS operating system on App Store, maintained by Apple Inc.

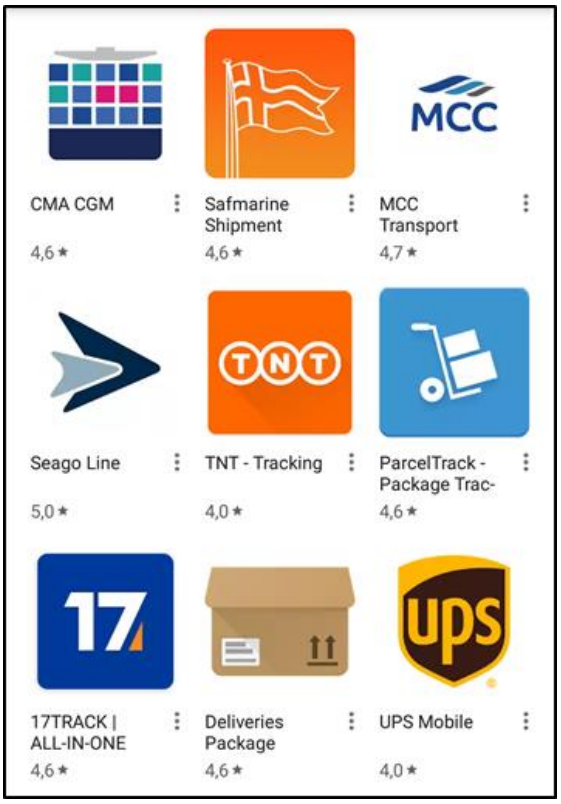

Figure 2. Transportation applications available on Google Play

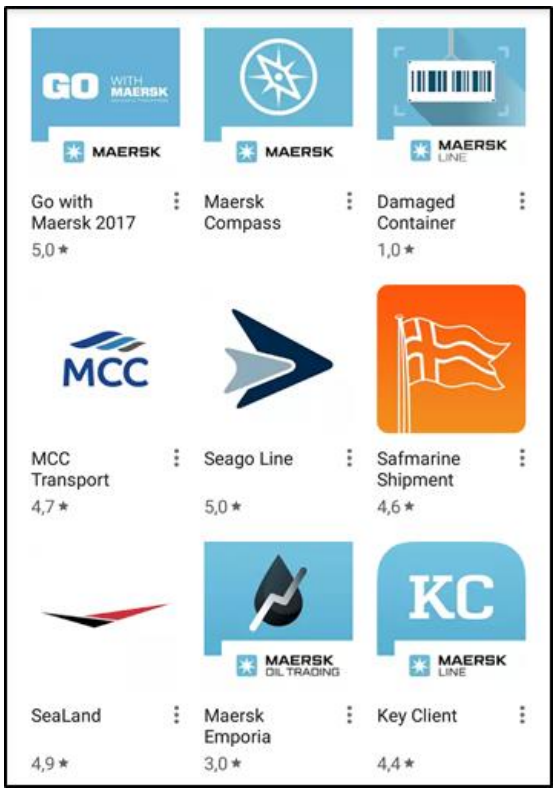

Figure 3. Shippers' applications available on Google Play

C. *Mobile Supply Chain Management*

Supply chain management intensively uses mobile devices for faster and better business process organization. For example, Oracle Mobile Supply Chain applications enable users to perform many common warehouse and shop floor transactions using wireless devices at the point of use, offering real-time transaction processing, improved data accuracy and increased mobility and convenience [7].

D. *Digital twins*

Digital twins are dynamic digital or virtual software replicas of the physical assets, products and constructions. Gartner predicts that by 2021, half of the large industrial companies will use digital twins, resulting a 10% improvement in effectiveness in those organizations [8].. As physical conditions change, the digital twin logs those changes in real time—whether it's a shipment of subassemblies delayed by a parts shortage, a delivery truck waylaid by a traffic hazard, a distribution center's operations threatened by extreme weather, or a service provider completing a maintenance job [9].

Digital twins in logistics already exist in some form. For example, Supply Chain Management uses software to simulate specific processes in order to test and analyze specific events under certain conditions, for the purpose of making the right decisions with minimum risk under controlled conditions. Such simulations could be considered as a version or type of digital twin of real production and supply chain that already exist. It is worthwhile noting that computer simulations are forerunners of digital twins that, unlike classic simulations, have far more potential for development. Simulations allow early detection of errors, proper optimization, and faster and better decision making that ultimately affects the competitiveness of the underlying business itself.

According to previously mentioned, this enables logistics companies to compete with each other in set up of a better product, i.e. a service, where each buyer/contractor could choose a future associate based on a digital twin presented.

Additionally, according to Supply Chain Quarterly, a 2016 Dotcom Distribution survey found that "almost half (47%) of shoppers said they had chosen not to order from a retailer again because of poor order transparency about their package status during the fulfilment and delivery process" [10].

Manufacturers, retailers, and other supply chain operators have some of the components of the digital twin in place—MES (Manufacturing Execution System), SCM (Supply Chain Management), ERP (Enterprise Resource Planning), and CRM (Customer Relationship Management) software to manage production; logistics and suppliers; procurement; and customer commitment. Some already use a geographic information system (GIS) to track assets and processes globally. But only a pioneering few are starting to fuse these systems to construct always-on connectivity that creates the real-time track-and-trace capability supply chain digital twin demands [11].

E. *Industry 4.0*

Just as Industry 4.0 is holistic, with a partial transfer of autonomy, intelligence and autonomous decisions to machines, supply chain and logistics in Industry 4.0 is very similar, albeit with, on top of the overlaps, different applications, technologies, human and business aspects and elements [13].

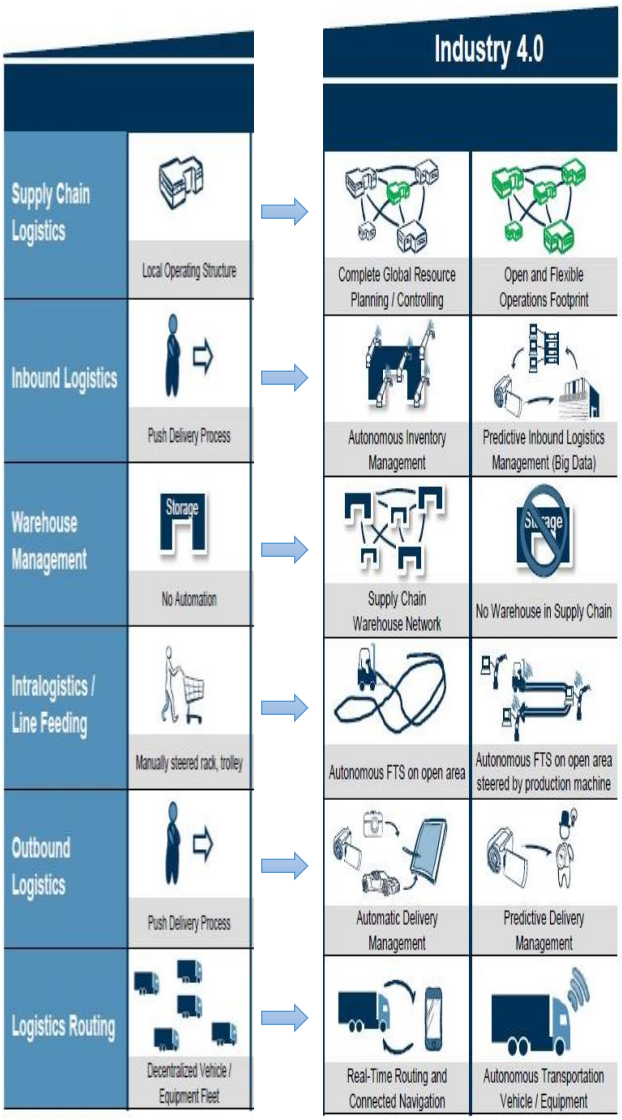

Figure 4. Evolution of Industry 4.0 [14]

Figure 4 shows the evolution of Industry 4.0. For example, warehouse management progressed from no automatization to semi- or fully automated, to finally no

warehouse at all. SCM started locally, as only locally operating structure and evolved to open and flexible operations footprint. Another example, which can already be seen tested on the roads, is logistics routing. New autonomous transportation vehicles and equipment are no longer part of distant future [14].

F. Autonomous vehicles

Autonomous forklifts and robot arms are common in modern warehouses. They load, unload and transport goods within the warehouse area, by connecting to one another and forming flexible conveyor belts. These tasks require advanced sensors, as well as vision and geo guidance technology. In addition to warehouses, autonomous vehicles are also used in airports, harbours, and yards. In the first stages of autonomous vehicle implementation, truckers' workplaces will not be endangered. The role of a trucker in the driving process will be similar to a ship's first officer. Their job will be to step in when conditions become difficult [15].

There are numerous applications of autonomous technology in modern logistics, providing further evidence that driverless vehicles are safe and successful in closed environments. It is the next evolutionary step to start applying this technology to outside premises and on public streets. Beyond warehousing operations, analysts expect many more applications in future along the entire supply chain, particularly in outdoor logistics operations, line-haul transportation, and last-mile delivery [16].

In Amazon, Kiva robots are another example of autonomous vehicle operation. On one edge of the cage, a group of human workers — the "stowers" — place products onto the shelves, replenishing the inventory. The robots whisk those shelves away, and when a customer order arrives for products stored on their backs, they queue up at stations on another edge of the cage like cars waiting to go through a toll booth. [17].

III. INNOVATIONS IN LOGISTICS

Innovation can be defined as a brand new product developed in order to respond to market needs. It can also be an already existing but improved product that was given a new, still non-existing purpose or value. Therefore, logistics has a lot of opportunities in the field of innovations. The following chapters provide a brief overview of the latest innovations in logistics.

A. Internet of Things and Internet of Everything

The industrial Internet of Things (IoT) market is estimated to reach $123.89 Billion by 2021 [18]. Internet of Things basically means connecting items or products over the Internet. IoT is a part of the Internet of Everything (IoE) or an extension of it. In this sense, it connects all of the M2M (Machine-to-Machine) communications involved in IoT, but also Machine-to-People (M2P) and technology-assisted People-to-People (P2P) interactions.

B. Start-ups

Start-up, shake up: in this scenario, new entrants in the form of start-ups make a bigger impact. The most challenging and costly last mile of delivery, in particular, becomes more fragmented, exploiting new technologies like the platform and crowd-sharing solutions. These start-ups collaborate with incumbents and complement their service offers [3].

Every five days, a digital logistics start up is born somewhere around the world. Five major start up clusters dominate the landscape: online platforms, asset management solutions, robotics/autonomous vehicles, shipping execution & tracking, and data and analytics solutions [19].

Shipping carriers, freight forwarders, and others in the supply chain struggle to deliver the right asset at the right place at the right time and reach the most optimal trade decisions. For example, ClearMetal is a start-up that generates highly accurate predictions to help the industry solve its most complex challenges, like how to efficiently place ocean containers and plan vessel space. ClearMetal's platform has shown millions of dollars of incremental savings potential and revenue generation for some of the largest logistics providers on the planet [20].

Darkstore is an on-demand delivery 3PL. They are enabling e-commerce brands to house inventory in major cities and offering on-demand and same-day delivery at low prices. Instead of owning fulfilment centres themselves, Darkstore uses extra space in storage facilities, malls, and bodegas. They don't charge e-commerce companies to store inventory but charge 3% per item that leaves Darkstore [20].

OpenSea is the first marketplace for ship chartering, enabling shipping agents to find the best matching vessels and cargoes at the best price – in effect connecting shipping agents and ship-owners [21], [22].

These start-ups are mostly producing innovations in shipping, SCM or the last mile delivery. These are some of the critical points that are still needing a better solution, speed and optimisation, because demand is focused on improvement in this areas.

C. 5th-party logistics

5th-party logistics (5PL) can be defined as broadening the scope of logistics further to e-business. [23]. A fifth party logistics provider will aggregate the demands for the 3PL and others into a bulk volume negotiation of more favourable rates with airlines and shipping companies. Non-asset based, it will work seamlessly across all disciplines [24].

The central ethos of 5PL is its commitment to collaboration and obtaining a higher degree of resource utilization in order to achieve savings and open up opportunities to secure the best possible solution at minimum financial and carbon cost [24].

D. 3D printing in logistics

Three-dimensional printing is increasingly being used in numerous business aspects, from toy manufacturing to logistics. For example, Mattel Corporation has partnered with a design software company to launch a Design App allowing users to intuitively design toys that can be connected to create larger toys. The 3D models can be created on a tablet or smartphone and sent wirelessly to the 3D printer [25].

3D printing technology can have a massive impact on how SCM works. Given that the impact on manufacturing is already apparent and cases already exist where people are printing the necessary parts (even the printed parts are already used for medical purposes), the question is when it will change the function of the supply chain we know today. DHL and DB Schenker are thinking in this direction and considering the option of the print-on-demand mode of business. Spare parts, for example, will be increasingly seen as a service with clearly defined lead time. Managing the complexity behind that service is where companies can leverage their capabilities. This will add value for the customers by reducing interfaces and complexity [26].

Thanks to 3D printing, companies may no longer need to store spare parts physically in a warehouse. Instead, they can print these parts on demand, where required, and rapidly deliver these items to the customer. In order to achieve coverage and efficiency in lead-time reduction, logistics providers could support companies in creating a dense network of 3D printers to print and deliver spare parts on demand instantly [27].

E. Drones

Logistics providers are experimenting with drone delivery to cut costs and ward off new competition from start-ups and technology companies, which have latched on to drone delivery as a potential path to disrupt (or partner with) traditional legacy logistics firms. However, delivering packages by drones to consumers' doorsteps is still years away from becoming a common occurrence. Important obstacles still need to be overcome relating to drone regulations, the development of autonomous flight and traffic control systems for drones, and consumer acceptance [28].

F. Virtual reality and Augmented reality

Virtual reality (VR) is an actual representation of reality in virtual space with the help of computer technology. Its full usage is assisted by the use of other technologies, such as a VR headset, for the user to accomplish a better sense of VR. Everything that users sees and hears impacts his feelings about the experienced VR. AR (Augmented reality) on the other hand does not simulate reality in virtuality, but instead combines them in one single experience. This way elements of VR are connected with reality simultaneously. The best example is game Pokémon GO, where the user uses the smartphone, which is an element of VR, in real life for catching Pokemon displayed on the smartphone, embedded in the real environment. Similar experiences can be implemented in several logistics processes such as transportation and warehousing.

As for Last Mile Delivery, it is the most expensive step for every e-commerce retailer. As customer bases grow and are more spread out, getting products shipped to customers cost-effectively has become a priority for many retailers. According to a DHL Trend Research report, it's estimated that drivers spend 40-60% of their time locating the correct boxes within their truck for the next delivery. For many, this process relies on their memory of how the truck is loaded. AR application could be used to streamline the time it takes to identify packages upon delivery and reduce the time it takes to figure out which package goes where [29].

G. Blockchain technology

Blockchain and Artificial Intelligence (AI) certainly made their presence felt in the logistics industry recently. With the security and transparency blockchain offers, it offers asecure and robust way to store and share transactional data, while improving credibility with a ledger of transactions that can be checked for authenticity. For example, if customer's ID proof is available digitally through a blockchain structure, it cannot be fudged by him at the time of delivery. Similarly, it's possible to map the unique blockchain-enabled registration number of every vehicle against the delivery job IDs. By 2021, as much as 25% of the large global companies will be using AI and blockchain-based automation in transactional procurement [30].

This recent technology is what drives bitcoin and other cryptocurrencies. However, the technology goes much further than a hack proof way of holding and exchanging money. Blockchain can be used for any kind of exchange, smart agreements or asset tracking. In a supply chain, it can apply to anything from self-executing supply contracts to automated cold chain management [31].

IV. CONCLUSION

As far as professions and jobs are concerned, trends suggest that the need for human workforce will reduce, but not immediately and drastically. Workers will be replaced, and already have been in the past, partially or fully, by automated machines and software. This is where the new potential and the need for development of the

specialized workforce occurs. This specialized workforce should aim to develop, maintain and improve such software and hardware. It is also essential to encourage the experts to continue moving the existing technological boundaries, which is the core foundation of all innovations.

By extending these boundaries, e-logistics will evolve, for example by 3D printing and new, virtual reality logistics where numerous tasks will be performed by software, spare parts will be printed out on the spot, and the transport process will be minimized. The idea of 3D printing will change the paradigm that cargo and goods must be transferred around the world to reach the destination. On the other hand, large orders from companies in B2B relations will be created in print shops. Those print shops would already have pre-programmed templates that are most often printed or templates prepared in advance for companies that contracted cooperation with them.

Industry 4.0 will result in the massive use of VR and AR, first in the manufacturing and then gradually in logistics. The costs of developing and implementing such technologies will initially be high. Therefore, the acceptance for the broader market will take longer. Unlike VR and AR, intelligent, independent automated vehicles and robots in distribution are already implemented in logistics. Amazon with its Kiva robots set off the market and raised the standards. Increased drone usage is closely connected with this forecast. They will be used mostly in outdoor environments with varying acceptance.

Start-ups will increasingly influence the introduction of innovations in all branches of logistics. AR, AI, the blockchain, and automated vehicles are developing independently, and their purpose and functionality in logistics are still being tested. It will take some time until their application becomes standardized. Until then, 4PL, m-logistics, MSCM, digital twins as well as cloud computing will be much more developed, and it is expected that their implementation will be globally faster and in all relevant parts of logistics, and in a standardised way".

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Internet of things, legal and regulatory framework in digital transformation from smart to intelligent cities

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***Abstract* — Digital transformation from "Smart" to "Intelligent city" is based on new information technologies and knowledge, as well as on organizational and security processes. The authors of this paper will present the legal and regulatory framework and challenges of Internet of things in development of smart cities on the way to become intelligent cities.**

The special contribution of the paper will be an overview of new legal and regulatory framework General Data Protection Regulation (GDPR) which is of great importance for European union legal and regulation framework and bringing novelties in citizen's privacy and protection of personal data.

Key words: smart cities, GDPR, intelligent cities, digital transformation, IoT, legal framework, regulation, security, technologies

I. INTRODUCTION

Digital transformation, by definition, presents the profound transformation of business and organizational activities, processes, competencies and models to fully leverage the changes and opportunities of the mix of digital technologies and their accelerating impact across society in a strategic and prioritized way, with present and future shifts in mind. While digital transformation is predominantly used in a business context, it also impacts other organizations such as local governments, public sector agencies and organizations which are a in tackling societal challenges such as ecology subjects and demographical problems by leveraging one or more of these existing and emerging technologies. While in the most European countries digital transformation is still at the beginning of process, in some countries, such as Japan, digital transformation even aims to impact all aspects of life. In the scope of this digital transformation overview, the main emphasis has been put at the business dimension. The mentioned development of new competencies revolves around the capacities to be more agile, the most important: people-oriented, innovative, customer-centric, streamlined, efficient and able to induce/leverage opportunities to change the status quo and tap into new information- and service-driven revenues.

The first step in digital transformation is definition of digital transformation strategy which aims to create the capabilities of fully leveraging the possibilities and opportunities of new technologies and their impact faster, better and in more innovative way in the future. It should be created as a staged approach with a clear roadmap, involving a variety of stakeholders, beyond silos and internal/external limitations. This roadmap takes into account that end goals will continue to move as digital transformation de facto is an ongoing journey, as is change and digital innovation. In the focus of the strategy the creator should determine multiple connected intermediary goals, who are at the end of process of transformation, striving towards continuous optimization across processes, divisions and the business ecosystem of a hyper-connected age where building the right bridges in function of that journey is key to succeed. [1]

From the aspect of impact of digital transformation on society and citizens the answer was found in development of "Smart Cities" (here and after **SC**), whose purpose is rising the quality of life is on the first place in digital transformation strategy. Although, according to some authors opinion the relationship between technology, communication, and power reflects sometimes in opposing values and interests, and engages a plurality of social actors in conflict. Both the powers that be and the subjects of counter-power projects operate nowadays in a new technological framework; and this has consequences for the ways, means, and goals of their conflictive practice. [2]

In spite of this complex, multidimensional social evolution, the decisive process shaping society, both individually and collectively, digital transformation is ongoing process with the dynamics of power relations and technology creating new technologies and new strategies based on "Smart Cities model which presents the future model of global development.

II. DEVELOPMENT OF DIGITAL ECONOMY AND STRATEGY OF THE DIGITAL AGENDA FOR EUROPE 2020

The development of information technology has greatly accelerated social and political changes on a global scale. Strictly defined, globalization denotes an economic, political and cultural process that is enabled by rapid development in the fields of transport and communication and it is often driven by desire of large corporations to win

new markets. Influencing the development of new information technologies and expanding the global market is coming to the development of a new form of globalization, which we call cultural globalization and which, with its growing development, proves itself as a pure contrast to the terminological distinction of the term "culture".

Smart cities are the result of the digitalization process of society in the context of the new economy and represents the relationship between man and technology in order to increase the quality of life. There is also an opinion that the relationship between technology, society and culture is defined so that technology can be viewed as a certain viewpoint on the broader aspects of society and culture where technology is a point of view that emphasizes the material or artificial aspect of society ie man rather than a distinct phenomenon that exists independently from society and to it externally. [2] Globalism as a new social paradigm and globalization as the process determines the future of the 21st century. [3] Establishing a balance, in terms of preserving national culture and sovereignty and national identity in the process of overcoming global culture, seems to be the only solution. Faced with the deep economic crisis in year 2008 that has erased the years of economic and social progress and pointed to the structural weaknesses of the European economy, the European Union has adopted a Strategy for Smart, Sustainable and Inclusive Growth - Europe 2020 in response to emerging problems and an incentive for the EU to become smart, sustainable and inclusive economy. The modern economy is increasingly relying on business through electronic communication services and information society services. The introduction of new information and communication technologies and services that require high speed of access are unthinkable without the development of broadband Internet access and the built-in broadband infrastructure enabling the introduction of numerous electronic and public communications services of the public and private sectors, for the benefit of consumers and society in general. The exclusion of the Republic of Croatia as a whole, with certain regions within it, from the process of digital economy development, threatens the equitable economic development of Croatia in the long term. Therefore, the primary objective of this Strategy is to determine the current lag of the Republic of Croatia, so-the digital divide that has led to the reasons in the recent past, and through which public policy measures, Croatia can reach the average level of development of the EU member states and eliminate the danger of losing the pace with the developed part of Europe and the world in the future. [4]

In this respect, the most important document of the Europe 2020 Strategy brings the vision of the European social market economy for the 21st century and proposes three complementary priorities:

- Smart growth: developing knowledge-based and innovation-based economies;
- Sustainable Growth: Promote an economy that is more efficiently exploiting resources, which is "greener" and more competitive;
- Inclusive Growth: Maintaining an economy with a high employment rate that brings social and territorial connectivity.

The stated goals are interrelated and crucial to overall success and encourage member states to fulfill them by adopting national strategies, taking into account the special features of each country's development. In the area of broadband access at the European Union level, the Digital Agenda for Europe has adopted concrete measures and targets and recommended deadlines for meeting these goals in order to achieve the greatest benefits from such development for the economy and the European Union population.

The pillars of the Digital Agenda for Europe are as follows:

1. A unique digital market;
2. Improving interoperability and standards;
3. Strengthening confidence in online and security;
4. Promoting fast and ultra-fast Internet access for everyone;
5. Investments in Research & Development;
6. Promoting digital literacy, skills and digital inclusion;
7. Benefits for European Society Enabling ICT. [5]

In recent years, EU Member States, in line with the efforts of the European Commission to promote the development of broadband access, independently adopt national plans and strategies for broadband access development. National plans and strategies differ from one member to another, with the following common trends being observed: plans and strategies relate to the three to five year period for a basic broadband approach and seven years for fast and ultra-fast broadband access; goals are set to cover a certain percentage of households, households with broadband access at a certain or least speed; goals differ for basic broadband access and fast or ultra fast broadband access; plans and Strategies promote, for the purpose of achieving the above goals, the introduction of new generation grids, using fiber optic technology based on the FTTx standard in the fixed communication network and the allocation and use of the available radio frequency spectrum for the construction of 5G based mobile communications networks; financial resources are provided for achieving the set goals.

A. Internet of Things in smart city development

By definition, a “Smart City” is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects. [1]

In order to deal with digital transformation processes, increasing urbanization trends, smarter and more sustainable means of managing urban complexities, reducing urban expenditure, increasing energy efficiency and improving the quality of life for urban residents, have to be developed.

In this regard, the concept of Smart Cites is used to discuss the utilization of modern technologies for everyday urban life. In SC, information and communication technologies (ICTs) are merged with traditional infrastructures. ICTs have a crucial role in SC

as it acts as the platform for the aggregation of information and data to help enable an improved understanding of how the city is functioning in terms of resource consumption and services. ICT based services in SSC include intelligent transport systems, which can significantly improve urban mobility. [6]

Integration of ICTs into existing urban services in SC can also assist in:

- Improving the energy efficiency
- Operation and transparency of the urban infrastructure
- Resilience of road networks
- Efficiency of water distribution systems
- Wastewater management
- Security
- Other services

Urban sensors in SCs have the potential to provide city stakeholders with access to real-time spatial, economic and environmental information about their cities.

Thus, ICTs in SC are not only capable of establishing defined urban functions but also promote the essential degree of engagement among citizens, governments, private stakeholders, and other interested parties, in the designing and planning process for cities. This helps ensure informed participation to create shared knowledge for urban governance along with providing the platform for urban simulation which inform future designs for economic, social and environmental development.

Additionally, the infrastructure of SC in terms of its operational functioning and planning through management, aims for equity, fairness and the realization of a better quality of urban life.

In order to define SC we have to look at it from the aspect of an integrated whole that places the emphasis on the interconnectedness and the clever development of the following six elements:

• Economy,
• People,
• management,
• Mobility,
• environment and
• quality of life. [7]

The whole concept of Smart Cities is based on the application of information and communication technology (ICT) solutions in the process of generation, transmission and distribution of electricity as well as in the increase of energy efficiency in buildings, households, industry and transport, thereby achieving a significant shift towards energy less demanding products and services. Apart from economic well-being, environmental pollution and greenhouse gas emissions are significantly reduced. Furthermore, the development of new control strategies and building and energy-efficiency procedures seeks to ensure a dynamic and efficient management of energy resources, especially given the changing nature of alternative energy sources. [7]

The key processes in the development of smart cities are based on the following:

- Apply the so-called. a smart network in which all the elements of this complex system are connected in an intelligent and energy-efficient way
- Internet of Things (IoT)
- Reducing environmental pollution through the introduction of intelligent transport systems
- Increasing energy efficiency through the application of so- smart measurements, but also by introducing innovative solutions in construction. [7]

It is necessary to achieve consensus regarding the architecture of the ICT communication network as well as such a data model that will meet the needs of different services. The development of broadband Internet is one of the key prerequisites since broadband systems provide greater data exchange between consumers, manufacturers and network infrastructure itself. Effective quality control of the delivered energy as well as interactive communication with end-users must be ensured. Essentially, every M2M (Machine to Machine) communication application has four processes:

- data collection
- data transmission via a communication network
- data processing
- response to appropriate information and control. [8]

The main “information workflow” is given threw communication channel between people, devices and systems as shown of Figure 1.

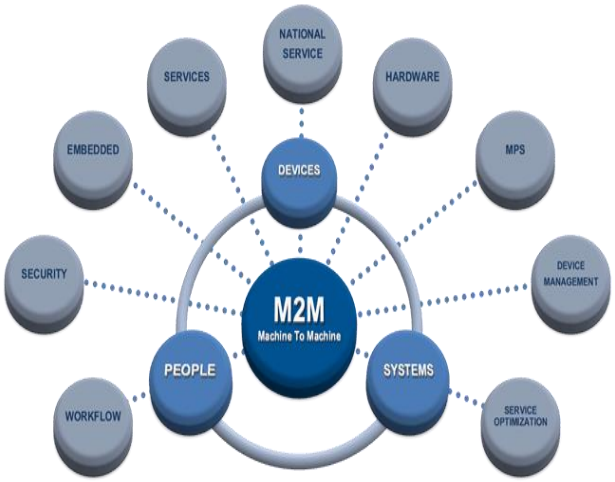

Figure 1. M2M/IoT Machine to Machine (M2M) Communication Technology [9]

The next step in expanding the process automation system and the process of connecting M2M communications over the Internet to a single, shared intelligent network, "Internet of Things". This technological advancement will certainly affect the change of the existing production, communication, and exchange of goods, both locally and globally. This way, a huge amount of data that needs to be analyzed and used appropriately is collected on a daily basis, so Big Data technology is created that combines all the data collected and makes it easier for them to understand. Only this is possible to integrate the functionality of smart solutions and the Internet of Things improvement to connect all the parts of the smart city, of course, with the emphasis on the security and protection of citizens' personal data. [7]

B. Digital transformation and intelligent information

In a digital transformation context, 'managing information' and data is crucial but it's not enough. In today's and tomorrow's information- and data-driven business, insights, intelligence and actions matter most: the outcomes. That's where context, semantics, artificial intelligence and activation come in. With the Internet of Things and Web 3.0 upon us the *intelligent dimension* becomes more important regarding to making sense of *unstructured information*, *automation*, *connected devices* and *putting information at work*. It's why we talk about *'intelligent information activation'*. As we shift towards information-based organizations and information has become part of the capital and business assets of the enterprise, an intelligent information management approach enters the boardroom. At the same time the activities around and value of data are looked upon from the perspective of engagement, outcomes and the last mile. Making data actionable, introducing devices (IoT) in an increasingly complex and growing data landscape, the steep growth of unstructured data, deriving meaning and insights from information and leveraging it at the right time and right moment for the right reasons and actions are all critical. [4]

Smart Cities are actually the product of accelerated development of new information technologies and knowledge, based on Internet technologies, wireless communication systems and other sensors based on the Internet of Things (here and after - **IoT**) technology. The term IoT implies the installation of various sensors and their connection to the local area network and the city's Internet network in order to gain recognition, monitoring, control and management of the facility. IoT is a complex system that might bring about numerous innovations and new rules of behaviour. Scientists, politicians, managers of large companies in Europe and the USA are currently discussing potential on potential regulation framework which has to take into account the complexity of the IoT system which is why the problem should be considered from several forward-looking levels. Special attention should be paid to results of market regulation, that is, to its impact on innovations and adjustment and speed of spreading of the IoT in society and business environments. Also, no matter are we discussing IoT in the private sector or in the public, key of discussions IoT problems should include privacy, security, ethics, data confidentiality, competition, economic development and freedom of innovation.

Although IoT enables a wide spectrum of applications in everyday life, its current application is limited and significant changes are expected in the future. Key enabling technologies include ubiquitous connectivity, smart devices and possibility for integration of smart objects into different applications. There are many different connected things ranging from machines to vehicles, devices, light fixtures and buildings. They are not limited only to material objects, for example, smart places and sensing of the environment are very important for many applications. The scope of application is very wide, including upgraded traffic safety and traffic management, transformation of the power grid towards advanced grids on the basis of new requirements such as energy efficiency, micro production of electricity, electrical vehicles and awareness of users about energy consumption. It may be divided into the following areas: personal and household use, economy, service programmes and mobile area. [5]

C. Legal and regulatory framework in development of the intelligent cities

Due to its demanding objectives of development of Smart cities and parallel development of IoT technologies as the main foundation, Europe has achieved the greatest progress in the IoT segment and its development is further supported by regulations in several sectors. Guidelines important for the for the IoT sector are defined in the following regulations and directives:

1. *"The Energy Services Directive*" – Directive 2006/32/ECon energy end-use efficiency of various devices and energy services In accordance with this Directive, it is expected that 80% of households will have installed smart energy meters by 2020.
2. "*eCall Directive*"– by 2015 the eCall service should be available in all EU Member States. Until then all new vehicles need to have installed devices that will automatically dial 112 in case of an accident and provide key information, such as GPS coordinates, data about the driver and the similar.
3. "*The EU 531/2012 Roaming Regulation"* – the Roaming Directive introduces important changes that may assist EU market, such as the introduction of an aggregator as a wholesale service provider. [10]
4. "*GDPR*" - *General Data Protection Regulation*, the general EU Regulation on Personal Data Protection 2016/679 which will have a great effect on Smart cities development, introduces major changes in personal data management methods and applies directly to all organizations that have personal data of EU citizens. Replaces the current EU directive and comes into force on the date of adoption and is directly applicable in all EU Member States. In Croatia, supervisory will likely be given to the Personal Data Protection Agency (AZOP) since the possibility of adjusting certain parts of data protection law is still left in national legislation as of May 25, 2018, when GDPR starts to apply. [11]

Looking back, the discussion on the importance of IoT in Europe started in 2006 and continued in 2007 when the concept of IoT was officially accepted in the Commission Communication on RFID [10]. In the report on "Future Networks and Internet" from November 2008, it was recognised that IoT has high potential for the development of new services but at the same time presents risk in terms of protection of privacy of individuals [10]. The need for discussion about architecture and management of the IOT has been recognized, and all the Member States have been invited to promote decentralised management in order to ensure confidentiality, safety, privacy and ethical management of data exchanged in the IoT [7].

The European Commission accepted the strategic action plan for IoT in 14 points in 2009 which represented a

collection of principles for management of the IoT, the assessment of possible risks, the financing of joint investments, participation in international dialogue, and integration of IoT into 4 research and development projects of a public-private partnership. In June of 2010 the EC established a multi-stakeholder working group consisting of people of different profiles including scientists, technicians, representatives of the industry, legal and social sciences as an advisory body of the European Commission dealing with main issues including management mechanisms, ownership of data, privacy, security, standards and international cooperation.
The EC conducted a public consultation in IoT management in 2012. The questionnaire collected opinions on the appropriate approach to management in order to stimulate faster development of IOT, while at the same time ensuring adequate protection of EU citizens. The results have demonstrated a joint position that IoT will contribute to significant economic and social progress, in particular in the areas of health, independent life and support for disabled persons. In all other areas, it illustrated differences in opinions between citizens and associations of citizens that desire a stricter regulation compared to the industry. According to the results, 77% of respondents supported the development of indicators for impact assessment in the field of data protection, including requirements related to the consent of users to collect data, data anonymization, restricted use and data retention and privacy. An interesting fact is that the majority of replies indicated that IoT will bring about many ethical issues related to the collected data but also that the development of IoT should not result in social injustice. The European Union expert group concluded in December 2012 that there is a significant disagreement between the business community (in the first place the industry) and the public on the majority of problems, in particular privacy, security and need for faster development of competitiveness in an IoT environment [10]. On the basis of this conclusion, the EC entrusted a non-profit institution that helps improve policy and decision making through research and analysis, named RAND with the development of guidelines for IoT management. Its report was published in August of 2013 stating that IoT is developing quickly and represents a challenge for traditional business, market, management and social models. Economic, social, political, legal and technological Internet management is based on a presumption of rational selection, market strength and efficient self-organization adjusted to systems under human control. Since interactive autonomous IT systems are significantly different from this paradigm [10], RAND recommends the application of a "soft law" approach that will include standards, supervision and ethical character and will at the same time ensure freedom for the industry to adjust to requirements in a simpler manner. This should ensure space for the development of IoT in the EU.
As opposed to Europe which stimulates the development of IoT with is regulatory activities, discussions on IoT in the United States are sporadic and scattered. The majority of debates take place within individual federal agencies interested only in some segments of IoT. From 25th of May, regulatory scope will change according to GDPR because the framework of the new EU data protection framework changes threw General Data Protection Reform The main foundation of GDPR is that the regulation applies if the data controller or processor (organization) or the data subject (person) is based in the EU. Furthermore (and unlike the former Directive) the Regulation also applies to organizations based outside the European Union if they process personal data of EU residents which wasn't the case before. (Art. 3. p.2, GDPR) The Regulation does not apply to the processing of personal data for national security activities or law enforcement ("competent authorities for the purposes of the prevention, investigation, detection or prosecution of criminal offences or the execution of criminal penalties, including the safeguarding against and the prevention of threats to public security").[12] This regulation is clearly stated in Art 1 p.1 of Directive (EU) 2016/680 of the European parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data by competent authorities for the purposes of the prevention, investigation, detection or prosecution of criminal offences or the execution of criminal penalties, and on the free movement of such data, and repealing Council Framework Decision 2008/977/JHA, which has followed GDPR. [12]

III. CONCLUSION: CHALLENGES RELATED TO DEVELOPMENT OF "INELLIGENT CITIES"

Smart cities research is in full swing in research and in practice. There are many possible directions for research on it's way to "Intelligent city" concept because the mature phase of development of IT brings new challenges related to market regulation, payment, security and improvement of performances and efficiency of work of platforms. So far, research focused on the establishment of functional platforms that will enable the provision of an increasing number of services, but, with the increase of the number of users, it will necessary to provide support to the quality of service. The open issues in the area of data processing include standardization of query language, definition of key evaluation (and comparison) parameters for various components and adjustment of algorithms for processing data flow in cloud computing and variable characteristics of entry data.
Energy efficiency will represent a significant challenge in the development of communication protocols and devices. Power sources and autonomous operation will be of great importance, in particular for sensory modules that will for the most part be battery-powered. The best indicators are today's sensors which are mostly battery-powered and constantly broadcast data by using Wi-Fi or Bluetooth technology.
The key challenges and possible problems that need to be considered and solved on the way of developing "Intelligent cities" before include the following:
1. Security privacy and confidentiality - the security domain has the following challenges: (a) securing IoT architecture, (b) proactive identification and

protection of IoT from arbitrary attacks (e.g. DoS and DDoS attacks) and abuse and (c) proactive identification and protection of IoT from malware. In the area of user privacy, special challenges include the following: (a) control of personal data (privacy of data), (b) need to improve privacy technologies and the relevant laws and (c) standards, methods and tools for managing the identity of users and objects. In the area of confidentiality, some of the specific challenges include the following: (a) the need for simpler exchange of critical, protected and confidential information and (b) confidentiality must be a constituent part of IoT design.

2. Standardisation: Management of heterogeneity - management of heterogeneous applications, environments and devices represents a great challenge as well as the standardization of heterogeneous technologies, devices, applications and interfaces. The lack of a single connection standard (a wide selection of wired and wireless and "proprietary" solutions) will represent a significant challenge to connectivity at the global level.

3. In security challenges great role play limitations of network capacity – the convergence of devices that arises from the IoT stimulates greater demand for a certain degree of expected QoS of the associated network infrastructure. New mobile applications that provide certain services may demand more frequent sending of small blocks of data (sessions) necessary for upgrading and synchronizing. The frequency of the above-mentioned sessions will have a great impact on delay and permeability of the network itself. This part of infrastructure must be securely delivered in order to ensure secure data flow.

4. And last but not least: the management of a large quantities of data and processing of large quantities of data to ensure useful information/service as well as to ensure confidentiality and integrity of data as a part of information/service (IoT except for "raw" data from the source may generate a large quantity of metadata or temporary data necessary for the realization of services (e.g. sensory reading may be stored in a relational and semantics database). Characteristics are the following: quantity (size of data), diversity (heterogeneity of processed data, e.g. tables, pictures, e-mail) and dynamics (characteristics of data, intensity and frequency of arrivals, manner of processing). Platforms for IoT must enable efficient processing of data in real time resulting from user demands because the user wishes to be instantly informed of interesting events (e.g. selection of the most favourable travel route).

In addition to the above-mentioned main challenges, there are also some other challenges such as: (a) market regulation, (b) designing of a more efficient architecture for networking of sensors and storage of collected data, (c) development of mechanisms for the processing of the flow of data gathered in sensory networks, (d) transition to IPv6 (large number of addresses, possibility for auto configuration and improved security parameters), (e) power sources of devices/sensors (devices are powered by electricity produced from the environment such as vibrations, light and air flow) and (f) decreased cost of IoT components.

One of the key challenges for the realization of the "SC" to "Intelligent City" concept includes security, privacy and confidentiality, management of heterogeneities, limitations of network capacities, management and processing of large quantities of data in order to provide useful information /service and enable an efficient regulatory policy in the area of IoT. Since, protection of privacy is one of the key constitutional rights of citizens' it is very important to note that IoT will have to be in compliance with the new European regulatory frameworks for data and privacy protection, as well as with all legal requirements of GDPR into a single group of rules in the EU and including also revised measures for data transparency and safety issues.

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Urban Accessibility Application for Users with Mobility Impairments: Conceptual Model based on Social Networking and Volunteered Geographic Information

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***Abstract* – Information and communication technology has a significant potential of improving the quality of life in urban environments. Smart cities as a concept try to implement various solutions that make urban environments more efficient, easier to maintain and more enjoyable for their citizens. In this paper we will propose a solution that is consistent with the primary goal of smart cities and aims to improve the quality of life of individuals with disability in mobility within the urban environment, specifically Zagreb city area. Proposed solution is based on currently implemented technologies that are already widely used in different application areas. Solution takes advantage of social networking technologies and assistive technologies. After a brief overview of the proposed mobile application system we will present results of the survey conducted among potential users of the application. This information will be used to determine the usefulness, user interest and feasibility of developing the proposed system.**

Keywords – assisstive technologies; urban accessability; disability; mobile application; social networking technologies

I. INTRODUCTION

Development of information and communication technologies has influenced almost every area of human society. It has become a tool that changes everyday activities, innovates them and potentially makes them more efficient, faster and more accessible. The quantity of data that is generated through processing all of these activities has become a resource that can be used to develop new and better solutions or better maintain existing ones [13, 14]. Common goal for all these implementations is improvement in quality of life. In terms of urban development, information and communication technology is being incorporated as fundamental part of city infrastructure. Information obtained through this technology has the potential of improving city management and offer new services for its citizens. Smart cities are just one of the terms that describe this approach to urban management.

This paper will focus on a particular topic of urban accessibility. Urban accessibility can highly benefit from smart city concepts as well as from less comprehensive projects by significantly improving the quality of life for people living with disabilities. In recent years a number of applications based on social networking, geographic information systems, mobile technologies and etc. have been proposed, developed and used [2, 10]. Unfortunately, most of these incentives do not successfully incorporate local administrations, public institutions or municipal authorities that should cater for this type of projects over the long term [5].

In this paper we propose a conceptual model of a system that incorporates the best properties of volunteered geographic information retrieval from users that actually use and benefit from accessibility solutions but also suffer restriction in their basic human rights when these solutions are not available, or they are not adequately implemented or maintained. Recent research has also shown that projects that are aimed at alleviating disabilities are rarely commercially viable and become unavailable to wider public and intended users [5]. We feel that, while implementation of novel technologies may push the boundaries of assistive technology, there is a great potential in using currently available and activated technology and services that require lower investment, maintenance cost and effort which in turn may prolong the viability of such project implementations.

Goal of this paper is to present preliminary research of the feasibility study for the conceptual model of an urban accessibility application aimed at users with disability in mobility, but also local municipal administration for the use in Zagreb city area. Proposed application incorporates extensive use of current technologies such as web technologies, mobile technologies, geographic information systems, global positioning system, but also various assistive technologies and social networking technologies specifically aimed at users with physical disabilities. System will collect invaluable information that can be used by local government when initiating projects that improve urban accessibility.

Structure of this paper is as follows: in Section 2 we will present background and related work in supporting individuals with disabilities with primary focus on physical type of disabilities and accessibility in urban environments. Here we will also take a closer look at the assistive technologies that are used to overcome and alleviate some of the challenges people with disability in

mobility face in their everyday life. Next, in Section 3 we will describe the main characteristics of the proposed model that can be used by majority of people with disability in mobility that brings together relevant information about urban environment accessibility, assistive technologies for user interfaces and social component in terms of volunteered geographic information submissions and social networking capabilities. In this section we will also take a look at the results acquired through research survey of potential users of the described system. Finally, in Section 3 we will present the main conclusions about the presented conceptual model and describe further steps toward the implementation of the system.

II. RELATED WORK

A. Disability in Mobility and Urban Accessibility

Currently 15% of world population has some type of disability [9]. In most part these disabilities include some form of physical disability that restricts motion, independent conscious motions, movement or mobility of a person. These impairments in body function or structure profoundly affect a person's everyday life by limiting activities and restricting participation. Overall, technology has the means to alleviate and effectively remove physical barriers. Specifically, information and communication technology has the potential to alleviate and effectively remove social limitations to a person's participation activities [6].

Over the past decades various solutions for different types of physical disabilities were conceived and implemented that substantially improved the quality of life for people with disabilities. At the same time the social awareness and understanding of the issues that challenge people with disabilities is also increasing [7, 10]. The social model of disability focuses on interaction with the environment – social, cultural, economic and physical [4]. If we consider disability as a gap between individual's capabilities and the demands of these environments we can see that there are two approaches to closing this gap [12]. First one is to remove the limitations of individual's capabilities. This is an approach that is mostly used when developing technological and medical solutions to overcome some of the limitations of physical disabilities. The second approach is to shape and adjust the environment and make it accessible to people with disabilities.

Urban accessibility refers to different aspects of planning and organizing urban infrastructure while at the same time considering the needs of disabled people and reducing the gap between individual's capabilities and created environmental demands. Mora et al. (2017) [7] define accessibility as "an element of life quality that is of universal interest, a right of all citizens, a determining factor of the liveability of cities, and an essential element in modern society. It provides security, comfort and autonomy to pedestrians, cyclists, public transport and private motor vehicle users, in its rational use. It is respectful of the urban fabric and should be approached from the many aspects that affect accessibility." Disability in mobility is one such aspect that modern urban management needs to consider and get actively involved using available resources and technologies. Here, information and communication technologies may provide benefits that will affect not only physical environment, but also social and economic environment as well [8].

B. Assistive Technologies

Assistive technologies is a collective term for different technologies and solutions aimed at alleviating or removing disabilities. In this paper we will primarily take a look at the technologies that allow for better interaction between physically disabled individuals and user interface for mobile devices and applications. There are various peripheral devices that can be used to assist with navigating software user interface and providing inputs for software applications that are in use today. Some of these solutions are open source, and some of more advanced ones are commercial products. Their main drawback is the high cost that can be restrictive for most of potential users. It is therefore important that the solutions rely on open source technologies or on established technologies in order to promote their usage by intended users.

Geo-crowdsourcing approaches such as volunteered geographic information using social networking technologies has become a popular trend in acquiring and sharing information in various social groups and especially virtual communities. Even though there are some concerns about the quality scope of obtained information in this way [11] these approaches have certainly establishing valuable data records concerning urban accessibility [7]. Social inclusion of disabled users through volunteered geographic information that describes various relevant aspects of accessibility within an urban infrastructure may potentially create valuable source of information for users, regulators and decision makers. Quality of this data can be further improved by registering most important points of travel i.e. travel generators for disabled people directly indicating the importance of particular accessibility issue.

There is a number of mobile applications based on this paradigm usually published by communities themselves as open source and sometimes as commercial services. One such example is AXS Maps app [15]. Main drawback of these approaches is exclusion of active participation of governmental bodies and exclusive focus on the social groups affected by urban accessibility issues.

Current technological paradigms allow for the activation of municipal authorities that are directly and indirectly responsible for the state of urban accessibility. In this paper we propose first step towards public involvement with continuous monitoring and managing the issues reported by users that are most afflicted by inadequate mobile urban planning – people with physical disabilities. One of the main strengths of the proposed system is low entry cost. Once established, this project may pave way to more elaborate smart city projects that introduce new set of converging technologies (such as RFID, IoT, etc.) to further innovate and enhance urban accessibility management [3, 4, 7].

It is important to implement assistive technologies that will cater for the needs for different types and levels of

physical disability while providing maximum interactivity with the application user interface as possible. This may require few innovative approaches to assistive technologies.

III. Conceptual Model and Analysis

Main functionality of the proposed system is to provide a medium for its users to use a map of the urban area where accessibility points are defined and described. Users of the system themselves can submit their own information and comments, add new accessibility points or even allow the system to trace their movement. The system will also be able to save preferred routes, recognize main travel incentives and recommend best movement routes to other users with same and similar travel incentives. As number of user routes increases the system will increase importance and priorities of commonly used infrastructure (roads, sidewalks, public transportation lines, service outlets or institutions, etc.). All the associated access points along these routes will also increase in priorities in the system database. This information will serve as an indicator of most important accessibility points that need to be further developed or introduced by local authorities when planning investments of public funding in urban accessibility projects.

A. *Urban Accessibility Application Overview*

The core system is based on web application architecture (Fig. 1).

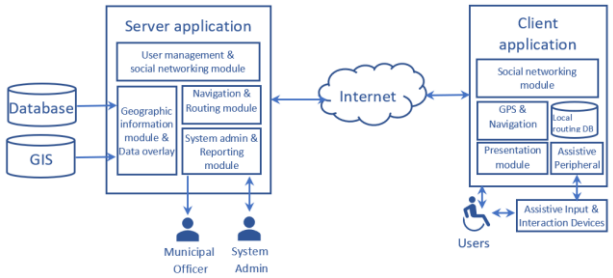

Figure 1. System architecture overview

Client-side application is adopted for mobile devices, primarily smart phone devices but also tablet devices that are able to connect to the Internet. Also, client-side part of the system relies heavily on global navigation satellite system (GPS & Navigation module) that provides high precision geolocation capabilities that are essential for adequate functioning of the system. Important part of the client-side component of the system is the inclusion of various assistive technologies that enable users with various levels of physical disabilities to access and navigate user interface of the application (Assistive peripheral module). Client application will also need to cater for various accessibility options in terms of presentation of data it provides (Presentation module), so that the user can take advantage of all the social networking tools and capabilities. Social networking module will include all required customization and personalization functions as well as the key feature of editing accessibility points on the map, up-voting or down-voting current status of each accessibility point, supplying evidence in form of comments or multimedia (video or photo). Additionally, users should be provided with local storage for their personal routes and travel generators that can be used to offer alternative routes depending on current states of accessibility points along the route alternatives.

Server-side application component holds the information available to all of the registered online users. Core part of the server-side component is the geographic information module and data layer with dedicated GIS database that holds relevant information about accessibility points, adequate and inadequate sidewalks and curb cuts, public transportation system lines with information on vehicle accessibility, public services locations and building layouts with connection points where adapted wheelchair access is provided. Application database stores information about unavailable access points and critical access points that prevent urban accessibility for people with disability in mobility. User votes are calculated there, and current status of these points is created. This information is used to establish priorities for local municipal authorities to initiate projects for removing these disruptive points in urban accessibility. Users also have the possibility to passively up-vote most important accessibility points by sharing their movement and routing paths with the system (Navigation and Routing module). The system will analyse the movements of users and adjust the priorities of various accessibility points. Officers representing local authority can receive reports about the status of urban accessibility, accessibility points and their status, maintenance priorities and other useful information for urban management. System Admins will have access for the purpose of data and application maintenance.

B. *Analysis of Market Research and Potential Users*

The intended area of implementation for the described conceptual model is the Zagreb City area. There are several main differences between the proposed model and other available models and incentives currently implemented and used:

a) Intention of this concept is to base the system implementation on technologies that are already widely available and used by the potential users of the system. Many of available systems try to innovate by incorporating new technologies or technologies that are currently not used or available in the current urban environment (such as RFID technologies, IoT sensors and software, etc…). Inclusion of these technologies provides many valuable benefits, but also implies additional costs increasing project budgets that may discourage authorities in investing resources in their implementation.

b) In order to implement this system local municipal government and administration needs to be actively involved in the project. They represent key stakeholders in the role of investors and users that will take advantage of collected information in order to improve urban accessibility infrastructure. Having insight in actual priorities of user needs municipal authorities can continuously provide maintenance and management of urban accessibility within the city area. There are a lot of similar applications that are either commercially available

or created by the user community but they fall short of support from local administration and politicians who may influence the actual state of urban environment.

c) Presented model takes high emphasis on public transportation services and organisation of railway and road network. Proposed model allows dynamic user feedback on the organisation and suitability of public transportation services, vehicles and stations. It can also detect movement issues in road and city rail network such as road and rail crossing points, etc. There are not enough examples of urban accessibility solutions that deal with this aspect of city infrastructure.

d) Finally, data collected by the system can be used to generate history of improvements for each particular point of interest and provide knowledge for solving future situations and problems in planning and maintaining urban accessibility.

In order to estimate potential benefits of the proposed model and potential interest of the target population a survey was conducted.

In Zagreb city there are 11,4% of people with disabilities [1]. Over 55% of people with disabilities in Zagreb city suffer from physical disabilities that limit their mobility [1]. Nonetheless, target population includes both people with disabilities and other interested groups (such as friends and families of people with disabilities). This is why the survey was conducted among both people with disabilities and non-disabled people (Fig. 2).

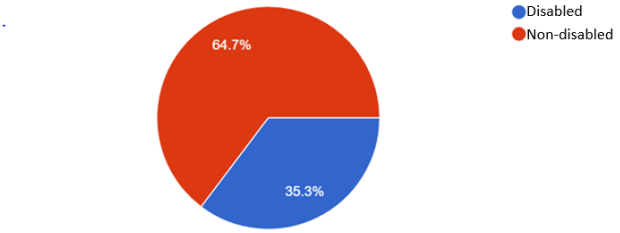

Figure 2. Number of responadents with physical disability and non-disabled responents in the survey

Some of the demographic data acquired pertains to the sex of respondents (female 65%, male 35%), age (teenagers and young adults up to 20 years 3,6%; adults aged 21-30 38,8%; adults aged 31-40 32,9%, adults aged over 40 24,7%) and education (primary education 3,5%, secondary education 36,5%, university 60%).

Over 87% of respondents use Internet on daily basis and 92,9% use mobile devices for access.

51,8% of people have reported that they either experienced personally or perceived problems with access to city amenities. When asked to rate accessibility on a scale from completely inaccessible (1) to completely accessible (5) majority of respondents rated accessibility with medium grade (3) both for building access and sidewalk access (Fig. 3)

Final section of the survey dealt with using mobile applications and map services alleviated movement in Zagreb city area. Here over 95% of respondents reported

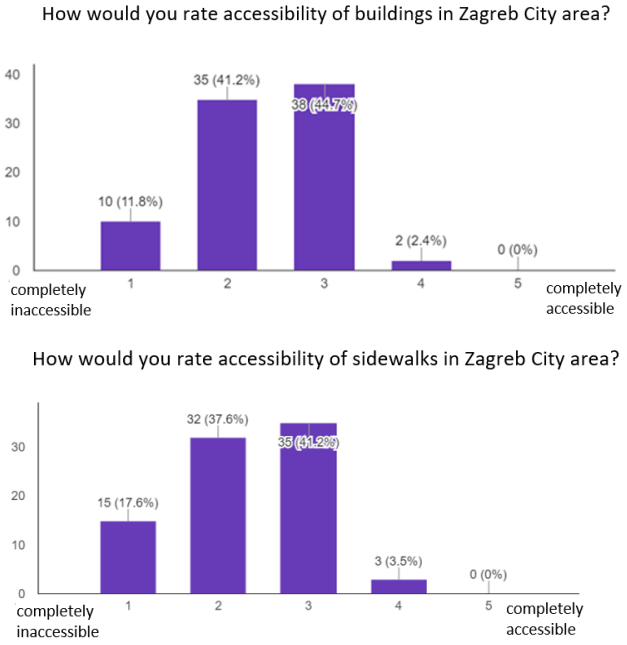

Figure 3. Urban accessability assessment results. Above: Acessability of buildings; Below: Accessability of sidewalks

that they never used any such service as they are mostly unaware of their availability. When asked whether they would use such application more than 81% of respondents answered positively. Additionally, respondent comments indicated that the critical area that would have most use from proposed application is the old city area of Zagreb (*Donji grad*). Most beneficial functionalities of the system as indicated by the respondents are: recommendations of movement routes based on travel generators, detailed information for building accessibility and detailed information on tram stations accessibility.

IV. Conclusion and Future Work

In this paper we have presented a conceptual model of a web based mobile application aimed at users with disability in mobility that will allow them to track urban accessibility information as well as supply feedback information to the system in order to better navigate urban environment and improve the quality of their everyday lives. The supplied information can also be used by the municipal authorities to prioritize incentives for the urban accessibility improvements according to actual need by their citizens. Additional benefit from the proposed application is the increase in social interaction of people with disabilities that promotes social inclusion.

Results of the survey conducted among potential users of the system have confirmed the need for this type of application and service in urban area. The research was conducted for urban area in Zagreb, Croatia.

In order to implement the described concept, municipal authorities need to take an active approach during the active phase of the service this application will provide; the application should take into consideration all of the aspects of physical disabilities potential users may suffer from and use innovative assistive technologies in order to enable as many users as possible to access user

interface of the application and use the system and benefits it provides.

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General Data Protection Regulation – Protection of Personal Data in an Organisation

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***Abstract* - Personal data represent all data (identifiers) relating to an identified individual. Identifiers can include first name and last name, network IP address, MAC address, GPS location, telephone number, personal ID, biometric data and other relevant data in connection with personal identity. The European Union (EU) has adopted a new framework for the protection of personal data entitled General Data Protection Regulation (GDPR) which will apply to Croatia from May 25th 2018. This paper analyses the differences between the new GDPR and the existing Data Protection Directive from 1995, which is currently still in force.**

Keywords – GDPR; personal data protection; regulation

I. INTRODUCTION

In 1950, the Council of Europe drafted the Convention for the Protection of Human Rights and Fundamental Freedoms (entered into force in 1953). A few years later, in 1958, the invention of the integrated circuit by Jack Kilby and Robert Noyce from Texas Instruments marked the beginning of the process of computer miniaturisation. Before the invention of the transistors and integrated circuits, electro-mechanical computers were used. They served exclusively for business and research purposes and were not intended for general public due to their price, as well as their dimensions. With the development of the transistor, both the dimensions and the prices of computers reduced, which lead to a wider use of computers in offices and homes. This is where the concern for the protection of personal data begins.

With the appearance of the hard disk for personal computers and portable media such as floppy disks, users were provided with new, simple and effective possibilities for storing personal data within databases. Before computer miniaturisation, the storage of personal data was based on media such as punched cards [1]. The emergence of Database Management System – DBMS in 1960s actually marked the beginning of an era of modern approach to data storage and management. The development of the relational database model in 1973 by Edgar Codd, a British computer scientist should also be mentioned, because it representeded a sort of revolution in the understanding of database models on computers. The main characteristic of the relational database model is the separate storage of database data and the applications using the same database. Queries over data from the database are based on efficient construction of statements using logical operators. As a result, today it is possible to process a large amount of data on the entire population of a single country in only a few seconds, by using an average home computer. However, with the introduction of new technologies, the protection of personal data has become more important than ever. This primarily refers to a remarkably swift development of Internet services, Internet of Things systems, Cloud systems, social networks and similar systems that use personal data (for example, for online banking). Furthermore, the appearance of fake identities on social networks can directly threaten both individuals or companies.

With respect to goods and financial markets in European Union member states, anyone operating within the EU processes personal data of all the people living and working within the borders of the EU. More specifically, this means that the seller selling their goods in the EU market processes personal data of all potential buyers within the EU. The major problem in practice has been the development of the legal framework, that has not been following the rapid development of Internet and Internet based services.

Up until the adoption (and entry into force) of General Data Protection Regulation (GDPR), the Convention of the Council of Europe has been the only legally binding act in the field of personal data protection outside the European Union [2]. The need to introduce a new “code of conduct” and legislation is evident from the fact that the said convention, as well as the current EU Data Protection Directive from 1995 [18] was adopted at the time the Internet was still in its beginnings. Cloud services and social networks did not exist, data was transferred on low-capacity media (for example floppy disks) and dial-up communication speed was negligible compared to today's communication speeds. Likewise, Internet and World Wide Web were mostly unknown back then, while Bulletin Board System (BBS) services which used regular telephone communication lines were very popular.

The introductory part of this paper provides a short historical overview of legally binding acts from the field of personal data protection and gives reasons for introducing a new "code of conduct". The second chapter contains the definition of personal data, everything that personal data represent and gives the overview of personal data protection and legislation in the Republic of Croatia. The third chapter contains basic information on GDPR and compares it to the previous EU Data Protection Directive from 1995. Chapter 4 gives the overview of the most important changes in an organisation brought about by the General Data Protection Regulation (GDPR). Chapter 5 provides some final considerations and conclusions.

II. PERSONAL DATA

The right to the protection of personal data is a fundamental human right, and personal rights are rights and freedoms directly related to a person, i.e. to an individual [4]. Personal data are defined in the existing Personal Data Protection Act as [3]:

"*Personal data means any information relating to an identified or identifiable natural person (hereinafter: data subject); an identifiable person is one who can be identified, directly or indirectly, in particular by reference to one or more factors specific to his physical, physiological, mental, economic, cultural or social identity*."

On the official website of the Croatian Personal Data Protection Agency it is stated [4]:

"*Right to personal data protection is a right to the protection of legitimate interests of citizens (individuals), which includes preventing and sanctioning of the abuse of personal data, and is guaranteed by international and national legislation.*" According to the same source: "*Individual (data subject) is a natural person who can be identified, directly or indirectly, in particular by reference to one or more factors specific to his physical, physiological, mental, economic, cultural or social identity*."

The definition of individuals is related to the factors that characterise them as such with respect to other individuals. The identity of an individual is usually established by means of a public document. However, the term "personal data" encompasses more than just the data in the public document (identity card, passport and similar). The present-day online services are large "collectors" of personal data. Furthermore, smartphones contain a large amount of personalised data that can be traced to an individual (owner). Therefore, personal data can include the following: first name, last name, address, e-mail address, IP/MAC computer address, GPS location, telephone number, photographs, videos, biometric data, Radio Fidelity Identification (RFID) tags, information about education, bank account details, information about credit debt and much more regarding the identified person/individual, as shown in Figure 1. However, when data about legal persons are concerned (legal person's name, ID number, e-mail address, financial data etc.), this is not considered personal data of an individual.

Figure 1. What is Personal Data? [17]

Special categories of personal data include the following [3]:

- Political opinions
- Religious beliefs
- Trade union membership
- Personal data on criminal/misdemeanour procedure
- Health or sex life.

A. Personal data protection

The reasons for the protection of personal data are very clear from the regulatory framework. Personal data refer only to a natural person characterising them as such. Therefore, if a buyer purchases a car, such car is owned by them, which can be proved with a receipt and/or signed agreement. Personal data are owned by a natural person, and are as such inalienable. However, with the development of technology and the Internet, personal data are becoming increasingly exposed and accessible to those who could use them for their own, unlawful purposes. Social networks can serve as a typical example. According to the information by Social media statistics from February 2017, the number of social network users, with personal data, reached 4.6 billion [5]. This number also includes so-called fake user profiles that represent duplicates of real profiles (persons) intended to harm them by using their personal data (first name, last name, photos, videos etc.).

Even though the Republic of Croatia ranks among the bottom 7 EU countries with respect to the use of Internet banking (30% compared to EU average of 51%), this does not mean that the safety of users' personal data is not threatened or that the number is negligible [6]. The theft of personal data in e-banking is mostly performed by so-called phishing, which includes a fake e-mail or web site where user is prompted to voluntarily fill out their personal data (bank account number of bank card PIN) by using fraud and misrepresentation. Trojan horses and Key loggers follow the activity on the keyboard and enable the attacker to access confidential personal data [14]. In addition, attackers use fake text messages to prompt users to send their personal data.

B. Personal data protection and legislation in the Republic of Croatia

Personal data protection in the Republic of Croatia is regulated by the Data Secrecy Act (Official Gazette of the Republic of Croatia no. 79/07, 86/12) [19], [20]. In practice, employers often consider the data related to, for example, employment contracts and annexes to employment contracts or employees' salaries a trade secret. Such data represent a trade secret and the publication of such data could cause damage to the company's business operations. The Data Secrecy Act is applied in the Republic of Croatia as an instrument for the prevention of unauthorised access [21]. However, according to this Act, the employer should adopt an internal general act to determine which data are considered a trade secret, and perform the classification of data. Pursuant to the Act, security classifications are as follows:

- Top secret,
- Secret,
- Confidential,
- Restricted.

A breach of protected and classified information which is considered a trade secret is a valid reason for applying sanctions in the sense of terminating the employment contract. The breach of a trade secret represents a serious breach of responsibilities arising from the employment relationship, and as a result the employment in such organisation is no longer possible. Pursuant to the legal frameworks and the Criminal Code of the Republic of Croatia (Official Gazette of the Republic of Croatia 144/12), Art. 262 [8], the breach of a trade secret can lead to an imprisonment for the duration of 3 – 5 years. Furthermore, it is necessary to specify the data representing a trade secret and to designate the persons in charge of keeping such data confidential, all for the purpose of determining the responsibilities more easily.

III. GENERAL DATA PROTECTION REGULATION – GDPR

Adopted in 2016 by the European Parliament, the GDPR (Regulation EU 2016/679) [22] is aimed at providing the citizens with control over their personal data and setting minimum standards for the use of data by the police and the judiciary. It repealed the Data Protection Directive from 1995. Taking into account the environment in which the Data Protection Directive was adopted (the year 1995) from the technological point of view, the reason for adopting this new GDPR Regulation becomes evident- The Regulation adapted to a new digital environment and technologies such as smartphones, social networks, e-banking, cloud systems, digital public administration and services etc..

Fig. 2 shows the key novelties in the application of GDPR. It should be noted that the application of GDPR refers to personal data only.

Figure 2. GDPR Key Facts [16]

The novelties in the regulation of personal data protection introduced by GDPR are as follows [9]:

- Right to erasure,
- Clear agreement to the processing of personal data (clear consent),
- Right to transfer of data (e.g. to another controller),
- Notification of a personal data breach (within 72 hours),
- The Croatian Personal Data Protection Agency will be authorised for supervision,
- The Regulation applies to all economic operators operating in the EU,
- Obligation to appoint a data protection officer – DPO,
- Fines from 0.5 to 4% of total worldwide annual turnover.

When talking about the abuse of data in the present-day sense, it all starts with the process of clear agreement to the processing of personal data. The first person coming into contact with the natural person in the process of providing their personal data is the controller. "Controller" means the natural or legal person, agency or other body which determines the purpose and means of the processing of personal data. The processor processes personal data following the approval of the controller. The controller must make sure to obtain a written consent from the person from which personal data will be collected. The written consent must be in a clear and intelligible form, and it should be as easy to withdraw as to give consent. The processor processes personal data following the approval of the controller. Any breach of secrecy (rights and freedoms) of personal data must be reported to the relevant supervisory authorities within 72 hours.

The main task of GDPR in the context of its application within business organisations is for organisations to know where their data are located at any moment and for which purpose they can be used. Right to erasure is one of the main novelties of GDPR, and it refers to the withdrawal (erasure) of personal data, which must be performed by business organisations within the legally prescribed time period. It should also be noted

that the obligation to apply GDPR does not refer to the data about legal persons or entrepreneurs who are legal persons (craftsmen, free/liberal professions or natural persons with the entrepreneur status) [10].

Right to portability enables the use of the same personal data through various services. The data can be copied (moved) through networked systems.

Right to erasure is contained in the EU Directive from 1995 currently in force, but the GDPR defines the process in more detail. The person has the right to request the erasure of personal data, and the controller is obliged to comply with this request if one of the following grounds applies: the personal data are no longer necessary; the person withdraws consent or the person objects to the processing [2].

The General Data Protection Regulation will come into force on 25 May 2018 and it is binding for all EU member states. However, the Regulation also applies to all countries beyond EU borders, i.e. to companies co-operating with EU member states, although not being member states themselves. This means that anyone co-operating with EU member states must adhere to their rules [12]. Table 1 shows the comparison between the currently applicable EU Data Protection Directive and GDPR.

TABLE 1. COMPARISON BETWEEN THE CURRENTLY APPLICABLE DIRECTIVE (AS OF 30 JANUARY 2018) AND GDPR

Rules	**EU Data Protection Directive from 1995**	**GDPR (EU 2016/769)**
Right of access	+	+
Right to rectification	+	+
Right to erasure	+	+
Right to stop direct marketing	+	+
Right to be informed		+
Right to restriction of processing		+
Right to data portability		+
Right to object		+
Notification of personal data breaches (within 72 hours)		+
Obligation to appoint a data protection officer – DPO		+
Fines from 0.5 to 4% of total worldwide annual turnover		+

The following scenario can serve as an illustration of the application of GDPR in the company's business operations: the common process of receiving regular e-mails containing information about the product or service offer of company X. If the user withholds the consent to receive information, that is, if the user does not want to receive any more information about products or services offered by the company X, the company X is no longer allowed to send product or service offers. In case the company X ignores the user's withholding and continues with its promotion and advertising of products and services towards the customer, it faces the risk of a legal action in the country where its registered office is located (any country).

On the other hand, if the person X assumes the role of a service provider and does not obtain the customer's consent for sending information regarding the new products, by sending messages/information to the customer, the person X would have committed an offence [7].

Pseudonymisation is one of data protection methods supported by GDPR for the purpose of minimising risk. Pseudonymisation, pursuant to Article 4 of the GDPR, means the processing of personal data in such a manner that the personal data can no longer be attributed to a specific data subject without the use of additional information. Such additional information is kept separately and is subject to technical and organisational measures to ensure that the personal data are not attributed to an identified or identifiable natural person [23].

IV. GDPR IN AN ORGANISATION

GDPR, among other things, also introduces the obligation to appoint a data protection officer – DPO, who is to be appointed by the controller and the processor. The legislation currently in force in regulatory frameworks does not prescribe that the data protection officer has to be an expert [11]. GDPR, however, prescribes that the data protection officer must be an expert, a person with the knowledge of law and information technology, case law, rules under GDPR and other regulatory provisions in connection with the application of GDPR. Knowledge of rules regarding data protection impact assessment is also required [2].

If a type of data processing performed using new technologies could result in a high risk to the rights and freedoms of natural persons, the controller should carry out impact assessment of such processing prior to the processing of personal data. A single assessment may address a set of similar processing operations that present similar high risks [22].

The role of data protection officer can be performed by a person (employee) designated internally, or the organisation can use outsourcing services. Fig. 3 presents four categories of the most important changes in organisations brought about with the introduction of GDPR. Changes in the field of information technology (IT) should also be mentioned.

Figure 3. The most interesting changes divided into four categories, including IT and training [15]

Major changes in an organisation brought about by the application of GDPR are:

- The application of General Data Protection Regulation will create a unique set of rules, thus facilitating business operations within the borders of the European Union and reducing costs,
- Companies will be monitored by only one supervisory body,
- Companies registered beyond the borders of the European Union, if working with organisations within the EU borders, will also be obliged to apply new rules under the Regulation,
- The Regulation will protect products and services in their development (emergence) stage by integrating specific data protection measures,
- Pseudonymisation methods and data encryption will be used in the context of data protection.

The regulatory framework of the Regulation guarantees a uniform right to the protection of personal data to all citizens across the European Union and prescribes mechanisms to facilitate the coordination of activities by supervisory bodies in the European Union member states [13].

V. CONCLUSION

Even though we still have to wait the official date when the Regulation (EU) 2016/679 or, more simply, GDPR will come into force, the adjustment of organisations must be completed before May 25th 2018. An important step in the application of GDPR is the harmonisation of business operations with other legislation applicable in each EU member state, including Croatia. Harmonisation with judgements of the Court of Justice is also required.

GDPR certainly introduces "order" into organisations when it comes to personal data and prevents personal data abuse. The most important novelties include erasing (withdrawing) personal data and reporting personal data breaches within the prescribed 72-hour time period. Organisations not complying with the instructions under the GDPR will face fines from 0.5 to 4% of the global annual turnover or up to 20 million euro. This should be reason enough for organisations to adjust to the new requirements prescribed by the Regulation as soon as possible.

Even though the Regulation primarily applies to the protection of natural persons, organisations could also benefit from knowing what personal data they have at their disposal and where they are located. On the other hand, there is an obligation to protect personal data, which will be the responsibility of the data protection officer – DPO, appointed by the controller and the processor.

In the Republic of Croatia, the GDPR will be under the supervision of the Croatian Personal Data Protection Agency, which will be authorised to sanction any organisation not complying with this Regulation. The application of GDPR will also be useful to citizens, who will be able to access their personal data more easily and know more about how their data are processed, in a clear and intelligible manner. The right to data portability will also be guaranteed, all for the purpose of an easier exchange of data. "Right to be forgotten" provides the possibility of erasing the collected data when the customer (natural person) no longer wants these data to be processed, provided that there are no legal constraints. For this reason, it is important to harmonise the company's operations with the GDPR provisions to prevent any financial damage, as well as the loss of customers' trust [11].

The harmonisation of company's operations with the GDPR requires complex technological solutions and significant changes in the company's business model [7]. Technological solutions are primarily related to the field of information technology and information security, while the second part of the harmonisation refers to changes in the approach to the use of personal data. Finally, it is important to note that GDPR does not apply to the data of legal persons, or entrepreneurs who are legal persons.

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Investigating Attitudes of Entrepreneurs Towards the Use of Information and Communication Technologies in Croatian SMEs in two Northern Adriatic counties

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Abstract - **One of the strategic factors for stimulating the economic growth of each region, as well as wider areas, is investment in the development of the digital economy. In this respect, it is especially important for SME entrepreneurs to accept innovative technologies and new business models. Attitudes of SME entrepreneurs towards the introduction of innovation, point to their ways of thinking and affect the intention to use innovation in business. The aim of this paper is to explore the attitudes of entrepreneurs towards the use of ICT in small and medium-sized enterprises. For this purpose, a new survey questionnaire was developed and corresponding data collected from 118 of Croatian SME entrepreneurs in two Northern Adriatic counties. The results of the research have shown that SME entrepreneurs have a positive attitude towards the introduction of ICT in business. In relation to gender, age and work experience in entrepreneurship, the difference in attitude of entrepreneurs towards the use of ICT in business was not confirmed; however, there was a statistically significant difference in entrepreneurs' attitude towards the use of ICT in business in relation to county, degree of education, previous education in entrepreneurship, frequency of competency development for business purposes and frequency of use of different cloud apps for business.**

I. INTRODUCTION

In the EU, 99% of all businesses represent small and medium-sized enterprises (SMEs) [1].

The European Commission in its document "The New SME Definition – User Guide and Model Declaration" defines SME as "the category of micro, small and medium-sized enterprises (SMEs) is made up of enterprises which employ fewer than 250 persons and which have an annual turnover not exceeding 50 million euro, and/or an annual balance sheet total not exceeding 43 million euro" [1]. The aforementioned definition also states that a small enterprise as an "enterprise which employs fewer than 50 persons and whose annual turnover and/or annual balance sheet total does not exceed EUR 10 million", a micro-enterprise is defined as an "enterprise which employs fewer than 10 persons and whose annual turnover and/or annual balance sheet total does not exceed EUR 2 million" [1].

According to Small and Medium Enterprises Report – Croatia - 2016 [2], in 2015 small and medium-sized enterprises represented 99.7% (106.221 registered enterprises) of the overall Croatian economy, with 54% of share in total income, 69.2% in employment and 50.3% in export.

This paper puts a special emphasis on the two Northern Adriatic counties: Istria and Primorje-Gorski Kotar.

Based on the basic indicators for 2015, there were 9.465 small and 70 medium-sized entrepreneurs registered in the Istria County ("Information on the State of Economy in Istria County" – "Informacija o stanju gospodarstva Istarske županije" [3]), while in the Primorje-Gorski Kotar County there were 9.436 registered SME entrepreneurs in the same year. Overall, there were 41.002 entrepreneurs registered in the two Northern Adriatic counties, and 106.569 nationwide [4].

In general, 98-99% of income of every national economy is generated by small and medium-sized companies which are also incubators for innovative technologies and as such are interesting to many practitioners and scientists on all levels, form local to global.

As an example, one of main objectives of the European Union (e.g. see The Entrepreneurship 2020 Action Plan [5]) is the implementation and development of information and communication technologies in medium-sized companies (SMEs) in order to improve their business and competitiveness.

Since the change in attitudes of SME entrepreneurs towards the use of technology in business is one of the important factors which affects their intention to use, and ultimately, the real use of ICT in business, this paper investigates the attitudes of 118 small and medium-sized entrepreneurs in two Northern Adriatic counties in Croatia: Istria County and Primorje-Gorski Kotar County.

The following section contains a discussion of the existing literature in this context. Research method is described in the third section. Fourth section presents and

discusses the empirical results. Concluding remarks are offered in the last section.

II. LITERATURE REVIEW

In general, Dutot and Horne [6] have found (according to Hull et al. [7]), that digital entrepreneurship can be categorized into three types:

- "the digital image is seen and implemented as a complement to the traditional entrepreneurship" ("treasure digital enterprise");
- "the company invests a significant amount of resources on digital, mostly product, delivery or other component of the value chain" ("moderate digital enterprise")
- "the whole company is digital, going from production to customers" ("extreme digital enterprise").

Key technologies with the potential to change and reshape business by SMEs are cloud computing, social media, internet of things, mobile computing, and big data analytics and information systems such as ERP, CRM, and SCM [8].

Neykova [9] has emphasized that the perception of the advantages of the new developing ICT in the business process in SMEs is closely related to the increase in efficiency of performed business processes on a global level.

According to Giotopoulos et al. [10], ICT adoptions by SMEs are complex and depend on a great number of factors related to strategic orientation, organization, firms' resources, and business environment. Furthermore, authors [6] have concluded, that the human capital embedded in firms' workforce appears as a very important factor for SMEs in their attempts to assimilate new technologies.

Based on research results of both French and Emirati digital entrepreneurs, Dutot and Horne [6], it can be concluded that agility, entrepreneurial alertness and entrepreneurial characteristics influence entrepreneurs' intention of adoption of digital entrepreneurship.

Barriers to ICT adoption in SMEs are (according to Antlová [11]):

- "Technological barriers (problems of security, insufficient infrastructure).
- Organisational barriers (management style, shortage of financial sources).
- Barriers arising from the surrounding environment (insufficient knowledge of the market).
- Individual barriers (insufficient knowledge, personal relations in organisation)".

Based on research results (31 businesses in Denzili, Turkey), Ertuğrul et al. [12] have found that SMEs adaptation level of IT can increase efficiency by investing in infrastructure, processing staff, and training of employees.

In the Croatian context, for example, only 20,4% of the analyzed enterprises (2016) were improving ICT skills of their employees and only 17,4% of small and medium-sized enterprises have ICT specialists as their employees [13]. Based on the previously mentioned research, Bedeniković et al. [13] have found that employees at SMEs are very slow to accept the process of digital transformation indicating further negative impact on their participation in e.g. e-commerce, e-government and e-practice at EU and global level, and in general on the development of the entire Croatian digital economy.

Li et al [14] have concluded that one of the main challenges that SME leaders face today is how to optimally integrate business and IT system in their organization to fully leverage the potential of digital technologies.

Based on research results, Li et al. [8] have concluded that digital skills and attitudes of SMEs' e-leadership is one aspect of digital entrepreneurship, but that "successful e-leaders" do not need to possess all digital skills. Authors [8] emphasize that the leaders' attitudes (positive or negative) impact the employees' perceptions of the benefits of IT innovations, and play an important role in adoption and development of digital entrepreneurship.

"Entrepreneurial digital competencies" (EDCs), according to Ngoasong [15], refers to a combination of entrepreneurial and ICT or digital competencies.

In the context of the Entrepreneurship Competence study (EntreComp study) [16], entrepreneurship is understood as a competence which includes a set of knowledge, skills and attitudes. According to The Entrepreneurship Competence Framework [16], "Attitudes are motivators of performance and they include their values, aspirations and priorities".

A number of theories and models on technology and innovation adoption explain individuals' attitudes towards ICTs. Implantation of ICT into SMEs' business is innovation, and the success of this process is related to the level of adoption of ICTs by SME entrepreneurs.

According to the theory of planned behavior (TPB) proposed by Ajzen [17], users' attitude toward the behavior refers "to the degree to which a person has a favorable or unfavorable evaluation or appraisal of the behavior in question". It is important to emphasize, according this model [17], that the "attitudes develop reasonably" from the beliefs of people about an object. In addition, Ajzen [17] concludes that attitudes towards the behavior can explain behavioral intentions with a high degree of accuracy.

Furthermore, according to the technology acceptance model (TAM) developed by Davis et al. [18], behavioral intention (BI) is determined by both the person's attitude towards using the system and the perceived usefulness. Based on the aforementioned, it is evident that if the entrepreneurs have the intention to use ICT in their business in SME, they will do it.

For example, Esmaeilpour et al. [19] in a study have examined barriers of adoption and use of e-commerce in small and medium-sized enterprises (SMEs) with the implementation of the technology acceptance model (TAM), and their results have shown that both, perceived ease of use and perceived usefulness of e-commerce have a positive and significant impact on the attitudes regarding its

use. In addition, according to [19], attitudes towards the use of e-commerce have a significant and positive impact on the intention (desire) to use, and the intention (intended use) variable has a positive significant impact on the actual use of e-commerce by SMEs.

Taylor and Todd [20] have shown that an expanded Augmented TAM model can explain the behavior of both groups, experienced and inexperienced users in the area of information technology, stating that there are differences. The authors have concluded that the factor of "previous experience" has proven to be an important determinant of users' behavior towards ICT. Also, the authors have stated that the knowledge of an individual's acquired experience helps shape the behavior and makes the relative difference between the influence of other determinants on individuals with experience and without previous experience in using information technology. For example, the perception of utility has proven to be a stronger predictor of intention to use information technology for users with no experience compared to users with experience in working with technology.

According to Antlová [11] the barriers of implementation of ICT in SMEs are "insufficient financial sources, lack of experience with ICT and insufficient knowledge and skills in the area of computer literacy of employees".

Orser and Riding [21] have found that the gender of small-scale entrepreneurs influences the adoption of information technology (IT), in a way that that men are more likely than women to adopt IT.

Therefore, the attitudes of small and medium-sized entrepreneurs towards the introduction of innovation(s), point to their thinking and influence the intention to use innovation in business. Based on the above, it is obvious that there is a need for explanation of factors which influence the attitudes of SME entrepreneurs towards the use of ICT in their business.

III. METHODOLOGY

This paper explores entrepreneurs' views on the use of ICT in small and medium enterprises from two Croatian counties: Istria and Primorje-Gorski Kotar County.

A. Procedure and Apparatus

The research was conducted by means of an online questionnaire (http://google.com) in March and April 2018. Following the request made by the authors of this paper, the questionnaire was sent out to small and medium-sized entrepreneurs via email (members' mailing list) by the Croatian Chamber of Economy – Regional Chamber in Pula, the Association of Trades and Crafts in Pula (Udruženje obrtnika Pula), the Association of Trades and Crafts in Rijeka (Udruženje obrtnika Rijeka), Municipality of Bakar and Municipality of Kostrena. Participation was voluntary and anonymous.

Based on the following documents: "The EntreComp Framework" [16], "e-Leadership Digital Skills for SMEs" (European Commission [22]), and "DigiCom" [23], Ngoasong [15], Babić [24] and Babić and Bubaš [25]; a new questionnaire was developed.

The questionnaire was composed of 24 items related to participants' demographics and 55 items assessing the competencies of small and medium-sized entrepreneurs for using ICTs in their business. Responses to the questionnaire items were modulated on a five-point Likert scale (1-strongly disagree, 5–strongly agree).

B. Participants

A total of 118 respondents (56.8% male, 43.2% female), aged 35 to 45 years (SD = 1.05) on average, took part in the research. The sample was composed of 59.3% entrepreneurs from Istria County and 40.7% entrepreneurs from Primorje-Gorski Kotar County.

The majority of small and medium-sized entrepreneurs (57%) had between 10 and 25 years of work experience, 44% of participants had university qualifications, 36.4% had secondary school qualifications.

In most cases (90.1%), small and medium-sized entrepreneurs are employing their smartphones for making and receiving calls for the purpose of business, 87.9% for sending and receiving emails, 78% for Web browsing, 74.5% for instant messaging (e.g. Viber, WhatsApp). In our research paper other demographic characteristics of respondents are shown (see Golob and Babić [26]).

IV. RESEARCH RESULTS

A. Attitudes of Entrepreneurs Towards the Use of Information and Communication Technologies in SMEs

According to the average mean shown in Table 1, it is obvious that the respondent entrepreneurs have expressed attitude toward the use of Information and Communication Technologies (ICT) in business with an average rating of 3.92 to 4.24.

Internal consistency of the scales was measured with Cronbach's alpha coefficient. The results show that the scale "attitude towards the use of ICT for business" had a satisfactory internal consistency (0.93).

The results of the t-test, a one-way analysis of variance (ANOVA), which tested the levels of attitude towards the use of ICT for business by entrepreneurs from Istria and Primorje-Gorski Kotar County with regard to the selected demographic variables, are shown in Table 2 and Table 3.

Furthermore, t-test and ANOVA results shown in Table 2 indicate that there is no significant difference in attitudes towards the use of ICT for business by entrepreneurs based on gender, age and work experience in entrepreneurship.

However, t-test results (Table 3) indicate that there is a significant difference ($p<0.05$) in the level of entrepreneurs' attitude towards the use of ICT for business based on the county. Entrepreneurs from the Istria County have a more positive attitude than entrepreneurs from Primorje-Gorski Kotar County.

TABLE I. ITEMS OF ATTITUDE TOWARDS THE USE OF ICT FOR BUSINESS (1-STRONGLY DISAGREE, 5–STRONGLY AGREE), PERCEIVED BY ENTREPRENEURS FROM ISTRIA AND PRIMORJE-GORSKI KOTAR COUNTY (N=118)

Construct: ATTITUDE(S) TOWARDS THE USE OF ICT FOR BUSINESS Items:	Response % in each level		**Mean (SD)**
ATT1. I believe that the application of information communication technologies in entrepreneurship is a very good idea.	1	2.54	4.24 (0.98)
	2	2.54	
	3	16.10	
	4	26.27	
	5	**52.54**	
ATT2. The opportunities offered by the application of innovative information and communication technology (ICT) in entrepreneurship to me are extremely interesting.	1	1.69	3.98 (1.05)
	2	7.63	
	3	22.03	
	4	27.97	
	5	**40.68**	
ATT3. I believe that the use of ICT in entrepreneurship can be very useful to me and my business.	1	3.39	4.04 (1.06)
	2	5.08	
	3	17.80	
	4	31.36	
	5	**42.37**	
ATT4. The application of innovative technologies in my business allows me to perform my work tasks more efficiently.	1	1.69	4.08 (1.03)
	2	5.93	
	3	21.19	
	4	24.58	
	5	**46.61**	
ATT5. In general, I like to use information and communication technology in business.	1	2.54	3.92 (1.05)
	2	5.93	
	3	26.27	
	4	27.97	
	5	**37.29**	
Cronbach alpha = .93			

TABLE II. RESULTS OF T-TEST AND ANOVA SHOWING RELATIONSHIPS BETWEEN THE SELECTED DEMOGRAPHIC VARIABLES AND ATTITUDES TOWARDS THE USE OF ICT FOR BUSINESS, PERCEIVED BY ENTREPRENEURS FROM ISTRIA AND PRIMORJE-GORSKI KOTAR COUNTIES (N=118)

Variable		***M (SD)***	***t-test/ ANOVA results***
Gender	Male	20.37 (4.74)	t= .30
	Female	20.12 (4.34)	Sig.=.764
Age	less than 18 years	-	F=1.77 Sig.=.124
	18-24 years	21.00 (0.0)	
	25-34 years	21.76 (3.99)	
	35-44 years	20.78 (4.34)	
	45-54 years	20.00 (4.59)	
	55-64 years	18.05 (5.03)	
	65 and over	23.00 (2.65)	
Work experience in entrepreneurship	no experience	-	F=.66 Sig.=.725
	less than one year	22.14 (5.55)	
	2-3 years	21.23 (3.75)	
	4-6 years	20.25 (4.37)	
	7-9 years	21.44 (4.50)	
	10-15 years	19.92 (4.24)	
	16-20 years	20.25 (4.75)	
	21-25 years	20.44 (3.33)	
	26-30 years	18.00 (6.07)	
	more than 30 years	18.75 (6.71)	

ANOVA results (Table 3) indicate that there is a significant difference ($p<0.05$) in the level of entrepreneurs' attitude towards the use of ICT for business based on the level of education. Tukey's post hoc test showed a significant difference ($p=.005$; $p<.05$) between the group of entrepreneurs with a university degree (M=21.52, SD=3.70) and the group of entrepreneurs with a secondary school education (M=18.49, SD=5.08), with the first group having a more positive attitude towards the use of ICT in business.

TABLE III. RESULTS OF T-TEST AND ANOVA SHOWING RELATIONSHIPS BETWEEN THE SELECTED VARIABLES AND ATTITUDES TOWARDS THE USE OF ICT FOR BUSINESS, PERCEIVED BY ENTREPRENEURS FROM ISTRIA AND PRIMORJE-GORSKI KOTAR COUNTIES (N=118)

Variable		***M (SD)***	***t-test/ ANOVA results***
County	Primorje-Gorski Kotar County	19.00 (4.67)	**t= -2.55 Sig.=.012**
	Istria County	21.13 (4.29)	
Level of education	university degree	21.52 (3.70)	**F=4.96 Sig.=.003**
	two-year post-secondary	21.35 (3.60)	
	degree	18.49 (5.08)	
	secondary school	16.67 (7.64)	
	other		
Ways of acquiring new entrepreneurial knowledge, skills and abilities	University	21.95 (3.52)	**F=3.42 Sig.=.004**
	secondary school	17.63 (3.96)	
	courses and/or workshops	20.15 (4.36)	
	independently through print and digital resources	22.28 (3.97)	
	from coworkers	16.50 (3.87)	
	do not have entrepreneurial knowledge, skills and abilities	18.50 (5.15)	
	other	18.62 (4.91)	
Frequency of education for the purpose of developing competencies in business environment	once a year	19.06 (4.57)	**F=3.41 Sig.=.020**
	several times a year	21.52 (4.17)	
	once a month	21.67 (5.77)	
	several times a month	-	
	every week	-	
	daily	25.00 (-)	
Frequency of use of cloud apps in business environment	do not use	16.91 (5.44)	**F=6.26 Sig.=.000**
	once a month	18.08 (3.87)	
	several times a month	20.00 (3.89)	
	several times a week	21.43 (3.69)	
	daily	21.98 (3.64)	
	other	18.00 (4.24)	

Furthermore, ANOVA results in Table 3 show a significant difference in the level of attitude towards the use of ICT for business based on the ways of acquiring new entrepreneurial knowledge, skills and abilities ($F= 3.42$; $p = .004$), frequency of education for the purpose of developing competencies in business environment ($F=3.41$, $p=.020$). In this context, Tukey's post hoc test did

not show a significant difference ($p<.05$) between the groups.

However, ANOVA results (Table 3) indicate that there is a significant difference ($p<0.05$) in the level of entrepreneurs' attitude towards the use of ICT for business based on the frequency of use of cloud apps in business environment. Tukey's post hoc test showed significant differences between the user group which does not use cloud services in business (M=19.91, SD=5.44), the user group which uses cloud services once a month in business (M=18.08, SD=3.87), and the group which uses cloud services in business every day (M=21.98, SD=3.64); with the third group having the most positive attitude towards the use of ICT in their business in SMEs.

V. CONCLUSION

The success of the development of the digital economy, in a large proportion depends on the level of ICT adoption in SMEs on all levels, from counties to a global level. Attitudes towards the use of ICT for business by entrepreneurs can explain their behavioral intention to adopt ICT, which has an impact on the real use of ICT in business. This paper, explores entrepreneurs' views on the use of ICT in Croatian small and medium enterprises from two Northern Adriatic counties: Istria and Primorje-Gorski Kotar County.

Research results show that SME entrepreneurs from those two Northern Adriatic counties have a positive attitude towards the introduction of ICT in business. The difference in attitude of entrepreneurs towards use of ICT in business has not been confirmed, in relation to gender, age and work experience in entrepreneurship. Furthermore, obtained results have confirmed that there is a statistically significant difference in attitude of entrepreneurs towards the use of ICT in business in relation to county, degree of education, previous education for entrepreneurship, frequency of competency development for business purposes and frequency of use of cloud apps for business.

Based on the results, prior experience in digital entrepreneurship is very important for entrepreneurs because they can develop positive or negative attitudes towards ICT in business which have an impact on the intention to use and the actual use of ICT in their business. ICT adoption in SMEs is one of the main factors for the development of the digital economy on all levels. It is therefore important to develop a strategy for education of SME entrepreneurs on county and national levels.

The limitations of this research can be observed in a small number of SMEs entrepreneurs (N=118) as well as in the selected factors. Around 19 000 SMEs entrepreneurs are active in the Istria and Primorje-Gorski Kotar counties (based on the data available in 2015); however, since only 118 of them have participated in this research, the obtained results should be considered with caution. Nevertheless, since the entrepreneurs that have participated in this research are those who have expressed interest in cooperation in this context, obtained results can be considered relevant, and as such, can be used as a basis for further research. Furthermore, positive feedback has been received regarding the quality and content of the questionnaire from the leading institutions that have participated in the research procedure, and which have been mentioned in the previous section. Therefore, the results of this paper can be used in practice and as a basis for future research that should include a larger number of SMEs from two Northern Adriatic counties: Istria and Primorje-Gorski Kotar.

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E E

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PAPERS

Comparison of Different Classification Techniques in Predicting a University Course Final Grade

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***Abstract* - In this paper, we subject the education evaluation to different classification techniques. Then, we compare their results. The main idea is to check the suitability of different classification techniques to be used as prediction tools. After that, we conduct a comparison of the obtained results. Some classification techniques show better suitability to respond to the given assignment than the others. At the end, we show the classification techniques, which can be used in these cases as a prediction tool.**

Keywords - classification; prediction; student grade; education; pattern recognition.

I. INTRODUCTION

The Educational Data Mining (EDM) is a flourishing discripline whose aim is the application of machine learning and pattern recognition approaches in different educational fields in order to analyse trends and patterns derived from the students. This kind of analysis is revealing some potential in developing new learning environments which may drive teachers, students and employes in a more conscious process of decision making in the educational field.

In particular, the EDM can be applied for pursuing the following four objectives [1]: (i) prediction of the student's learning, which can be obtained by including different information about knowledge and behaviour of the students as input variables, (ii) improvement of existing educational models, (iii) analysis of the education support on the students' learning, and (iv) increasing knowledge about learning and students. In this context, supervised classification in terms of prediction tools can play an essential role in predicting trends and patterns which provide a valid support for teachers in understanding the learning level of the students.

Supervised classification is an important data mining subfield whose aim is predicting the behaviour of a dependent variable from known independent variables [2]. In particular, it aims at learning a model called classifier from training labeled data, which is able to predict the class label of unknown test data given as input to the model. Accordingly, different classifiers have been introduced in the literature for solving different problems of data prediction, including: (i) statistical-based classifiers, (ii) structural predictors, (iii) knowledge-based methods, (iv) combination of multiple classifiers, and (v) multi-stage classification. The first methods include classifiers based on statistical concepts, e.g. decision tree, neural network and support vector machine. The second ones create models in the form of objects from the training data, which are used for the classification of test data. The third methods generate a set of rules which are adopted for classifying new instances. Combination of multiple classifiers includes the paradigm of ensemble learning, where different classifiers are combined for the final classification. At the end, multi-stage classification provides a more refined classification in multiple steps from an initial coarse classification.

A. Related work

Different relevant studies have been introduced in the recent time on the application of classification tools for educational purposes [3]. Among the others, Ref. [4] introduced a method for classification of chat messages in education environment using a Bayesian classifier. Also, Carmona et al. [5] proposed an adaptive Bayesian Network model for predicting the student's preferences over time, based on prior knowledge and adaptive behavior according to the interaction of the student with the model. Pechenizkiy et al. [6] used classification tools, i.e. decision tree and rule-based models, clustering and association rule mining, for analysing the ability of test's questions and feedback in satisfying the student's needs. Also, Ref. [7] employed decision tree and neural network classifiers for predicting the students' behaviour pattern, which was presented to the teacher as a valid support for the interaction evaluation. On the contrary, Ref. [8] reported a comparison of different classification tools, including decision tree, neural network and Bayesian classifier, in order to identify the slow learners among the students. Finally, Cortez and Silva [9] adopted decision tree, random forest, neural network and support vector machine in order to predict students' failure in a class of students.

B. Our contribution

In this paper, we overcome the limitations of the previous studies in the literature which employ a small

population of students, or use a high number of predictor variables, or obtain an accuracy result up to 93%. In fact, we perform an evaluation of different classification tools on a population of 700 students for making prediction in the educational environment. In order to achieve our objective, we only employ a selected set of 5-6 variables which can obtain an accuracy up to 99.7%. Furthermore, we add to the evaluation two classifiers which, to the very best of our knowledge, have not been employed in the presented form in the educational context: (i) the multiclass ensemble of support vector machine, and (ii) the multiclass ensemble of linear discriminant analysis. Accordingly, we provide a double contribution:

1. a general study which evaluates the potential of different classifiers in predicting the final students' grade in an educational environment,
2. a classification system which is able to predict with high accuracy the final students' grade from pre-exam student-based information.

It will provide an invaluable support for teachers in different educational environments in order to reliably monitor the status of their class prior of any final evaluation and to make decision about the improvement of the class level.

The paper is organised as follows. Section II provides details of the adopted dataset. Section III describes the classification tools used for the analysis. Section IV presents the experimental setting. Section V describes the obtained results of the experiment. Finally, Section VI concludes the paper and outlines future work directions.

II. DATA DESCRIPTION

A. Data gathering

We collect education data from a population of 700 students attending a university course. Collected data is characterised by different information about the students, including pre-exam test grades, attendance, seminar grade, and final grade (final exam). Information about the students is completely anonymous and each student is denoted as an identification number which is different from the ID number inside the university. Tests, seminar and final exam occur during the same semester.

B. Data pre-processing

We include the collected data in a dataset composed of 700 samples (or instances). Each instance represents a university student. It is characterised by some of the most relevant features which are useful to identify the student from an educational point of view, including: (i) first test grade, (ii) second test grade, (iii) attendance, (iv) seminar grade, and (v) final grade (final exam). In particular, first and second test grades are integer numerical features ranging between 0 (minimum grade) and 20 (maximum grade). On the contrary, attendance and seminar features take integer numerical values between 0 (minimum grade) and 10 (maximum grade). At the end, the final grade is an integer numerical feature in the range [0 (minimum grade), 10 (maximum grade)]. However, in the education dataset, the final grade has a value between 5 and 10 (hence it takes 6 different values). Table I reports the different features included in the education dataset and their corresponding values.

TABLE I. EDUCATION FEATURES AND THEIR VALUES IN THE EDUCATION DATASET

Feature	Characteristics		
	Name	***Value***	***Type***
1	First test grade	[0, 20]	Numerical
2	Second test grade	[0, 20]	Numerical
3	Attendance	[0, 10]	Numerical
4	Seminar	[0, 10]	Numerical
5	Final grade	[5, 10]	Numerical

Before any processing task, we normalise the feature values of the dataset to be included in the range [0,1]. In particular, we employ a min-max procedure of normalisation as follows:

$$\hat{x}_i^k = \frac{x_i^k - \min_k}{\max_k - \min_k} \quad (1)$$

where x_i^k is the value of k^{th} feature of dataset sample x_i, and $\min_k$ and $\max_k$ are respectively the minimum and maximum values of k^{th} feature in the dataset.

III. CLASSIFICATION TOOLS

The obtained education dataset is subject to classification analysis in order to test the prediction ability of different classifiers in the education evaluation. In particular, we employ two different statistical-based classifiers: (i) decision tree, and (ii) *K*-nearest neighbour, and three ensemble-based classifiers: (i) multiclass ensemble of support vector machine, (ii) multiclass ensemble of linear discriminant analysis, and (iii) random forest, for a total of five different classifiers. In the last years, the ensemble learning has emerged as an effective and robust learning strategy for solving complex prediction tasks.

A. Decision tree

A decision tree is one of the most utilized classification methods that uses a function which calculates the value of the dependent variable based on the values of independent variables [10]. The tree has a root, nodes, branches and leaves [11]. Different decision tree algorithms can be used, such as ID3 or C4.5 algorithm [11]. In particular, the C4.5 creates a binary tree that represents classification [12]. It is the most widely used decision tree algorithm that usually provides high precision compared to other decision trees [11]. The algorithm uses the Gain Ratio to determine the difference between instances contained in a set of training samples, followed by the creation of a tree node that has the value of the chosen feature. From the node, child links are created, with each link representing a unique value. These

unique values are then used to further subdivide the samples in subclasses.

B. K-nearest neighbour

K-nearest neighbour (KNN) is a supervised learning algorithm that uses a distance function. As a distance function between the unknown test sample and the training samples, the Euclidean distance is usually adopted. This function calculates the similarity or the difference between instances [13], where *K* nearest neighbour refers to the distance in the *n*-dimensional space. KNN algorithm classifies samples based on their nearest vectors in the vector space [14]. This distance is defined by *n* features in the training set. Lastly, the KNN algorithm classifies the unknown test sample based on the majority vote of the found neighbours. The contribution of each neighbour can be weighted, with the closest neighbours contributing more to the average.

C. Multiclass ensemble of support vector machine

The multiclass ensemble of support vector machine (SVM) with *L* classes is based on the combination of classification results from $L(L\text{-}1)/2$ SVM ensembles, one for each pair of classes [15], [16].

The SVM ensemble is based on a strategy of AdaBoost. Initially, each training sample is equipped with a weight which is $1/d$, if d is the number of training samples. At the t^{th} iteration, a subset of training samples of size $d' < d$, selected according to the weights' value at iteration $(t\text{-}1)$, is used for training the t^{th} SVM classifier. Then, the performances of the t^{th} classifier are computed on the whole training set. Accordingly, the uncorrectly classified training samples are assigned to a higher weight. Hence, the $(t+1)^{\text{th}}$ classifier is trained by selecting the samples according to the new weights. After training the *T* SVM classifiers, a majority voting strategy is used for the classification of a test sample.

An SVM classifier aims at finding the parameters of the linear separating hyperplan maximising the margin between the classes [17]:

$$\min_{w,b,\xi} \frac{1}{2} w^T w + P\sum_{j=1}^{d'} \xi_j, s.t.\ y_j(w^T\phi(x_j)+b) \geq 1-\xi_j,\ \xi_j \geq 0,\ j=1,\ldots,d', \quad (2)$$

where ϕ is the kernel function, *P* is the penalty factor of the training error, x_j is a training sample with class label y_j, d' is the number of considered training samples. A test sample x_i is classified according to the decision function $y_i = \text{sgn}(w^T\phi(x_i)+b)$, where *sgn* is the sign function, and *w* and *b* are the learned parameters.

D. Multiclass ensemble of linear discriminant analysis

The multiclass ensemble of linear discriminant analysis (LDA) with *L* classes is given by the aggregation of $L(L\text{-}1)/2$ LDA ensembles, one for each pair of classes [15].

The LDA ensemble employs a strategy of Bagging. In particular, *T* subsets of the training samples are randomly selected using re-sampling with replacement. Each training subset is used for training an LDA classifier. A test sample is classified by using a majority voting strategy on the decisions of the LDA classifiers.

An LDA classifier is based on the generation of the intra and inter-class matrices [18]:

$$\hat{\Sigma}_w = \sum_i \sum_{x \in c_i} (x-\bar{x}_i)(x-\bar{x}_i)'. \quad (3)$$

$$\hat{\Sigma}_b = (\bar{x}_1-\bar{x}_2)(\bar{x}_1-\bar{x}_2)',$$

where $\bar{x}_i$ is the mean of class *i* (C_i). The aim is to find the linear transformation ϕ maximising the ratio of the determinant of the intra and inter-class matrices. Classification of a test sample *s* is given by the class label of minimum Euclidean distance ε between the transformed *s* and mean of the class as follows:

$$\arg\min_k \varepsilon(s\phi, \bar{x}_k\phi). \quad (4)$$

E. Random forest

The random forest is an ensemble classifier characterised by a set of decision trees [19]. Similarly to the LDA ensemble, a strategy of bagging is employed for training the decision trees from the training samples. At the end, a test sample is classified by using a majority voting on the class labels generated by the different decision trees. A decision tree in a random forest is differently learned than a traditional decision tree. The difference consists of randomly selecting a subset of features at each node on which the best split for that node will be selected. This procedure is important for avoiding correlation between the decision trees of the forest. In fact, if some feature is a strong predictor of the dependent feature, it could be selected in many decision trees.

IV. EXPERIMENT

Our experiment consists of employing the different classification tools on the education dataset in order to make prediction of the final grade (final exam) from the other features: (i) first test grade, (ii) second test grade, (iii) attendance and (iv) seminar grade. Hence, we perform an evaluation of the different prediction tools in order to find the most suitable classifiers for education-based tasks.

Accordingly, we use Weka 3, available at https://www.cs.waikato.ac.nz/~ml/weka/, for running the C4.5 algorithm learning the decision tree and the KNN procedure. For adopting the C4.5 algorithm on the education dataset, we use the J48 classification filter in Weka. Accordingly, we change the final grade feature from numerical to nominal. Also, for running the KNN, we employ the IBk classification filter in Weka. On the contrary, we implement the multiclass ensemble of SVM and LDA, and the random forest classifier in Matlab R2017a.

TABLE II. MULTICLASS CONFUSION MATRIX *CM*

Actual class	Predicted class					
	Fail	Sufficient	Good	Very good	Excellent	Outstanding
Fail	**c11**	c12	c13	c14	c15	c16
Sufficient	c21	**c22**	c23	c24	c25	c26
Good	c31	c32	**c33**	c34	c35	c36
Very good	c41	c42	c43	**c44**	c45	c46
Excellent	c51	c52	c53	c54	**c55**	c56
Outstanding	c61	c62	c63	c64	c65	**c66**

All experiment has been performed on a laptop computer Quad-core at 2.2 GHz, with 16 GB RAM and UNIX operating system.

In the context of the classification tools, we adopt a linear kernel function for the SVM classifier, which obtains satisfactory results on the education dataset. Also, for the KNN classifier, we use the Euclidean distance and a variable *K* value from 1 to 8. Then, we select the *K* value obtaining the best results on the education dataset.

Our classification task consists of predicting 6 class labels, which are the final grade values from 5 to 10. The class labels are the following: 5 - Fail, 6 - Sufficient, 7 - Good, 8 - Very good, 9 - Excellent, and 10 - Outstanding. In order to evaluate the classification results, we employ the multiclass confusion matrix *CM*, reporting at each position cij the number of instances of actual class *i* predicted as class *j*. From *CM*, we compute the following performance measures: (i) Accuracy, (ii) Precision, (iii) Recall, and (iv) F-Measure. Table II shows the employed confusion matrix *CM*.

In particular, precision, recall and f-measure are computed as follows:

$$\mathrm{Pr}ecision = \frac{1}{m}\sum_{i=1}^{m}\frac{cii}{\sum_{j=1,j\neq i}^{m} cji}, \quad \mathrm{Re}call = \frac{1}{m}\sum_{i=1}^{m}\frac{cii}{\sum_{j=1,j\neq i}^{m} cij} \qquad (5)$$

$$F-measure = 2\times\frac{\mathrm{Pr}ecision\times\mathrm{Re}call}{\mathrm{Pr}ecision+\mathrm{Re}call}.$$

On the contrary, the accuracy is computed as follows:

$$Accuracy = \frac{\sum_{i=1}^{m} cii}{\sum_{i,j}^{m} cij}, \qquad (6)$$

where *m* is the number of classes equal to 6.

In order to assess the different classifiers, we perform a first evaluation on the education dataset using the *k*-fold cross validation with *k*=10, which is a well-known value in the literature. In particular, the dataset is randomly divided into *k* folds. Then, each fold is used as the test set, while the remaining *k*-1 folds are merged as the training set. Each classifier is trained *k* times, one for each fold, and the values of precision, recall, f-measure and accuracy are computed. At the end, the training configuration with the best performance measures is used by the classifier in order to provide the classification on the overall dataset. Accordingly, we report and analyse the performance measures obtained on the full dataset.

V. RESULTS AND DISCUSSION

Table III reports the performance measures obtained by the different classification tools on the education dataset.

Results suggest that J48 algorithm (decision tree) is able to correctly classify 79.69% of the instances. Precision represents the number of correct positive predictions over the total number of positive predictions, with a value of 79.8% [20]. Recall is equivalent to True Positives rate, where high recall indicates that the results are relevant [20]. In our case, recall is 79.7%. Lastly, f-measure is the combination of precision and recall, and has a value of 79.7% (see Table III).

Table IV shows the confusion matrix of the J48 algorithm. The sum of the diagonals in the matrix represents the number of correctly classified instances. The model predicts that 211 samples will fail, 145 will get a sufficient grade, 124 will get a good grade, 82 will get a very good grade, 85 will get an excellent grade, and 52 will get an outstanding grade. Compared to the real number of samples (presented in the rows), the model most successfully predicts 94.9% of the grade Fail, while the lowest values can be found for grades Good (63.1%) and Very good (65.1%). This indicates that the model most accurately predicts failing an exam. On the other

TABLE III. RESULTS OBTAINED BY THE FIVE CLASSIFICATION TOOLS ON THE EDUCATION DATASET. THE CLASSIFICATION TOOL OBTAINING THE HIGHEST PERFORMANCE MEASURES IS MARKED IN BOLD

Classification method	Performance measure			
	Precision	Recall	F-Measure	Accuracy
Decision tree	0.798	0.797	0.797	0.797
KNN	0.867	0.864	0.865	0.864
SVM ensemble	**0.997**	**0.998**	**0.998**	**0.997**
LDA ensemble	0.978	0.984	0.980	0.973
Random forest	0.995	0.996	0.996	0.957

hand, the model does not provide a very high accuracy for middle grades, such as Good and Very good.

On the contrary, KNN correctly classifies 86.4% of the instances. Precision of this model has a value of 86.7%, while recall is 86.4%. The value of f-measure is 86.5% (see Table III).

The confusion matrix generated by KNN is shown in Table V. The model predicts that 211 samples will fail, 146 will get a sufficient grade, 116 will get a good grade, 94 samples will get a very good grade, 78 will get an excellent grade, and 54 will get an outstanding grade. The model most accurately predicts the class Fail (95.8%) and Outstanding (94.2%), while the lowest accuracy is achieved for the class Good (73%). This suggests that the algorithm better predicts very high and very low grades, such as Outstanding and Fail.

We have also changed the parameter *K*, and accordingly, the classification accuracy is influenced. From Figure 1, it can be seen that the accuracy is the highest at *K*=1 and *K*=8, then falls down to the lowest point at *K*=3. It then peaks at *K*=4, falls down at *K*=5, and then continues to rise from *K*=6 to *K*=8.

On the contrary, the SVM ensemble (see Table III) obtains a higher precision of 99.7% and recall of 99.8%. Accordingly, the f-measure value is very high, too, and equal to 99.8%. We can observe that the method correctly classifies 99.7% of instances, which is a noticeable result. This is confirmed by the confusion matrix obtained by the method and reported in Table VI. In particular, we can notice that only two instances of actual class Fail are incorrectly classified as Sufficient.

Regarding the LDA ensemble, it correctly classifies a high number of instances, too, equal to 97.3%, while precision, recall and f-measure are respectively equal to 97.8%, 98.4% and 98% (see Table III). Hence, the classifier obtains lower performances than the SVM ensemble. This result can be also observed from an inspection of the confusion matrix in Table VII, reporting 17 instances of actual class Fail which are predicted to be in class Sufficient, and 2 instances of actual class Good which are predicted to be in class Very good. Hence, the class Fail obtains the worst performances.

Finally, the random forest classifier obtains better results than the LDA ensemble classifier but worse results than the SVM ensemble classifier (see Table III). This is confirmed by the values of precision, recall and f-measure which are respectively 99.5%, 99.6% and 99.6%, while the correctly classified instances are 95.7%. From the confusion matrix in Table VIII, we can observe that one instance of actual class Sufficient is predicted to be in class Fail and 2 instances of actual class Good are predicted to be in class Very good.

From a comparison of the classification methods, we can conclude that ensemble learning is the most powerful tool for prediction in the educational field. Among the others, the SVM ensemble obtains the best performances with very high accuracy results almost equal to 1. This is followed by the random forest and the LDA ensemble. Among the statistical-based classifiers, KNN shows very promising prediction abilities when compared to the

TABLE IV. CONFUSION MATRIX OF THE J48 ALGORITHM (DECISION TREE)

Actual class	Predicted class					
	Fail	Sufficient	Good	Very good	Excellent	Outstanding
Fail	**203**	11	0	0	0	0
Sufficient	8	**109**	27	0	0	0
Good	0	24	**77**	20	1	0
Very good	0	1	20	**54**	8	0
Excellent	0	0	0	8	**69**	7
Outstanding	0	0	0	0	7	**45**

TABLE V. CONFUSION MATRIX OF THE KNN ALGORITHM

Actual class	Predicted class					
	Fail	Sufficient	Good	Very good	Excellent	Outstanding
Fail	**205**	9	0	0	0	0
Sufficient	6	**124**	14	0	0	0
Good	0	13	**89**	20	0	0
Very good	0	0	13	**66**	4	0
Excellent	0	0	0	8	**71**	5
Outstanding	0	0	0	0	3	**49**

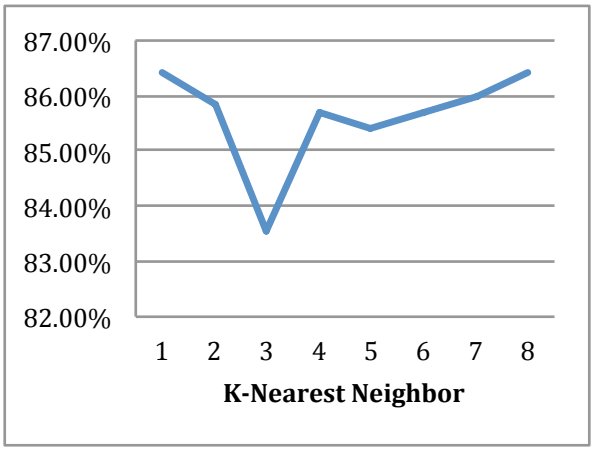

Figure 1. Accuracy results obtained by the KNN algorithm at different values of the *K* parameter

TABLE VI. CONFUSION MATRIX OF THE SVM ENSEMBLE ALGORITHM

Actual class	Predicted class					
	Fail	Sufficient	Good	Very good	Excellent	Outstanding
Fail	**212**	2	0	0	0	0
Sufficient	0	**144**	0	0	0	0
Good	0	0	**122**	0	0	0
Very good	0	0	0	**83**	0	0
Excellent	0	0	0	0	**84**	0
Outstanding	0	0	0	0	0	**52**

decision trees in this context. Also, from an inspection of the confusion matrices, it is worth noting that Fail, Sufficient and Good classes are the hardest to be predicted by the ensemble-based classifiers, that correctly predicts the highest grades. On the contrary, failing on the exams is better-predicted by the statistical-based classifiers than the other classes. In this sense, both classification approaches can complement each others.

VI. CONCLUSION

This paper presented a study about the prediction ability of different classification methods in the education context. It provided a double contribution: (i) a method for predicting the students' final grade from pre-exam students' information, and (ii) a depth analysis showing the potential of different types of classifiers in the educational context. From this analysis, we observed that the SVM ensemble classifier obtained the highest accuracy. It will provide an invaluable support for teachers as well as educators in different domains for making decision about the students and eventually improving the class level before the final examination.

Future work will test other supervised classifiers on larger datasets of different typology in the educational field and will add unsupervised classification to the analysis. Also, the analysis will be extended by adding new inputs of success in prior classes and from a test of prerequisite knowledge for predicting student performances also based on historical data.

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TABLE VII. CONFUSION MATRIX OF THE LDA ENSEMBLE ALGORITHM

Actual class	Predicted class					
	Fail	Sufficient	Good	Very good	Excellent	Outstanding
Fail	**197**	17	0	0	0	0
Sufficient	0	**144**	0	0	0	0
Good	0	0	**120**	2	0	0
Very good	0	0	0	**83**	0	0
Excellent	0	0	0	0	**84**	0
Outstanding	0	0	0	0	0	**52**

TABLE VIII. CONFUSION MATRIX OF THE RANDOM FOREST ALGORITHM

Actual class	Predicted class					
	Fail	Sufficient	Good	Very good	Excellent	Outstanding
Fail	**214**	0	0	0	0	0
Sufficient	1	**143**	0	0	0	0
Good	0	0	**120**	2	0	0
Very good	0	0	0	**83**	0	0
Excellent	0	0	0	0	**84**	0
Outstanding	0	0	0	0	0	**52**

Laboratory Model for Research on Computer Cluster Systems

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***Abstract* - This paper discusses the project-oriented learning for students in Computer Science. The proposed laboratory model of computer cluster is designed and built by students and lecturers in the courses of Computer Architectures and Fault-tolerant Computer Systems in Burgas Free University. The cluster consists of four nodes - single-board computers Raspberry Pi 3, and is used in education for research on the relationship between the number of the nodes working simultaneously and its performance. Additionally, refusals are simulated for studying the fault-tolerance of the system in condition of degradation and reconfiguration.**

The proposed model of a computer cluster is aiming at 1) involving students in scientific research and 2) solving the longstanding problem concerning the price of high-performance computer systems.

Keywords - project-oriented learning, computer cluster, fault-tolerance, computer performance

I. INTRODUCTION

Project-oriented learning (POL) involves students in various projects, usually leading to products. However, this process aims at the learning effect rather than the product itself. POL didactic strategy portrays active learning as an educational paradigm that transforms direct experience into a tool for supporting and stimulating learning [1]. Key aspects of POL, according to [2], are working autonomy; practical relevance; learning of soft skills; cooperation between university and practice.

In this context, students in Burgas Free University are involved into small projects within individual courses, progressing to a final year project course. The projects are combined with traditional teaching methods within the same course with focus on the application. Projects are undertaken throughout the length of the course and vary in duration from a few weeks up to a whole year [3].

The proposed laboratory model of computer cluster is designed and built by Master Degree students and lecturers in the courses of Computer Architectures and Fault-tolerant Computer Systems in Burgas Free University. POL, as a part of active learning, is sought and achieved in four directions:

1) teaching the graduates how to build a cluster;
2) teaching the first and second year students how the cluster is built and how it works;
3) studying the relationship between the number of the nodes working simultaneously and the cluster performance;
4) studying the fault-tolerance of the system in conditions of degradation and reconfiguration by simulating refusals.

The laboratory cluster consists of four nodes, which are single-board computers Raspberry Pi 3.

II. GENERAL SCHEME OF THE LABORATORY MODEL

A. Computer Clusters

A computer cluster is a group of individual computing systems (nodes), provided with an internal network communication, controlled by an operating system and working together to complete a single task [4]. There are many types of computer clusters ranging from the fastest computers in the world to simple single-chip microprocessors. Cluster is one of the first architectures to achieve a significant improvement in performance and fault-tolerance.

The concept of a computer cluster as a parallel data processing system was proposed by Gene Amdall in 1967 in [5]. He is the author of the famous Amdall Law, which describes mathematically the acceleration that can be expected from the parallelization of any serially executable program.

Clusters are designed to meet the increasing needs of productivity and computational power [6]. Originally developed for scientific purposes, now they are widely used for their key features: scalability; price/quality ratio; flexibility of configuration and system upgrading; possibility for development.

B. Types of Cluster Systems

The computer clusters are classified by different criteria.

Operationally the clusters are:

- *stand-by system*, consisting of one active and one standby node;

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- *mutual stand-by system*, consisting of two or more nodes, which are active and if one of them refuses, the other performs the operations on both;
- *n:1 stand-by system*, consisting of *n* active nodes and one stand-by node;
- *scalable system*, the nodes are not divided into active and standing by and if a node refuses the process continues at lower productivity.

According to the purpose of use clusters are *High Performance Computing Cluster*; *High Availability Cluster*; *Load-Balanced Cluster* [7].

According to the hardware clusters are: *Personal Computer Cluster*; *Cluster of Workstations*; *Single Board Computers.*

The goal of the project team is to design and build a high-performance fault-tolerant computer cluster of single-board computers. Such machine is a fully functional computer system, having a microprocessor, memory, I/O systems and all other features needed for the basic operation of a computer. Unlike PCs, single-board computers often have no extension slots, and its components are soldered to the board so that subsequent processor or memory upgrade is impossible. However, such clusters are easily portable and with a small form factor. They have low total cost but are still excellent for running and testing parallel algorithms. The connection between nodes is similar to other clusters by building a local network using switches and routers.

The conceptual idea is shown in Fig. 1.

III. Realization of the Cluster Model

A. Hardware implementation of the computer cluster

The following hardware components are used in the implementation of the computer cluster:

1) 4 x Raspberry Pi 3;
2) 4 x SD cards Class 10;
3) 10/100 Mbit Tenda S108 Switch;
4) 6 ports x 2.4A Tecknet U601 14.4A Power Supply;
5) 4 x CAT 5E UTP cables;
6) 4 x USB power cables.

Raspberry Pi is a single-board computer, developed by the *British Raspberry Pi Foundation* aiming at increasing availability of computer science education [8]. Raspberry PI's hardware develops and releases several versions with different performance, memory capacity and peripheral support (Fig. 2).

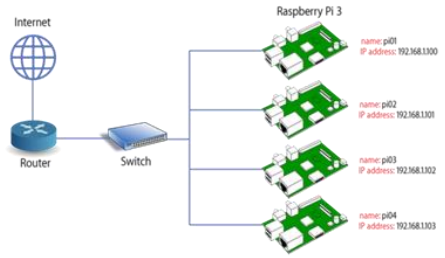

Figure 1. General scheme of the cluster

Figure 2. Models of Raspberry Pi

The last edition of *Raspberry Pi* family, *Raspberry Pi 3* is a third-generation single-board computer, released on February 2016, with added Wi-Fi and Bluetooth Low Energy connectivity without the need for additional modules. What is more, the price is not changed.

In the process of configuring the system, the four nodes are linked in the following steps.

Step 1. Each Raspberry Pi 3 is provided with electricity by *Tecknet U601 14.4A Power Supply 6 ports x 2.4A power supply*. This is done via USB 2.0 power cables (Fig. 3a).

Step 2. Each Raspberry Pi 3 is connected to the network by a *10/100 Mbit Tenda S108 Switch* with *CAT 5E UTP cables*. For scanning the network connected devices the Advanced IP Scanner program is used. MAC addresses of each device (*pi01*, *pi02*, *pi03*, *pi04*) are found and then the router configured to set static IP addresses for each node (Table I).

TABLE I. General Information for Cluster Nodes

Hostname	IP address	Cluster Role
pi01	192.168.0.100	Head node
pi02	192.168.0.101	Compute node
pi03	192.168.0.102	Compute node
pi04	192.168.0.103	Compute node

Step 3. Another computer, needed for control and monitoring, is connected to the same network as the cluster. The Head node (*pi01*) is the only device with installed graphics environment, so it is accessed with Remote Desktop application. The other nodes are accessed through *pi01*.

Figure 3. a) Power cables b) LAN cables

B. *Software implementation of the computer cluster*

The software implementation is completed in 7 steps.

Step 1. Installing an operating system. The used operating system is *Raspbian Jessie, ver. July 2017*. It is Linux-based and can be downloaded from [9].

Step 2. Configuring the operating system. The access to the device is accomplished by using the *PuTTY program* and the *SSH protocol*. Knowing the IP addresses of the nodes is very important, as they will be needed not only for connecting these devices but also for the communication between them.

Step 3. Installing and configuring *MPICH3*. The needed commands are entered into the operating system's terminal by *PuTTY/SSH*.

Step 4. Installing *MPI4PY* which is *MPI* for *Python* [10], [11].

Step 5. Preparing the other devices. Once the cluster node is initially configured, the information is passed to the other nodes. At this point, *Win32DiskImager* is used for making a copy of the SD cards. Firstly, all devices are named *pi01*. One possible approach is to change the node names manually. Another option is to set static addresses on the devices themselves, but if the router has already set these addresses, it will duplicate the IP addresses.

Each access device requires *SSH* authentication, which interferes with the direct link between cluster nodes. To do this, each node must generate an *SSH* key and share it with the other nodes of the cluster.

After configuring the connection from node *pi01* to all other nodes, the other nodes have to be connected to *pi01*.

Step 6. Installing a program for parallel computing. In this step the open source program *Cluster SSH* is used (Fig.4).

Step 7. Monitoring the system. One of the most important parts of studying a computer cluster is its monitoring. In particular, it is important to monitor whether the nodes are functioning, what their load is, and to aggregate cluster data. *Ganglia Monitoring System* software is used to monitor the system status and system's parameters. This software uses PHP and Apache to create a server. The Web interface is used to display information. As can be seen in Fig. 5, the system shows the number of processors, the nodes that are active, and those are not. It provides graphs of the state of the cluster in the last hour,

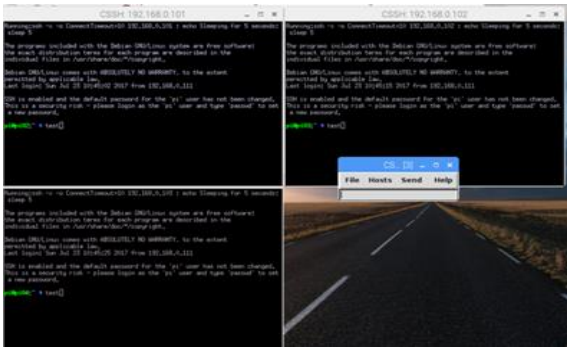

Figure 4. Interface of *Cluster SSH* program

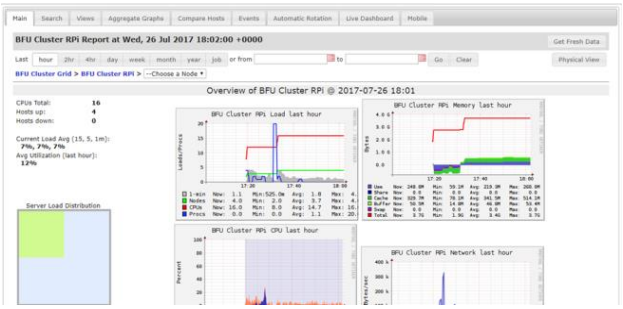

Figure 5. Interface of Ganglia

but it can go a year back. One of the most important components is *Server Load Distribution*, which visualizes the nodes load.

IV. EXPERIMENTAL RESULTS

To achieve parallelization of calculations, *Message Passing Interface (MPI)* interface is used. *MPI* is based on *Single-Program Multiple-Data (SPMD)* architecture.

A. *Performance analysis*

For testing the performance of the computer cluster two tests have been conducted.

Test 1. Calculating π.

Calculating π is a standard performance test. The program used for calculating π up to the 16th decimal digit, is written on Python and is executed by the command:

pi1 # ***time mpiexec -n X -f machinefile python example.py Y,***

where *X* is the number of kernels running in parallel, *Y* is the number of iterations and the function *time* shows the run-time of the program.

A series of experiments have been conducted, and obtained results for *Y=10 000 000* and *Y=50 000 000* are shown in Fig. 6 with abscise axis displaying the number of used cores, and the ordinate axis – time in minutes.

In case a single core is running and *Y=1 000 000*, the

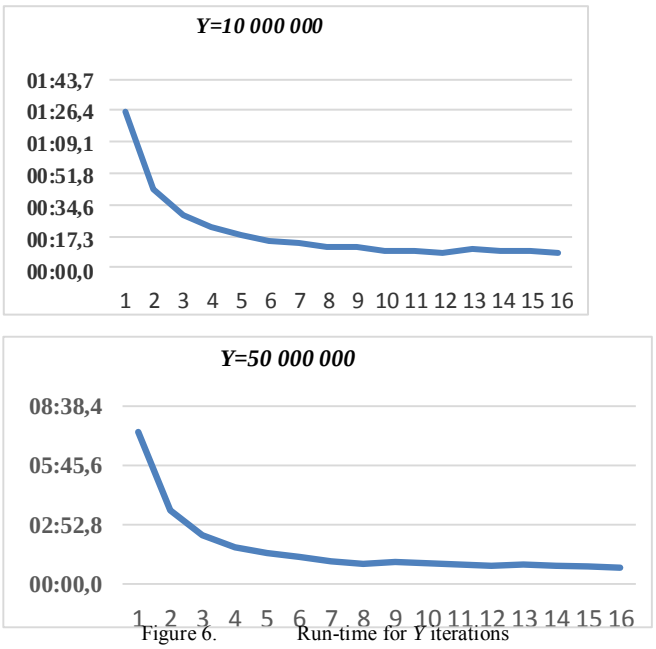

Figure 6. Run-time for *Y* iterations

average run-time is a little over 8 seconds and if all 16 cores are running it is around 2 seconds, so the acceleration is 77.53%. Interestingly, the most significant acceleration is observed with increase of the number of the cores from 1 to 8 and the best result is at 12 cores - 82.02%.

For *Y=10 000 000*, the 1-core performance is at an average time of 85 seconds. Again, as in the previous case, there is a bigger change in acceleration when increasing the number of cores initially and a slighter drop in execution time for *X>8*. The best results are obtained with the launch of 12 and 16 cores, respectively a 90.49% and 90.61% decrease in time.

For *Y=50 000 000*, the complexity of the calculations significantly increases and therefore, the run-time is increasing. When using a single core, the time is in the around of 7:20 minutes, and the shortest reached time is 46 seconds, which is a decrease of 89.51%.

With the obtained results, it can be concluded that run-time can be further improved with the addition of more cores, but only future experiments will show how considerable.

Fig. 7 shows the load on the nodes. The conclusion here is that the cluster system correctly distributes the calculations between nodes and that it is used almost at full capacity.

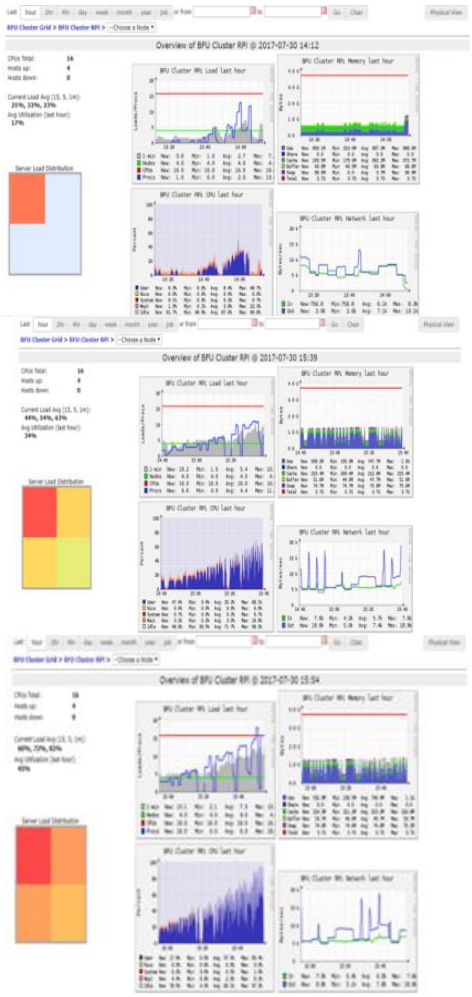

Figure 7. The load when 1 core, 12 cores, 16 cores are used

Test 2. *N-Body* simulations

In the *N-Body* simulation a system of particles under the influence of physical forces such as gravity or magnetism is studied. It is mainly used in astrophysics to study the processes of non-linear structural formations, such as the formation of galaxies, suns and planets. Such simulations require large computational resources.

To run the program, it is necessary to enter the command:

./GalaxSee.

This command opens a new window in which the interacting bodies are visualized as white dots (Fig. 8).

There are several parameters that can be changed:

- the number of simulated bodies;
- the speed of the simulation;
- simulation time in milliseconds.

By default, the *GalaxSee* is set up for simulating 200 objects for 10 seconds, but this is virtually impossible, as there is always a delay in the simulation. However, the effect of using a computer cluster can be demonstrated.

In the visualization, the performance on 1 core vs. 4 cores is significantly improved but it is arguable whether increase in number of cores will lead to improvement in performance (Table II).

TABLE II. RESULTS FROM GALAXSEE PROGRAM

Number of nodes	Run-time (minutes)	Time improvement (%)
1	01:47,356	0.00
2	01:00,945	43.23
3	00:49,282	54.09
4	00:46,833	56.38

With these results, a conclusion can be made again: run-time improves with increasing the number of cores, but conducting future experiments will show how this improvement depends on the number of cores.

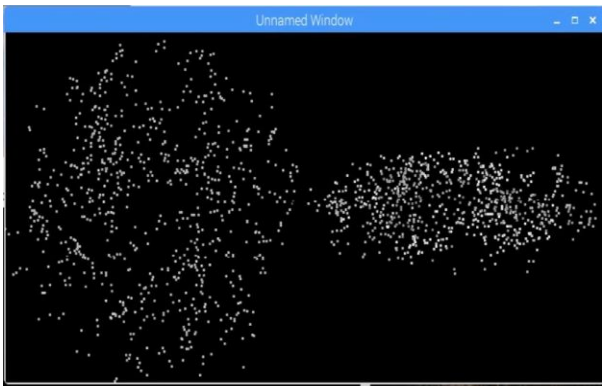

Figure 8. Simulation of interacting celestial bodies

B. *Fault-tolerance analysis*

The experiment, designed to test the fault-tolerance of the computer cluster [12], is conducted in two stages:

1) installing software for visualizing the results;

2) simulating failures of nodes.

During the first phase, the following 5 steps are performed:

1. Installation of *the Docker Platform* on all nodes through the *SSH* protocol with the *PuTTY* program by the command:

https://get.docker.com | sh

2. Creating a swarm.
3. Adding other computers.
4. Starting the first service

A web interface service created by GitHub's *ManoMark* and called "visualizer" started and used for visualization of how the services are distributed across the nodes. The version of the service has been developed for Raspberry Pi and other ARM devices.

The launch of the service is from the main computer *pi01*. Once the service is complete, the result is checked by opening the address 192.168.1.100:8080 in the browser. This provides a comprehensive preview of the nodes and the services they run (Fig. 9).

5. Starting a distributed on all nodes service

At this stage a service that will ping to the public DNS address of Google - 8.8.8.8 is started by the following command in the *SSH* protocol of the control computer:

sudo docker service create --name ping hypriot/rpi-alpine-scratch ping 8.8.8.8

The service currently created is single and this is visible in Fig. 10.

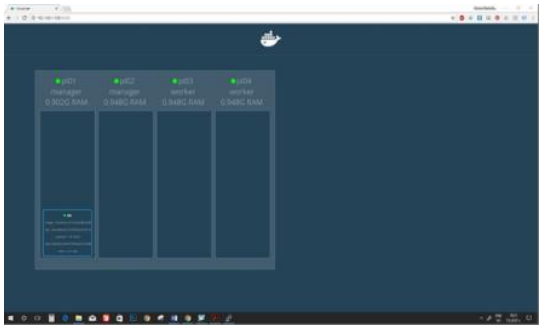

Figure 9. Preview of the nodes

Figure 10. Preview of the nodes and the services they run

Figure 11. Visualization of distributed services

Next, the ping service divide is divided into 4 parts. This is done with the command:

sudo docker service update ping --replicas 4.

The results are visible in the viewer and it can be seen that the four ping services work simultaneously on all nodes (Fig. 11).

In the second phase, after the preview proves that the services are distributed, the fault-tolerance test is conducted by turning off the nodes of the cluster one by one, and the result is monitored on the visualization program.

First, *pi03* is turned off and as can be seen see in Fig 12, its tasks are transmitted to *pi04*. This proves that the cluster continues to work with only 3 nodes (Fig. 12).

If another node of the cluster is excluded, for instance pi04, the cluster continues to perform all the services, and the two processes that worked at *pi04* have already been transferred to *pi01* and *pi02* (Fig. 13).

Figure 12. Turning off *pi03*

Figure 13. Turning off *pi03* and *pi04*

Figure 14. Turning off *pi02*, *pi03* and *pi04*

In the final step of the experiment, *pi02* is turn off a computer, and the fault-tolerance is proven again as all the cluster processes are run by the main computer *pi01* (Fig. 14).

From the hardware simulation of failures on some of the nodes, the system degrades and automatically reconfigures but still retaining its functionality. This is a result from the structural redundancy embedded in the cluster hardware [13], [14].

V. THE CLUSTER IN EDUCATION

The goals that the team has set prior to the process of designing and building the cluster and according to of project-oriented learning are fulfilled over a two years period. The first year, five MD students deepened their knowledge in the field of parallel calculations and two of them – the coauthors M. Zhekov and A. Kostadinov, being highly motivated focused their MD theses in this area. What is more, once the hardware configuration was designed and built up, the model became a demonstrational tool in the bachelor courses on Computer Architectures and Fault-tolerant Computer Systems. In the second year, a group of 15 bachelor degree students joined in and studied the procedures described in I, II and IV stages and became acquainted with the results of the conducted tests. Four of them made a presentation for the Annual Students Conference 2018, held in Burgas Free University. The project won funding from the University Research Fund for 2018 for further development.

VI. CONLUSION

The proposed in this paper laboratory model of computer cluster is a scalable, high-performance, fault-tolerant system which is composed of four single-board computers. The goals that the team has set prior to the process of designing and building the cluster and according to of project-oriented learning are fulfilled:

1) a group of master degree graduates, being an active part of the team, have learned how to build a computer cluster;
2) the process is taught in two courses of the curriculum of the first and second year students in Burgas Free University - ;
3) the research on the cluster performance is included in the master degree course on Parallel Algorithms;
4) the fault-tolerance analysis of the system is included in the bachelor degree course on Design and test of computers and the master degree course on High performance computer systems.

The next challenges that the team is facing are 1) to increase the number of nodes and 2) to implement parallel algorithms, created by students, on the more powerful cluster.

At this stage, the following observation can be made: project-oriented learning in engineering education, being directed to knowledge applications, provokes strong interest in students. What is more, they receive both theoretical and technical knowledge and additionally soft skills such as working in a team, time and resource management, and last but not least - finding solutions, arguing and standing up positions.

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Effective collection and selection of research articles for a Systematic Review

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Abstract - The first step in any research work is to gain a better understanding of selected research topic and its placement in the research field. To achieve this a Systematic Review (SR) is usually performed in one of two forms. A Systematic Literature Review (SLR) addresses a specific research question by providing insight into selected literature, while a Systematic Mapping Study (SMS) uses a principle of classification of a large number of collected articles to present a wider picture of the research topic. In both cases, the collection and selection of proper articles are crucial. Due to a lot of available articles from different sources and its diverse quality, a lot of tedious (often manual) work is required.

This article addresses the issues of effective collection and selection of an appropriate set of articles. First, the importance of using suitable guidelines for conducting an SR is presented. Then, the practical considerations for the collection of articles are shown with an emphasis on effective search in Digital Libraries (DLs). Finally, the issues connected with an effective selection of an appropriate set of articles (from all collected) is described. In this part, we advise to collect as many articles as possible and perform sequential three-step selection to efficiently eliminate the obviously incorrect ones without a tedious manual screening of entire article contents.

I. INTRODUCTION

The initial phase of research work in any research field is to get insight into the state-of the-art by reviewing the existing knowledge [1]. The empirical evidence is presented in several different types of research works (for instance books, journal articles, technical reports, conference proceedings) each containing a description related to research topic in a specific form. A large enough portion of all important works of different types (to simplify we use the term article or study in the further text) concerning specific research topic has to be studied to extract the necessary understanding of existing knowledge. Such a research is called a Systematic Review (SR) [2].

One form of SR is a Systematic Literature Review (SLR). Here a specific research questions are usually addressed, and consequently the method includes a detailed (and time consuming) study of all collected articles to answer specific questions. Thus, the number of collected articles tend to be still large, but carefully collected to provide required quality of evidence [3].

Another form of SR is a Systematic Mapping Study (SMS), where the collected articles are classified into a set of predefined clusters. The classification gives less specific answers, mostly concerned with the frequency of works with specific view [4]. Such studies are used to gain a broader insight, usually the quantity of evidence on a wider research topic.

Both forms of studies have to follow a strictly defined protocol. This protocol is valid, when it is consistent with the guidelines for performing such a SR [3]. In case of Software Engineering (SE), guidelines are based on SR in the field of medicine, and some important differences between the both research fields are identified [1]. Both forms of SR's share most guidelines, but the SMS and SLR guidelines have import differences, too [3, 4]. In any case, the appropriate understanding and later use of suitable guidelines is a necessary precondition for all further work.

This paper is based on our experience of an actual SMS performance in the field of Model-Driven Engineering (MDE) [5] and Domain-Specific Languages (DSL) [6]. Thus, we address some practical considerations and issues connected to the actual execution of the SR process as described in the guidelines for SE, and advise how to efficiently overcome them.

First, we address the article collection. Once the research topic and a set of specific questions determine appropriate inclusion/exclusion criteria, the collection of a large number of approximately suitable articles of different types (for instance conference proceedings, research journals, technical reports or expert opinions) using diverse sources (like DLs, snowballing, manual collection or others) is performed. Here, a few important issues arise. Most importantly, we have to answer the questions which sources to include and how long to perform the collection. In our view, the aim has to be to collect as much evidence as possible and not to limit the collection in any way. Unfortunately, the amount of collected evidence is usually very large (more than 5000) and demands a lot of manual work [7, 8].

The next step is to select a set of actually appropriate works by screening entire amount of works using defined inclusion/exclusion criteria [9]. In one way or another, the collection and selection of appropriate articles demands a lot of tedious manual work. For instance,

Syriani [10] reported on a SMS where more than 558 hours were needed for screening of 11,173 articles, while Kosar's SMS needed 81 hours for 1636 articles [11]. Still, a lot can be saved by using a suitable approach.

Faced with a huge amount of studies, an efficient selection is a must. We advise to divide this phase into three steps, which are sequentially performed one after another. In this manner the obviously incorrect articles are excluded first, while the possibly correct articles require abstract screening or even entire contents reading. To ease the selection, the text analysis tools might be helpful, too. Further phases of SR process (i.e., data extraction) are out of scope of this paper.

In Section 2 the SLR and SMS processes based on guidelines are explained in detail. Section 3 introduces our SMS and the practical considerations/advices on guidelines use, the collection and selection part of SR process. Finally, a conclusion is given in Section 4.

II. THE SYSTEMATIC REVIEW (SR)

The SR is an *Evidence-Based research method*. The term Evidence-Based Practice (EBP) defines an up-to-date research evidence to inform clinical decisions in the field of medicine [12]. Here, the approach is enforced by a huge corpus of predominantly well-structured experience and research work. Unfortunately, the research work in SE is mostly focused on the very versatile evidence presentation, which is less consistent to predefined rules due to the use of diverse empirical research methods in SE [3].

Zelkowitz and Wallace [13] define twelve types of research methods and divide them into observational, historical and controlled methods. A literature review (equivalent to SR) is described as a *historical evidence-based research method*.

Wieringa [14] proposed a division of the research methods from the view of intended use. The SR is considered a m*eta research method* as it collects knowledge from other research works.

Another division is given in work of Kitchenham [3], who divides studies into primary, secondary and tertiary studies. SR is considered a *secondary study* as it aims on reviewing several the primary studies related to a specific research question.

The goal of this section is to provide a deeper insight into the two types of SRs (in the SE research), namely SLRs and SMSs.

A. *The Systematic Literature Review (SLR)*

Systematic Literature Review is a secondary study that uses a well-defined methodology to identify, analyze and interpret all available evidence related to a specific research question in a way that is unbiased and (to a degree) repeatable [3]. Several authors defined guidelines for SLR research in SE [7, 15], most notably the researchers around Barbara Kitchenham [3, 16]. Consequently, the following description is based on her main work [3].

The main phases of each SLR process are **(1) planning**, **(2) conducting** and **(3) reporting** the review, each containing several steps. The steps are presented in a sequential way as they are usually conduced, but some of them can be performed in parallel (or iterative) way, too. The Figure 1 presents the phases and steps of SLR process as described in [3].

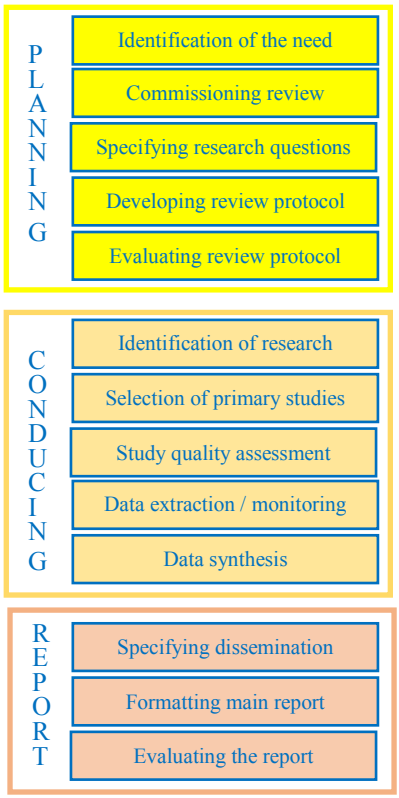

Figure 1: The SLR process

In **(1) planning** the need for a review is identified. Additionally, the review is planned by specifying research questions and a review protocol is defined. Main steps of this phase are:

1a. *Identification of the need for a review* is the entry step into any SLR, where the aim of review, the sources, restrictions, the inclusion/exclusion criteria, the performance of SLR steps and their quality are questioned.

1b. *Commissioning a review* is needed when the SLR is outsourced. A commissioning document has to be prepared to define the review questions, expected methods of the review, the project timetable and budget.

1c. *Specifying the research question(s)* is crucial part of any SLR as they identify articles included in SLR, how to extract the suitable data and the way the conclusion summarizes answers on them. The structure of the research question enables the definition of the population addressed, the intervention performed and the outcome obtained. An extended framework for the question elements definition - a PICOC (Population, Intervention, Comparison, Outcome, and Context) criteria [17] is used.

1d. *Developing a review protocol* step specifies the methods that will be used to perform a specific SR and

presents them as a defined protocol. The protocol usually includes the background, the research questions, the strategy, the study selection criteria, the study selection procedures, the study quality assessment, the data extraction strategy, the formal or non-formal synthesis strategy, the dissemination strategy, and project timetable.

1e. Finally, the *evaluating the review protocol* step validates the correctness of the protocol.

In **(2) conducting** we actually perform the systematic review by collecting the empirical evidence, selecting the appropriate part of them and extracting the required data. This phase contains the following five steps:

2a. *Identification of research* defines a rigorous search strategy to find as many as possible suitable primary studies. A list of keywords (e.g., synonyms, abbreviations, and alternative spellings) is extracted from the research questions using the PICOC elements, which is used to iteratively search for primary studies in DLs (for instance Science Direct [18], IEEExplore [19], ACM Digital library [20], Web of Science [21], Google Scholar [22]). Then, other sources of evidence (like journals and conference proceedings or gray literature) must also be (manually) checked, and the specific researchers in the field could be also approached for advice on appropriate source material. Special care must be used dealing with publication bias as the positive results are more likely to be published than negative ones, and the bibliography management and document retrieval tools should be used to manage the large number of articles. The process must be documented in sufficient detail, too.

2b. *Selection of primary studies* assesses the actual relevance of all potentially relevant primary studies. The study selection criteria use the inclusion and exclusion criteria, which are based on the research questions. Those are defined iteratively using pilot studies. The selection is initially performed by the screening using loose criteria on title and abstract only. For all included articles a full copy should be obtained. Next, the inclusion/exclusion criteria based on language, journal, authors, setting, participants or subjects, research design, sampling method, or date of publication is used. A list of included (and excluded) studies should be maintained. The assessment should be performed by at least two researchers, and disagreements must be resolved. The process should be verified using a test-retest approach or by re-evaluating a random sample of collected studies.

2c. *Study quality assessment* step is applied to further investigate the quality of conduced selection and to guide the interpretation of findings and further research. Initially, the quality evaluation can be restricted on one type of included studies only, while a detailed one assesses several factors (like selection, performance, measurement and exclusion bias) using checklists. The quality data can be collected during the main data extraction using a joint form and they can be used to assist primary study selection (to define detailed inclusion/exclusion criteria) or the data analysis and synthesis (to investigate the association of the quality differences with primary study).

2d. *Data extraction and monitoring* step designs the data extraction forms to accurately record the information. They must collect all the information needed (usually a set of numerical values), so they need to be carefully piloted on a sample of primary studies by all the researchers involved. The data extraction should be performed independently by two or more researchers, the data must be compared and all disagreements resolved consistently (and documented). Multiple publications of the same data should be excluded from a SR, too.

2e. *Data synthesis* step contains the aggregation of the results of the included primary studies. Synthesis can be descriptive or quantitative in a clear, structured tabulated form (including the statistical information). The data synthesis activities should be specified in the review protocol. Sensitivity analysis is important to determine whether the results are robust enough.

Finally, the (3) the reporting puts together and publicize the findings. The three steps of this phase are:

3a. *Specifying dissemination mechanisms* has the purpose to efficiently present of the SR results. This carefully planned activity usually aims to publish them in academic journals and/or conferences.

3b. *Formatting the main report* requires at least a technical report or (one section in) a PhD thesis to adequately publicize the SLR. This is due to size limitations of a journal or conference paper, which doesn't allow the detailed enough presentation.

3c. *Evaluating the report* is needed as only the scientific journal articles and PhD theses are rigidly enough reviewed. Usually, a peer review performed by experts in specific domain is required.

B. The Systematic Mapping Study (SMS)

A **Systematic Mapping Study** is a (broad) review of primary studies in a specific topic area that usually aims to identify what evidence is available on the topic [3]. The main differences between SLRs and SMSs concern the goal of research (SMS points to a broader, less concrete research questions than SLR), its execution process (SMS uses classification, the quality of studies is not so important in SMSs, and data extraction methods differ) and the number of studies involved (SMS aims to a larger set of primary studies then SLR) [3, 23].

Due to these important differences between SLRs and SMSs the SLR guidelines might be to restrictive [4]. The adapted guidelines for SMS in SE include additional methods for article collection, adaptive classification and enhanced visualization of results [23]. In [4] Peterson described four main phases of the SMS process: **(1) the need for the map**, **(2) study identification**, **(3) extraction and classification**, and **(4) study validity and presentation.** The phases and steps of the SMS process (as described in [4]) are presented in Figure 2. The emphasis of the following text description of SMS process is on the main differences with SLR process.

The first phase **(1) the need for the map** is equal to the initial part of planning phase of SLR as it identifies and plans a SMS. Due to different goals the resulting

research questions tend to be less specific and oriented towards "what answers actually exist" instead of "what is the meaning of those answers".

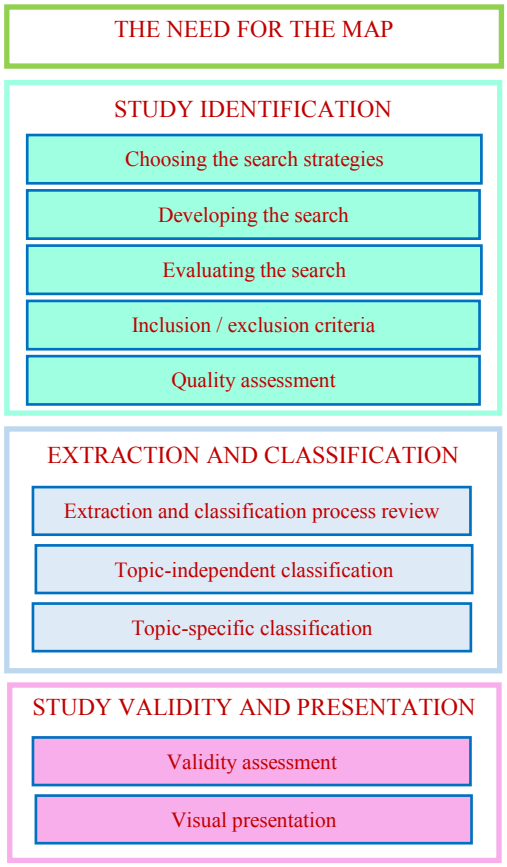

Figure 2: The SMS process

The evidence for a SMS is collected in the phase **(2) study identification** using different complimentary methods to assure the best possible coverage of available empirical evidence. This phase contains five steps.

2a. *Choosing search strategy* enables a wide enough collection of studies. The main source is database search, but it is required to be enhanced by the manual search, the snowballing (i.e., the search for referenced studies of collected evidence), and other approaches. Wohlin [24] advises to obtain articles from different clusters (non-connected communities), include different authors, years and publishers, and start the snowballing with a reasonable, not to small number of articles.

2b. *Developing the search* should include multiple approaches as using PICO(C) strategy only tend to be too restrictive in case of SMSs. It is advised to use experts in the field of research, to iteratively improve the search, and to give special attention when dealing with precision and noise in case of SMS.

2c. E*valuating the search* step is needed to determine the quality of collection and it consequently answers when the search can be stopped. The before mentioned methods like test-retest or expert opinion are used here.

2d. *Inclusion and exclusion criteria* is a specific step devoted to the definition of inclusion/exclusion criteria. To obtain a less restrictive criteria suitable for a SMS, three strategies have been proposed. First, the objective criteria for decision have to be identified, the disagreements have to be resolved using two or more experts. Finally, clear decision rules have to be defined.

2e. The *quality assessment* uses one or more of the SLR approaches, but in practice the quality assessment is not a priority in case of SMS.

In **(3) extraction and classification** the required data is extracted from collected evidence and classified into appropriate set of classes. The classification is a specific approach used in case of SMS only.

3a. *Extraction and classification process* is performed in one of two alternative ways to properly address the objectivity of criteria. The first is to use several experts to check the same evidence, while the second uses a pilot set to determine the objective criteria for decision.

3b. *Topic-independent classification* is a desirable and most commonly used solution. In most cases, the venue, research type and research method are the most common types of classification.

3c. In case of *topic-specific classification* it is advised to use keywords from paper's abstracts to create classification scheme.

Finally, in the **(4) study validity and presentation** the SMS is validated and the results are presented in the most appropriate visual form.

4a. The *validity identification* is usually aimed on the most important validity threads for a SMS: the publication bias, the poorly designed data extraction, the researcher bias (i.e., the incompatible decisions), the quality of sample studies obtained, the aggregation problems with the results of mapping, and the reliability of conclusions taken.

4b. In case of SMS, the *visual presentation* is very important, so the use of several types of charts is strongly advised. To efficiently present the results of classification, the bubble plots, bar plots and pie charts are most frequently used as they are most suitable to present the numbers related with the categorization. Additionally, charts like the line diagram, the Venn diagram or the heat map can improve presentation, too.

III. Effective Study Collection and Selection

Both (SLR and SMS) guidelines clearly stress out main tasks for SR performers. Still, conducing a SR in practice introduces additional important considerations and issues. In this section our experience with collection and selection of articles is presented after short presentation of SMS research we currently perform.

A. The context: a SMS on examining different processes while developing a DSL or DSML

After some research experience in the area of MDD and DSL [25, 26], we currently investigate the use of formal development approaches in (the industrial) DS(M)L development. The first step is a SMS to research the use of processes while developing a DS(M)L.

Using similar SMSs on DSLs [10, 11] we gained insight into some practical issues for conducting a SMS. Using this information and guidelines we defined a SMS protocol which provides a concise insight into our SMS. The main outlines are: 4 research questions (and 3 sub-questions) were defined, the articles were collected from four different types of sources (most of them from four DLs, some from snowballing, from another SMS project, and from manual search). Inclusion/exclusion criteria are clear and short (articles in English language published between 2006 and 2016 in research field of Computer Science), enabling simple, yet effective search.

We initially collected 1541 articles from all available sources. After excluding the wrong hits (duplicates and articles with unavailable full contents) exactly 1350 articles remained for further selection. The first part of selection process (screening) excluded 699 studies, thus 651 studies remained for further data extraction.

B. The use of guidelines

Clearly, the use of suitable SR guidelines is required to correctly conduce a SR. Yet the guidelines tend to be general (for versatile SE research) and cover diverse aspects, thus some parts might not be required for a specific SR. Additionally, certain SLR guidelines tend to be too rigid when conducing a SMS.

Advice 1: our advice is to use a simplified version of [3] enhanced with some specifics from [4] (when conducing a SMS), which focuses on crucial parts only. There must be a clear identification of the SR need, correctly defined research questions, appropriate research methods (including obligatory DL and other search), search strings and inclusion/exclusion criteria described in a rigid review protocol. Additionally, a data extraction spreadsheet is needed to consistently collect data as well as certain documents (checklists) for quality assessment of important decisions in the process (i.e., why to include/exclude specific articles).

C. The article collection

Contemporary DLs (as the primary source) contain huge amounts of evidence, so it is very important how to steer the collection to efficiently gain correct insight into specific research topic. The goal is to collect a lot, but not too much articles, which are (most) important for the topic in question.

Advice 2: due to versatile evidence in SE the number of DL hits vary a lot – in case of more general search string the number quickly becomes huge, while a specific search limits the hits considerably. As large number of article requires too much effort, researchers sometimes adopt the research questions and consequently the search (or even research method) to obtain expected number of hits. In our view this is a bad practice as some important evidence might be omitted in this manner. We strongly advice to always collect as much as possible evidence, but to provide an efficient selection part of SR process.

Advice 3: to achieve this, all possible sources should be used. The first source are the main DLs for specific research field, where most of important articles should be found. We should focus on the journal and conference articles as it is most probable important ideas are first presented here. Next, similar SRs are valuable source of studies. In this manner we should identify several core works (e.g., most citied) on research topic, which should be used for forward and backward snowballing. This search should identify important experts. All their published works should be checked separately. The process should be iterated till no more evidence is found.

Advice 4: it is not probable to define a correct and effective search without experience on the topic. Even an imprecise search can yield a lot of vague hits giving a wrong signal to the researcher. Piloting can be very valuable in this case. The limited sources (and the number of hits) enables effective control over results and gradual discovery of most efficient way of searching. One of most important practical results might be a set of synonyms used to address specific topic.

Advice 5: an important question is when to stop collecting evidence. The before mentioned approach (several sources, piloting, snowballing) clearly takes time, which would be very valuable in the following steps of SR process. Wohlin [24] advices to stop collecting when no new articles can be found by manual search for some time. Kosar [8] on the other hand defines a margin of error, which defines when a good enough collection was performed. In our view the collection might be stopped when we performed a complete collection using several sources iteratively, but (most importantly) found out the most citied works, their authors and completed the snowballing on them.

Advice 6: collecting (all important) references of articles is only the first part of problem. For further analysis, we must obtain entire contents of article, which is sometimes payable or even not achievable. To pay for one specific article may be reasonable, but payment for a large number of articles for a SR is simply too expensive. Our advice is to try to assess the article using abstract only (in selection step) as the abstract is usually available. The university researchers have an adequate access to most important digital sources, thus we can consider omitting the payable evidence won't cause harm. Manually collected articles can be a bigger problem, but here the number of articles is lower and we can decide considering all specific aspects of each case.

Advice 7: it is very important to maintain a consistent list of all articles to collect. Reference management tools (like JabRef [27] or similar) have to be used for this task. These tools sometimes ease the collection of entire article's contents, too. Still, automatic obtaining of several articles at once is usually limited by the providers.

D. The selection of articles

Once all the references and article contents are collected, the selection of actually relevant articles for research topic is performed. In (usually) large amount of collected articles most of them is actually not suitable for further analysis as they might address different topic, have different format, don't have entire contents, duplicate another article, etc. Due to advice 2, this situation might be even worse and even more tedious manual work might be needed for selection [8, 10].

Advice 8: To rise efficiency of selection, we advise to divide this phase into three steps, which are sequentially performed one after another. The first step is to quickly exclude obviously incorrect articles (for the research topic in question) using a *quick browse through the basic information on the work* (e.g., the source and the title). Next, the set of remaining works are screened again using the *quick screening of the work's abstract*. Finally, the third repetition in a more detailed manner by *quick reading the entire contents* may be performed, if needed.

Advice 9: Important part of incorrect articles address an entirely different research topic or even field. Acronyms are frequently used for searching the DLs and the usual reason for this issue are same acronyms used for different meaning. By understanding the collected results, it is possible to quickly recognize the articles, which were collected because of such situation. Thus, those are mostly excluded by quick title browsing.

Advice 10. Another set of incorrect articles are duplicates and related articles, which describe the same topic. Reference management tools sometimes eliminate (clear) duplicates. Additionally, they enable the references to be sorted (by title or authors). This is a valuable aid to efficiently identify neighbor duplicates by quick title browsing.

Advice 11: most of the wrong articles is usually excluded during abstract screening. Here a clear inclusion / exclusion criteria become very handy. In case of SMS they should be defined in such a way, that the decision can be taken almost automatically (i.e., the presence of a specific keyword in abstract means inclusion/exclusion). Consequently, the text analysis tools might ease this part of selection.

Advice 12: an effective abstract screening should yield predominantly included and excluded articles with a fairly small portion of possibly included articles. Only for those the entire contents has to be read. This reading can be performed quickly considering article structure and clear inclusion / exclusion criteria, too.

IV. CONCLUSION

The presented experience may seem clear and rational once it is packed in a form of 12 advices in context of SR guidelines, but it was gained in a hard way by misconducting (and repeating) some steps during our SMS research. We hope it represents that hands on information a SR performer wish to hear before starting such a research.

In our further SMS research, we intend to collect additional practical considerations concerning other steps of SMS process. In this manner the information presented in this paper will be hopefully upgraded.

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Teaching Professional Skills in Microwave Circuit Design Classes

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***Abstract* - In addition to solid grounding in technical skills of their chosen specialty, engineering students are expected to also acquire various professional skills during their studies. One description of such skills is given by various accreditation agencies, e.g., ABET. Arguably, need for extensive training in the area of professional skills is even more important for graduate students. In this paper we describe a somewhat expanded set of these skills and how they are honed in two senior / graduate courses in microwave circuit design. They include: critical thinking, metacognition, writing, reading and teamwork. Details of implementation and possible transfer to similar courses are discussed. In particular, we describe educational use of systematic literature reviews in graduate engineering education as a tool to teach all of these skills.**

Keywords – professional skills; engineering education.

I. INTRODUCTION

There are long-standing calls for improved preparation of engineering graduates so that they can, for example, address interdisciplinary grand challenges [1], [2]. More recently, similar calls for "T-shaped professionals" have been formulated, e.g. [3], [4] and references therein. If we look at the horizontal part of "T", i.e. the part that addresses "Boundary Crossing Competencies", we find competencies such as: teamwork, communication, critical thinking, global understanding, project management etc. [5]. In not too distant past these were considered "soft" skills, as opposed to "hard" technical skills. Question then becomes one of a) defining these skills, and b) deciding how to teach them. It would seem logical that a curriculum-wide approach to b) would be most effective but it is also one that is hardest to implement, due to variety of institutional, practical and ideological problems [4].

However, there are still opportunities to provide learning opportunities to students even if they are limited to one or two courses, or to provide lower-case "t" training, as mentioned somewhat tongue-in-cheek by [4]. First, we will discuss how to define some of these boundary-crossing competencies, followed by more detailed examples of how they are incorporated into course instruction.

II. DEFINING PROFESSIONAL SKILLS

The following list provides a selection of professional skills that fit more naturally within our context of teaching microwave circuit design.

1. Reading comprehension: *"Reading comprehension is the ability to process text, understand its meaning, and to integrate it with what the reader already knows."* [6]
2. (Technical) writing: *"An ability to communicate effectively with a range of audiences"* (ABET Student Outcome (SO) 3. [7])
3. Critical thinking: *"using logic and reasoning to identify the strengths and weaknesses of alternative solutions, conclusions, or approaches to problems."* [8]. Note that even defining what critical thinking is and whether it can be taught is controversial [9], [10].
4. Life-long learning and metacognition: *"An ability to acquire and apply new knowledge as needed, using appropriate learning strategies"* (ABET SO 7. [7])
5. Teamwork and project management: *"An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives*" (ABET SO 5. [7])

Arguably, out of seven proposed new ABET criteria for engineering programs, four are related to what may be considered non-technical or professional (a.k.a. "soft") skills. One further complication is division between undergraduate and graduate education. The former is at least partially shaped by accreditation requirements (ABET) while the latter is usually much less constrained. There is no reason, however, to believe that students should stop being taught these skills at graduate level. On the contrary, they should be even more emphasized given the complexity of the problems and new knowledge students are expected to acquire. In the following sections we will discuss first four skills in detail, while teamwork and project management will only be touched upon because they were discussed in previous publication [11].

III. READING COMPREHENSION

Despite its importance being demonstrated in [8], reading comprehension gets practically no attention as a separate skill that students should acquire as part of their engineering education. One can only surmise that this is left to general university studies and implicit training through reading assignments of technical textbooks. The

latter can be problematic to assess and unless e-textbooks that contain some activities are used, e.g. [12], this activity is invisible to instructors. Recent development of a reading platform Perusall [13] has made it possible to get some insights not only into whether students are reading but also how long they stay on task and how well they understand the text. In addition, groups of students share their comments ("annotations") which makes the whole reading activity a social event. This also presents an opportunity for instructor to identify common problems that can be addressed during class.

We use the Perusall platform in a slightly different fashion in our senior/graduate level courses in microwave circuit design. Instead of textbook readings, students are assigned readings from technical journals and so-called "gray literature", such as applications notes and white papers. This is very likely to be literature they will have to consult in their professional life. Gray literature has additional advantage that its quality varies a lot and we can assign some not-so-good reports to illustrate to students that they have to be critical of what they read. Fig. 1 illustrates raw data on student reading activities. Perusall automatically evaluates quantity and quality of students' annotations on a scale 0 to 3. While this sounds too good to be true, so far it has worked reasonably well. We consider score of 2 or above as meeting expectations.

However, in our classes primary purpose of the grading is to keep students focused on their reading. Reading scores are folded into overall participation grade which carries between 7% and 10% of the total grade. Recently, we have also noticed that some students skip reading altogether possibly due to availability of extra credit activities in their projects and strict deadlines. One other item that becomes very visible is the exact time when students do their reading. Fig. 2 shows the so-called "heat map" illustrating the time of day and date when students do most of their reading, as indicated by red color. Clearly, in this case they waited for the night before the reading was due, which defeats the purpose of having one's comments available for others to examine. This was not always the case but we will have to revisit our assignment strategy to counteract these negative tendencies.

IV. TECHNICAL WRITING

The need for stronger writing skills has been documented for decades [14]-[20], and some techniques, such as the use of rubrics for evaluating writing (e.g., [21]), have been widely adopted. In our classes students practice writing in several contexts: lab reports, project reports and Systematic Literature Review report, which is required only from graduate students. For writing practice to be useful, students need timely feedback and an opportunity to rewrite. This is accomplished through detailed examination and feedback for the first lab report submission (out of 7 total), which students can resubmit if they did not score well. Some initial guidance is given by providing examples and rubric given in Table I. However, we typically find that writing and proper data representation have to be discussed in class before students start to take it seriously. Follow-on labs and project reports are done as teams which precludes identifying and grading individual contributions. However, some developments in collaborative writing, namely Google Docs and Share-LaTeX, may make this aspect of team writing visible to instructor, and are currently being investigated.

Viewing time (min)	Active reading time (min)	Activity
42 minutes, 9 seconds	41 minutes, 10 seconds (98%)	7 annotations
0 seconds	0 seconds	
1 hour, 1 minute	24 minutes, 19 seconds (40%)	1 annotation
10 minutes, 13 seconds	7 minutes, 37 seconds (75%)	
48 minutes, 26 seconds	12 minutes, 55 seconds (27%)	
3 hours, 4 minutes	1 hour, 40 minutes (54%)	7 annotations
3 minutes, 3 seconds	2 minutes, 15 seconds (74%)	
7 hours, 32 minutes	59 minutes, 9 seconds (13%)	2 annotations
1 hour, 42 minutes	1 hour, 22 minutes (80%)	13 annotations
2 hours, 14 minutes	1 hour, 56 minutes (87%)	7 annotations

Figure 1. Example of Perusall active reading time tracking.

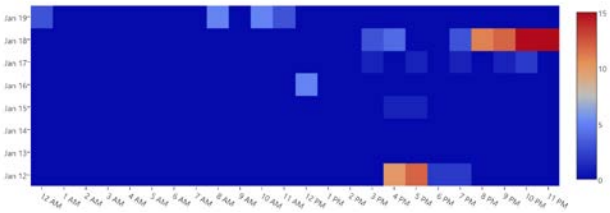

Figure 2. Heat map from Perusall illustrating when students do their reading. Horizontal axis is hour of the day, vertical axis is date. Most students read the assignment the night before it was due.

More detailed rubrics have been developed for project reports and are shared with students. In general, well-functioning teams that have designed, build and tested a functional prototype as part of the design project will also produce a good quality report. One persistent feature of less-well written reports is that students tend to write them as historical narrative by recounting how their design developed over time. This is explicitly discouraged in instructions but its persistence seems to point to students' deeper lack of knowledge or understanding of their own knowledge of what happened during the project.

TABLE I. RSUBRIC USED TO EVALUATE LAB REPORTS.

Criterion	*Target characteristics*
Comprehensive	Answers all questions specifically asked for in lab description.
Data presentation	All tables and figures are legible, accurate and visually pleasing. Misses at most two of the items related to figure and caption quality.
Text of data analysis	Text is: succinct, accurate, complete, and grammatically correct.
Conclusions	Conclusions follow from the discussion. Data and results are critically examined. Items logically organized.
Overall quality	Worthy of inclusion in student's portfolio of projects to show potential employers. References included as needed.

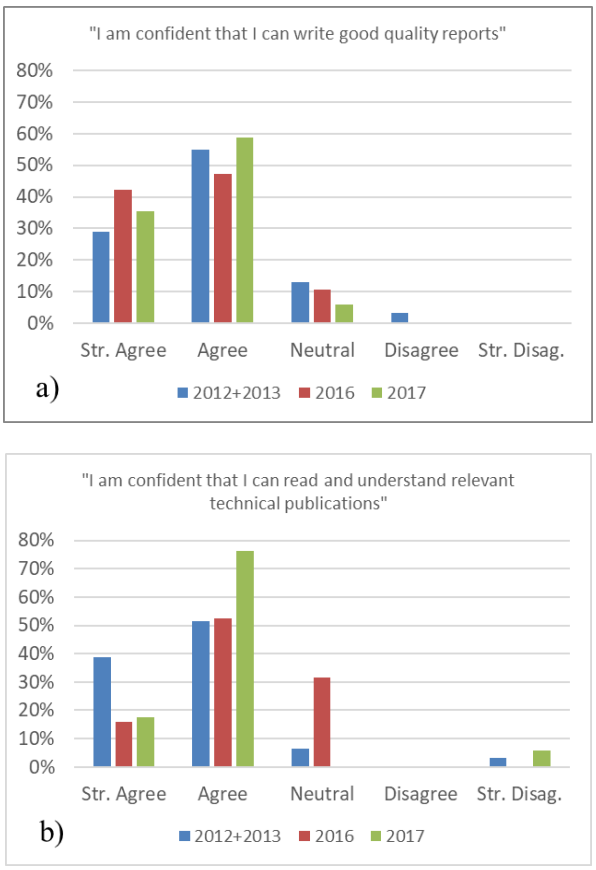

Figure 3. Historical data on self-efficacy in a) writing, and b) reading, winter term in years 2012+2013, 2016 and 2017.

Figure 3 presents data on student self-efficacy regarding their ability to a) write good reports and b) read and understand relevant technical publications. These two items score consistently lower than the two questions related to technical aspects of the course, namely ability to design, and ability to build and test circuits. Surprisingly, students are less confident about their reading comprehension than writing. More recent data from 2017 shows decrease in reading self-efficacy relative to earlier years. This may be attributable to the use of Perusall which started in 2017. More systematic approach to reading assignments may have exposed students to their own deficiencies in this area - deficiencies that they may not have been aware of previously.

V. Critical Thinking and Metacognition

Students find describing, evaluating and synthesizing what they have read in an accurate and concise way to be challenging, especially when required to do so in a written form. These are the higher cognitive tasks that we should expect engineering students, especially graduate ones, to perform during their studies. All students face an additional problem of exponential growth of information which makes its proper handling an urgent problem [22]. In a traditional research environment, students will learn these skills through mentoring and not coursework, but that approach does not scale well.

Some or all of these skills can be considered part of critical thinking but what is meant by critical thinking in engineering is ill-defined and "engineering programs […] often claim to develop critical and reflective thinking, but fail to explicitly address what each means and how they intend to achieve this outcome" [23]. However, there is no doubt that critical thinking is essential to STEM professionals. In a recent study, Jang [8] examined a gap between STEM education and required workplace skills. Based on approximately 50,000 questionnaire responses he identified and ranked in importance 35 skills. The two most important ones were critical thinking (as defined earlier) and reading comprehension. Critical thinking is rarely taught as such, and even less frequently assessed [24]. Lack of proper training in critical thinking in Nursing has led to warnings that "... if the Master's degree is not to become a Bachelor's degree in all but name, educators need to […] allow time for discussion, debate, reflection and engagement" [25]. We believe this warning should be heeded in engineering graduate education as well.

Metacognition, i.e., the ability to understand the state of one's knowledge and thought processes, is an important component of learning and one that distinguishes experts from novices:

> *"To become self-directed learners, students must learn to assess the demands of the task, evaluate their own knowledge and skills, plan their approach, monitor their progress, and adjust their strategies as needed … these metacognitve skills … are often neglected in instruction. However, helping students to improve their metacognitive skills can hold enormous benefits."* ([26] p. 191)

We have observed that students have poor metacognitive skills and do not understand the state of their own knowledge and how to improve it, which can prevent students from becoming life-long learners.

Given the complexities involved, we cannot take it for granted that engineering students will acquire critical thinking and metacognitive skills simply by taking more courses; instead, they have to be taught. In our courses we attempt to teach these through Iterative Systematic Literature Reviews (ISLR). Our initial implementation and results have been reported elsewhere [27]. Here we discuss our experience in using ISLR in microwave circuit design course sequence.

A. *Description of ISLR*

One attractive feature of the ISLR process is that it allows refinement of results at various stages in the process. This flexibility makes it suitable for novices because their understanding of the problem and process improves as they perform ISLR [28], [29]. There are eight stages in the ISLR process, as shown in Fig. 4 [28]. Note that ISLR allows iterations between different stages. For example, finding too many references during the initial search (stage 3) may indicate that the question (stage 2) was defined too broadly and needs to be modified. In our pilot study [27] we followed procedures discussed in [28] with few changes, e.g., modifying the Search strategy stage. Instead of letting students come up with search

strings right away, we provide them with one seed article that they use for finding references cited in that article and for looking up papers citing that article. In this way students can gain better understanding of the context of the problem, learn the conventions and language of the specific sub-area, examine keywords used in the article, etc. This eases them into the heart of the problem and helps them formulate the initial question. Note that stages 1, 2 and 8 rely on meta-cognitive skills, stages 3-7 require application of critical thinking, and stage 7 requires clarity in writing the final report.

Figure 4. Iterative systematic literature review flow chart.

B. *ISLR Project*

Details of our two-quarter sequence in microwave circuit design were described in [11]. Each of the two courses in the sequence is 10 weeks long. One quarter can be sufficient for performing a full ISLR project, as shown in [27] but the schedule is very tight. In the microwave circuit design classes we have two quarters so that we can split the project into two parts: a) training in writing paper summaries first, and b) performing a full ISLR. In part a) we do not ask just for summaries of three papers, but also ask students to perform paper selection from a given pool, define research question that these papers address, explain how they are all connected, and list quality criteria they used in selecting papers. These are all stages in ISLR but simplified by providing a set of dozen papers out which three need to be selected. Students submit summary report individually. We have found this preliminary exercise to be very useful but there are some issues with timing and integrating it with the rest of the course. In particular, because this is required only of graduate students it is left as the last assignment and some students may lack motivation for it or may not have allocated enough time to do it. None the less, of the 11 recent reports, there were 6 excellent and only 3 that were of marginal quality.

The biggest issue for full ISLR project, which is done during the second quarter, is finding a good topic. It should be relevant to the course, not cover the same ground as the rest of the course, and be specific enough so that manageable number of references is found. Initially, topic selection (research question) were left to students but that turned out to be too time consuming and not producing good results. Recently we have settled on the topic of Doherty amplifiers. These are classic designs with many reports available so this was narrowed down to three sub-categories: a) Doherty amplifiers implemented as MMIC with GaN transistors, b) Modeling of Doherty amplifiers, and c) Broadband design of Doherty amplifiers. We also allow some high-performing teams to define their own topic. To help students organize their work we provide templates for Zotero [30] which is used for reference management and keeping annotations, and for Trello [31] which teams can opt to use for project management. Teams consist of three members and submit one final report. We have developed an assessment rubric [27], which is constantly refined as we gain more experience in using it.

Given that the number of teams is small and varies from three to five, we can only make some preliminary observations. Teams perform most SLR tasks well but formulating common themes and being critical of papers they read both need to be improved. On the other hand, some teams do not perform simple tasks that are explicitly asked for, such as giving annotated bibliography in a specific format. This may be attributable to general carelessness or lack of time due to poor planning. Overall, roughly half of the teams will exceed expectations, one quarter will meet expectations and one quarter will be borderline acceptable or below. With more feedback these results could be improved and this should be accomplished through similar assignments in other courses. We are currently working with other faculty to expand ISLR implementation.

ISLR should be transferable to other engineering topics so long as effort is made to find appropriate topic for students to work on. We have demonstrated it in the context of graduate semiconductor physics class [27] and ISLR has been extensively used in software engineering. If possible, spreading the project over 20 weeks (two quarters) is advantageous but it can be done in 10-15 weeks, or roughly one semester. Tools like Perusall, Zotero, and Trello are generic and should easily fit within any course with similar emphasis on projects.

VI. CONCLUSION

We have discussed what professional skills may entail, why they are important, and have provided some examples of how they may be taught at a course level. Professional skills we considered include: reading comprehension, writing, critical thinking, metacognition and teamwork along with project management. Each was defined and briefly discussed in relation to accreditation and curricular requirements. Practical examples of activities within microwave circuit design course that foster student growth and training in these skills have been provided. We believe that ISLR is particularly well suited for all graduate students, even those who are not pursuing research theses. Finally, some preliminary observations on effectiveness of these activities have been shared.

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Prijedlog modela izrade i izvođenja praktične nastave za IoT rješenja u simulacijskom okruženju

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Sažetak **- Računalne mreže su jedna od bitnih sastavnica ICT-a, zbog čega se u području informatike i računarstva na Tehničkom Veleučilištu (TVZ) pojavljuju kao obavezni kolegij. Osnovni cilj svih tečajeva iz područja mreža očituje se u proučavanju osnovnih koncepata na kojima se temelje računalne mreže. Danas je moguće povezivati različite uređaje preko interneta i takvim spajanjem ostvaruje se niz mogućnosti poput njihovog aktiviranja, kontrole i praćenja. U računalnim mrežama to se područje naziva Internet stvari (IoT). Zbog sve većeg utjecaja koje to područje ima na poslovanje, bitno je u postojeće kurikulume iz područja računalnih mreža uvrstiti dio koji se odnosi na IoT. Kada je u pitanju osposobljavanje studenata za rješavanje praktičnih problema iz područja računalnih mreža i primjene IoT-a, upotreba realne opreme može predstavljati financijski problem. U tu svrhu mogu se koristiti simulacijski softveri poput Packet Tracer-a, uz primjenu primjerenog metodičkog pristupa učenja. U ovom radu bit će prikazan model pripreme, izrade i izvođenja laboratorijskih vježbi pomoću simulacijskog sustava Packet Tracer i korištenje STAR Legacy modela učenja utemeljenog na konceptu istraživačkih projekata. Predloženi metodološki pristup može se primijeniti kako u srednjim školama, tako i na visokim učilištima i fakultetima.**

Ključne riječi – Internet stvari; obrazovanje; simulacija; softver

I. UVOD

Internet of Things (IoT) ili Internet stvari danas u području Informatičko komunikacijskih tehnologija (ICT) sve više poprima važno mjesto u poslovnom i u privatnom području. U tom smislu pojavljuje se i potreba za odgovarajućim kadrovima koji trebaju popunjavati radna mjesta za tu vrstu poslova. Kako bi se zadovoljile potrebe tržišta rada iz područja IoT-a, od obrazovnih institucija koje školuju kadrove u području ICT industrije, očekuje se edukacija kadrova i za područje IoT-a.

Osim prilagodbe kurikuluma za edukaciju kadrova potrebna je nabava adekvatne opreme, hardvera i softvera. Kako na realnom tržištu postoji velika raznolikost hardverske i softverske opreme, a uz to se gotovo svakodnevno na tržištu pojavljuje sve više novih stvari, u edukacijskim ustanovama jednostavniji pristup je korištenje adekvatnih simulacijskih softvera.

U tu svrhu će se u ovom radu prikazati mogućnost primjene simulacija IoT rješenja, kao i model izrade i izvođenja praktičnih vježbi kroz koje studenti mogu stjecati temeljna znanja i koncepte na kojima mogu dalje razvijati svoje kompetencije u realnoj praksi.

II. POJAM I PRIMJENA IOT

Napredak mrežnih tehnologija i interneta omogućio je objedinjavanje, odnosno slanje i primanje različitih vrsta komunikacijskih obrazaca poput tekstualnih, glasovnih i video poruka kroz jednu zajedničku konvergiranu mrežnu platformu. Danas ovakva zajednička mrežna platforma predstavlja osnovu za izgradnju inteligentnih informacijskih mreža koje će podržavati Internet stvari. Kao konvergirana platforma internet danas omogućuje povezivanje različitih uređaja kroz različite modele komunikacije poput uređaj - uređaj, uređaj – čovjek ili uređaj - aplikacija.

Sukladno preporučenim definicijama Specijalizirane agencije Ujedinjenih naroda za informacijske i komunikacijske tehnologije (ITU), osnovne preporučene definicije za IoT su [1]:

- Internet stvari (IoT) - Globalna infrastruktura za informacijsko društvo, koja omogućuje napredne usluge spajanja (fizičkih i virtualnih) stvari na osnovama postojećih tehnologija i razvija međusobno ovisne informacijske i komunikacijske tehnologije.
- Uređaj je dio opreme s obveznim sposobnostima komunikacije i opcionalnim mogućnostima detekcije, aktiviranja, unosa podataka, pohrane podataka i obrade podataka.
- Stvar je objekt (predmet) fizičkog svijeta (fizičke stvari) ili su to informacije (virtualne stvari), koje se mogu identificirati i integrirati u komunikacijske mreže.

Internet stvari danas predstavlja paradigmu za inteligentno povezivanje ljudi, procesa, podataka i stvari, koje danas promatramo kao tranzicijski korak do potpunog iskorištenja i ostvarenja potencijala IoT-a. Prepoznati tehnološki potencijali koji sudjeluju u potpunom ostvarenju IoT-a su [2]:

- *Mobilnost* koja obuhvaća pristup resursima s bilo kojeg uređaja, u bilo koje vrijeme, s bilo kojeg mjesta.
- *Računalstvo u oblaku* kojeg čini distribuirani računalni resursi i servisi preko mreže;
- *Veliki podaci* (eng. Big data) koji nastaju porastom količine podataka, raste i zahtjevnost obrade, analize i transformacija podataka u informacije.
- *Prelazak na ipv6* čijim se povećanjem adresnog prostora osigurava mogućnost dodavanja 50 milijardi novih uređaja do 2020.

Internet stvari ne čini samo međusobno internetsko IP povezivanje senzora, uređaja i sl. koji se nalaze u jednoj mreži s uređajima, aktuatorima, ljudima ili aplikacijama koji su u nekoj drugoj mreži, već se taj pojam odnosi i na protokole, standarde i arhitekturu [3]. Ujedno trendovi pokazuju da se širom svijeta pojavljuje sve veći broj IoT projekata (Slika 1).

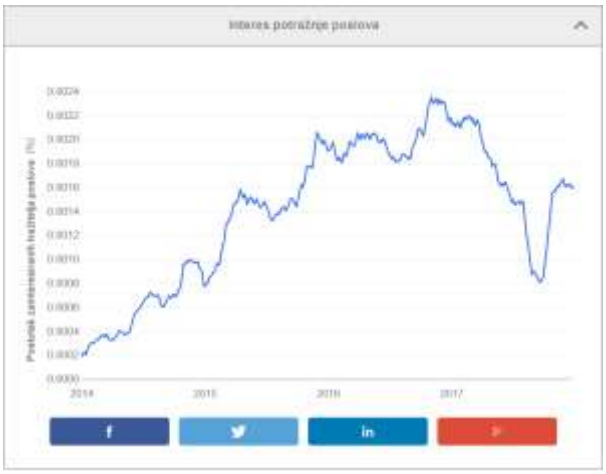
Slika 1. Analize 640 IoT projekata po područjima [4]

Kompanija Cisco navodi kako postoje četiri ključna IoT elementa, a to su [2]: ljudi, procesi, podaci i stvari. Kako bi objekti (stvari) mogli komunicirati i donositi inteligentne odluke, moraju biti spojeni na internet žično ili bežično. Pri tome oni uređaji koji se tradicionalno ne spajaju na mrežu trebaju dodatne senzore, RFID-ove i kontrolere.

Zbog velike količine generiranih podataka dobivenih iz povezanih uređaja potrebni su novi produkti i tehnike za njihovo upravljanje te pohranu i analizu, a jedan dio rješenja ovog problema je virtualizacija i računalstvo u oblaku. Korist od toga za one organizacije koje skupljaju i analiziraju velike količine podataka očitovat će se u tom što će moći lakše identificirali trendove i predvidjeti ponašanja u cilju donošenja odluka. Rezultati toga odrazit će se ne samo na organizacije, već i na ljude u smislu prilagodbe, promjena ponašanja, donošenja strateških odluka i slično.

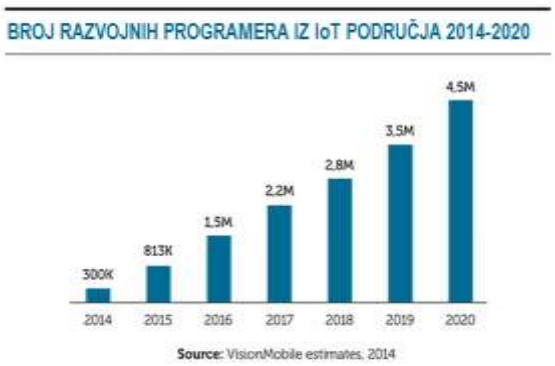
III. POTREBE ZA KADROVIMA

Iz prethodno izloženog može se zaključiti kako IoT područje ima veliku perspektivu te će u budućnosti zahtijevati sve više raznovrsnih stručnih kadrova što se na tržištu rada očituje već i danas (Slika 2) [5].



Slika 2. Trenutne potrebe za stručnjacima iz područja IoT [5]

Sukladno ovakvim trendovima postupno se kristaliziraju određene kompetencije koje budući stručnjaci moraju usvojiti. Predviđa se da će potreba za kadrovima biti sve veća (Slika 3).



Slika 3. Očekivani trend u broju potrebnih razvojnih programera u području IoT-a [5]

Ipak, u takvom okruženju, neka znanja pokazala su se kao svojevrsni temelji na kojima se gradi IoT svijet i koja pružaju studentima mogućnosti da se kroz relativno jednostavne projekte počnu baviti Internetom stvari. Tako na primjer studenti Tehničkog veleučilišta u Zagrebu kroz temeljni dio studija na raznim kolegijima nauče kreirati mobilne ili web aplikacije, programirati mikrokontrolere i koristiti se raznim mrežnim protokolima i uređajima. Projekti vezani za IoT su idealni za spoj tih stečenih znanja u jedan zadatak. [7]

IoT je sačinjen od širokog skupa različitih specifičnih mreža koje povezuju pametne objekte na internet, kako tradicionalne računalne tako i netradicionalne uređaje kroz sljedeće komunikacijske modele [2]:

- *Stroj–stroj* (Machine-to-Machine – M2M) odnosno komunikaciju između uređaja bez ljudske intervencije npr. povezivanje putnog računala u vozilu s temperaturnim senzorom i automatsko prilagođavanje vožnje vremenskim uvjetima

- *Stroj–čovjek* (Machine-to-People – M2P) gdje tehnički sustav prikuplja informacije iz M2M sustava i šalje ih čovjeku koji donosi odluke
- *Čovjek–čovjek* (People-to-People – P2P) gdje se ostvaruje suradnja između ljudi preko M2M sustava i postojeće mrežne infrastrukture.

Ono čega treba biti svjestan je činjenica M2M komunikacije, odnosno povezivanja i komunikacije velikog broja uređaja poput pametnih telefona s automobilima, pametnim zgradama i sl. Gartner Grupa predviđa da će tržišna vrijednost IoT na globalnoj razini preći 1,9 trilijuna $ u idućih 5 godina i da će do 2020. godine instalirana baza pametnih jedinica s IoT imati više od 26 milijardi stavki. [8]

Ove brojke su enormne i ukazuju koliko ćemo biti pod utjecajem IoT-a kako u tzv. svakodnevnoj kućnoj primjeni tako i u industriji i svim ostalim segmentima.

Dakle, obrazovne institucije kao i poslodavci moraju toga biti svjesni i pripremiti se za vrijeme koje dolazi. Predviđa se da će u području IoT-a trebati najviše sljedećih vještina [9]:

- Iz područja poslovne inteligencije i analitike - jako veliki broj uređaja stvarat će veliki broj tzv. „ sirovih podataka“ koji će se prikupljati, pohranjivati i analizirati. Tu će trebati veliki dio stručnih specijalista s potrebnim vještinama.
- Iz područja informacijske sigurnosti potrebne za izgradnju i održavanje sigurnosnih IT rješenja.
- Za dizajn i razvitak aplikacija u oblaku te web i drugih vrsta aplikacija za razne vrste IoT uređaja.
- Za dizajn, razvitak, izradu, instalaciju, održavanje i upravljanje raznim računalnim uređajima, elektroničkim i drugim hardverskim komponentama za IoT.
- Za mrežne profesionalce za dizajniranje, implementaciju, održavanje i optimiranje raznih vrsta računalnih mreža.

IV. KOJE METODE POUČAVANJA KORISTITI

Kako bi omogućili da studenti usvoje potrebne kompetencije i vještine u području IoT, potrebno je koristiti aktivne metode poučavanja koje uključuju istraživačke metode, metode analize i rješavanja problema (timski i samostalno), studije slučaja, simulacije i sl. Simulacija kao metoda učenja zasniva se na oponašanju funkcioniranja stvari, procesa ili sustava realnog svijeta zasnovana na modelu ili nekoj situaciji uzimajući u obzir protok vremena i eventualno ostale parametre koji se odnose na dio realnog svijeta koji se simulira. Cilj simulacije je dobivanje određenih informacija ili obuka osoba. Ideja simulacijskog pristupa može se opisati s četiri osnovna koraka [10]:

1. Opis funkcioniranja originalnog sustava.
2. Razvoj računalnog programa, odnosno simulacijskog modela.
3. Simuliranje, odnosno eksperimentiranje s računalnim programom (modelom) na način kako bi se to željelo s originalnim sustavom.
4. Analiza i interpretacija rezultata simulacije i njihovo dovođenje u vezu s originalnim sustavom te njihova konačna primjena na originalnom sustavu.

Uz to, suradničko učenje (timski rad) u sklopu simulacija daje studentima mogućnost prakticiranja vještina koje cijene poslodavci, poput komunikativnosti, rješavanja problema, kritičkog promišljanja i analize usmenih i pisanih, financijskih podataka, unutar okruženja koje dopušta ispravljanje pogrešaka i uvođenje alternativnih strategija bez mogućnosti nastanka stvarnih štetnih posljedica. S obzirom na razinu kompleksnosti, simulacije potiču studente da uspješno integriraju pojedine koncepte unutar vlastite discipline te da razmišljaju izvan okvira pojedine poslovne funkcije (odjela) u stvarnom poslovnom okruženju [10].

Istraživanja prednosti poslovnih simulacija u usporedbi s drugim obrazovnim metodama, upućuju na više razine zadovoljstva i predanosti studenata, a oni studenti koji su uključeni u simulacije u prosjeku postižu bolje rezultate od onih koji su podučavani drugim metodama [10].

A. Prijedlog STAR Legacy modela izvođenja laboratorijske nastave

STAR Legacy model pogodan je za učenje kroz istraživačke projekte koji se mogu primijeniti kako u srednjim školama tako i na visokim učilištima i fakultetima. Ciklus STAR Legacy razvio je Vanderbilt - University Engineering Research Center [11]. Primarni kriteriji za korištenje tog modela su da projekt treba biti usmjeren na znanje, orijentiran na studente i usmjeren na procjenu uspješnosti od strane studenata [12].

Model se sastoji od nekoliko faza, a započinje s tzv. početnim izazovom (Tablica 1). Ciklus STAR Legacy pruža okvir za studentske istraživačke projekte. Nastavnik - mentor se usredotočuje na različite aspekte razvoja početnih izazova i vodi studente kroz proces istraživanja. Ciklus se može provesti kroz razne projekte, fundamentalna istraživanja, istraživačke pokuse i slično [12].

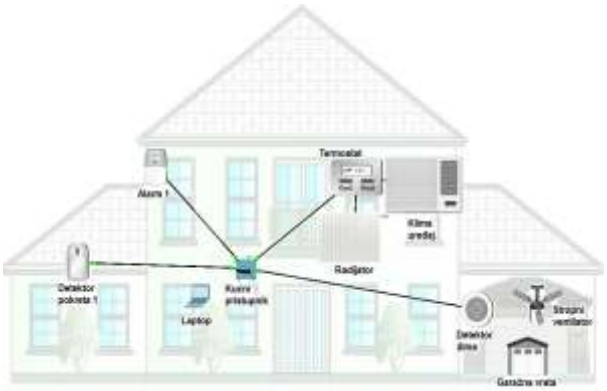
Kao primjer jednog od početnog izazova (zadatak) može se primijeniti na simuliranje okruženje u kojem će se putem pametnog telefona upravljati razinom vlage i temperature u dnevnom boravku. Za realizaciju su potrebni pametni telefon, termostat, klima uređaj, radijator, senzor vlage, ovlaživač zraka i kućni pristupnik i sl. Znanja i iskustva uključena u ovaj scenarij zahtijevaju prethodno savladane teme kao što su: IP adresiranje, automatsku dinamičku dodjelu IP adresa (DHCP), servis razrješavanja imena (DNS), bežični pristup (Wireless AP), pristupne liste na usmjerniku i sl.

Tablica 1. Faze STAR Legacy modela

Faze	Opis	Primjer
Početni izazov	Pitanja koje potiču studente na razmišljanje o temi i motiviraju ih na početak bavljenja njome. Pitanjima se pokušava definirati opseg zadatka, te se zahtijeva dozivanje i prijenos postojećeg znanja o temi. *Npr. u tzv. „pametnoj kući" trebamo implementirati IoT upravljanje pomoću pametnog telefona.*	U tzv. „pametnoj kući" treba implementirati IoT upravljanje pomoću pametnog telefona. *Pretpostavite da ste budući stanar jedne takve kuće, koje informacije bi ste u svakom trenutku željeli znati o kući kada ste na putu ili godišnjem odmoru? Kojim uređajima bi ste željeli upravljati u kući, kako i na koji način?*
Generiranje ideja za rješenje	Aktiviranje studenata o tome kako bi sastavili i prikazali svoja postojeća znanja / ideje / percepcije. To se može ostvariti i u obliku pitanja: *Što bi morali znati kako bi mogli dati odgovor na postavljeno pitanje? Koje dodatne informacije bi trebali, a koje bi pomogle u odgovoru na to pitanje?*	Moguće aktivnosti (obavezno uključuje neki oblik pisanog zapisa): brainstorming, razmišljanje (pisanje, rad u paru, dijeljenje informacija), individualno opisivanje, višestruka javna razmjena ideja i sl.
Višestruke perspektive i prikupljanje dodatnih	Pretraga više vanjskih izvora i resursa koji pružaju dodatne informacije vezane za temu. (Cilj je usmjeravanje studenata u pravom smjeru za daljnje istraživanje).	Mogući izvori (okružje): web stranice, članak iz stručnog časopisa ili magazina, izvadak iz udžbenika, vanjski stručnjak (uživo, na videu ili kroz prijepis odlomka), isječak iz videa i sl.
Istraživanje i revidiranje	Dodatne informacije koje student/i dobivaju/ traže. To može biti u obliku predavanja, čitanja, web stranice itd. Student/i revidiraju svoje originalne ideje na temelju novih informacija.	Mogući izvori (okružje): Web, razna predavanja, udžbenik i slično, sve ostalo što je navedeno u višestrukoj perspektivi.
Preispitivanje stavova	Niz aktivnosti u kojima sudjeluju student/i, a koje pomažu dubljem pronicanju u vlastita znanja. Izrada praktičnog rješenja u simulacijskom okruženju. Cilj je stvaranje situacija kroz koje će student/i evaluirali (procijeniti) što im je znano, a što nije, te ih po potrebi vratiti korak unazad (faza istraživanja i revidiranja) kako bi saznali više i/ili popravili nedostatke.	Moguća zbivanja: izrada i istraživanje u simulacijskom okruženju (npr. Cisco Packet Tracer), traženje povratne informacije (evaluacije) od drugih o uratku, instruktor – mentor daje povratne informacije o uratku.
Javno predstavljanje	Konačni zaključak/ci koje student/i javno prezentiraju.	Moguća zbivanja: prezentacija rješenja u uz usmeno izlaganje npr.: ppt prezentacija, poster/projekt, test i sl.

B. Alati za simulaciju i modeliranje IoT

Postoji širok izbor alata za modeliranje i simulacije u IoT, primjenjivih u različitim fazama razvoja, različitim segmentima sustava i različitim domenama primjene [13]. U ovom radu u fokusu je alat Cisco Packet Tracer, zato što on studentima omogućuje modeliranje i izradu prototipova za sva tri tipa interakcije (M2M, M2P i P2P) za razne segmente realnog svijeta, kao i za različite mrežne tehnologije (žične i bežične), kako u fizičkoj (Slika 4) tako i u logičkoj topologiji (Slika 5).



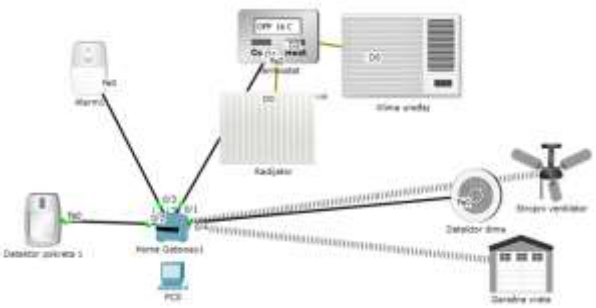
Slika 4 IoT okruženje s fizičkom topologijom uređaja

Izlaskom inačice Cisco Packet Tracer 7.0 alata za simulaciju okruženja računalnih mreža, uvedene su dodatne mogućnosti vezane za simulaciju Interneta stvari [14]. Njime se mogu simulirati raznoliki segmenti realnog svijeta od proizvodnih (tvornice, strojevi, lanac dostave), energetskih (kućanski uređaji i pametna mreža, nafta i plin), prijevoznih (javni, pomorski, željeznički promet, vozila i automobili), zdravstvenih i dr.

Alatom se može kreirati i u simulaciju povezati i više različitih hijerarhijskih okruženja u koja se mogu postaviti i povezati različiti IoT čimbenici (uređaji i senzori i sl.) čije se varijable mogu podešavati, na primjer visina, brzina, ph vrijednosti, tlak, vlaga, temperatura, plinovi (CO, CO2 i sl.), elektromagnetska radijacija, infracrveno zračenje itd.[14]

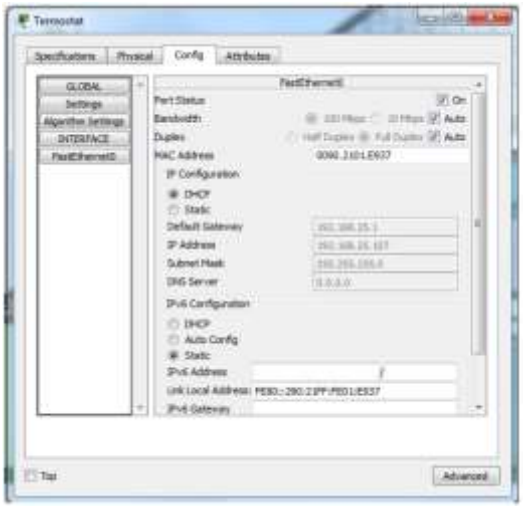
U fizičkom se simulacijskom okruženju (Slika 4) mogu postaviti različite komponente tzv. pametnih stvari grupiranih u četiri kategorije (kuća, pametni grad, industrija i energetska mreža). U te kategorije moguće je postaviti predefinirane komponente logičke topologije (Slika 5) kao što su [14]:

- *Aktuatori* – uređaji za grijanje i/ili hlađenje, alarm, stropna i podna prskalica, LED dioda te LED dioda s podesivom jakosti osvjetljenja, toplinski element, LCD zaslon, električni motor, zvučnici, višebojna LED dioda, servomotor i drugi.
- *Senzori* – senzor savitljivosti, senzor vlage i temperature, senzor tlaka, metala, pokreta, fotosenzor, razna tipkala i potenciometri, detektor vode, vjetra, i drugi.
- *Kontrolne ploče* – mikrokontroler (MCU Board) i mikroračunalo (SBC – Single boarded computer).



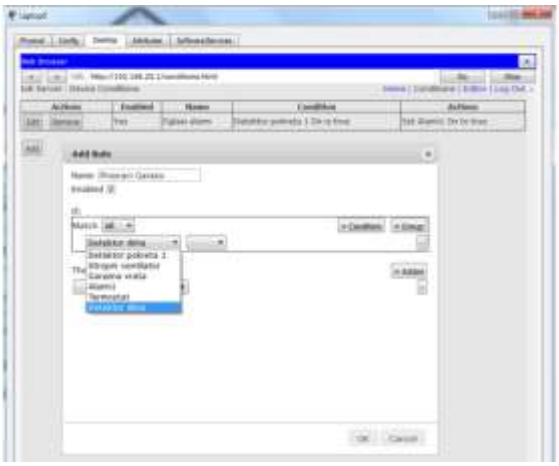
Slika 5 Logička topologija IoT komponenti

Kod modeliranja logičke topologije, komponente se mogu spojiti na mikrokontroler ili mikroračunalo, a oni se dalje mogu povezati i komunicirati s tzv. registracijskim poslužiteljem ili kućnim pristupnikom.
Uloga aktuatora je nadzor i uzrokovanje promjene u okolini u kojoj se nalaze, a povezuju se na MCU ili SBC uređaje posebnim kabelima namijenjenim isključivo za Internet stvari ili s registracijskim poslužiteljem odnosno kućnim pristupnikom.
Senzori su dijelovi pametnih uređaja i najčešće imaju samo jednu funkciju (npr. mjerenje temperature, tlaka i sl.), a mogu se povezati i s MCU ili SBC-om. S druge strane ugrađeni pametni uređaju već imaju implementiran senzor i/ili aktuator te stoga mogu djelovati kao samostalni uređaji.
Nakon dodavanja pametnih stvari u logičku topologiju, otvaranjem određenog izbornika mogu se prikazati specifikacije dotične stvari. Tako se na primjer za termostat mogu vidjeti značajke kompatibilnosti s registracijskim poslužiteljem, način rada (isključeno, hlađenje, grijanje) te način na koji se može povezati s nekim drugim uređajem, npr. klima uređajem. Internet stvarima se upravlja pritiskom tipke alt i klikom miša. Internet stvari mogu imati i dodatne prozore za napredne postavke, postavljanje IP adresa i slično (Slika 6).



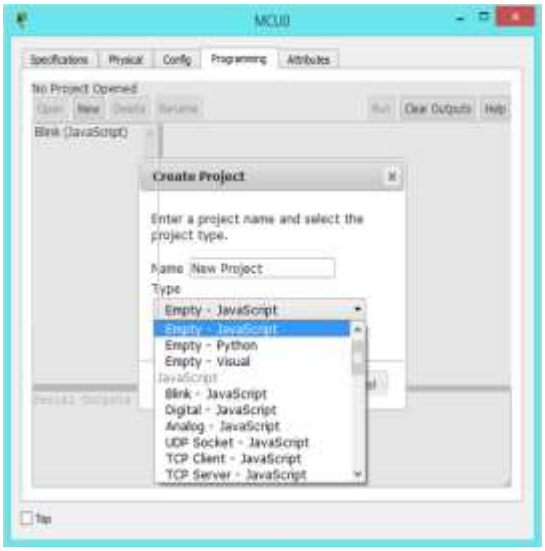
Slika 6 Dijaloški okvir za postavke

IoT uređaji spajaju se na tzv. kućni pristupnik (Home Gateway) i/ili registracijski server. Kućni pristupnik je uređaj koji služi za lokalno spajanje pametnih uređaja na mrežu. U lokalnom okruženju se ponaša identično kao i usmjernik davatelja usluge, a služi za upravljanje i nadzor komponenti i uređaja pametnih stvari. Registracijski poslužitelj služi za udaljeno upravljanje pametnim stvarima i za njega je potrebna korisnička autentifikacija.
Postavljanje scenarija simulacija odnosno definiranje parametara i pravila ponašanja stvari u određenim uvjetima okoline obavlja se preko Thing Editora (Slika 7).



Slika 7 Odabir uređaja i uvjeta

Mikrokontroler (MCU Board) i mikroračunalo (SBC – Single boarded computer) imaju mogućnost programiranja odnosno dodavanja ugrađenih ili novih skripti za simulaciju rada. Podržane skripte mogu se napisati u JavaScriptu, Pythonu ili se može koristiti tzv. vizualni način programiranja korištenjem blokova (Slika 8).



Slika 8 Sučelje za programiranje mikrokontrolera

C. *Praktična primjena STAR Legacy modela i prijedlog za daljnja istrživanja*

Eksperimentalna primjena STAR Legacy modela na TVZ-u kroz simulacijska rješenja u Cisco Packet Tracer-u primijenjena je na desetak studentskih završnih radova na stručnim studijima informatike i računarstva te elektrotehnike. Sukladno fazama predloženog modela (Tablica 1) studenti šestog semestra navedenih stručnih studija svoje projekte (završne radove) realizirali su u međusobnoj timskoj suradnji (2-3 studenta) pod vodstvom svojih mentora, što je vremenski trajalo cca 4 do 6 tjedana. Zbog toga što je TVZ stručni studij, naglasak radova bio je fokusiran na praktični dio, odnosno na proučavanje, primjenu i implementaciju određenih IoT tehnologija kroz praktična rješenja. Ovisno o studiju kojeg su upisali, svaki od studenata naglasak rada stavlja na ono što mu je primarni interes, tako na primjer studenti elektrotehnike više pažnje posvećuju mikrokontrolerima i hardverskom dijelu rješenja, dok studenti informatike i računalstva hardverske komponente koriste kroz simulacije kako bi prikazali načine rješenja kroz programsku podršku ili koji su komunikacijski protokoli bolje rješenje u zadanom okruženju.[7]

Rezultati ovakvog pristupa potaknuli su na razmišljanje o uvođenju STAR Legacy modela u redovitu praktičnu laboratorijsku nastavu za pojedine stručne i specijalističke studije na kojima se koriste simulacijskih alata, što će biti jedan od smjerova budućih istraživanja vezanih za što bolju primjenu predloženog modela na TVZ-u.

V. ZAKLJUČAK

Svijet u kojem se predviđa izuzetno veliki broj IoT uređaja do 2020. godine i porast potražnje radnih mjesta u ovom području ljudske djelatnosti, zahtijeva nova znanja i kompetencije. U tom smislu edukacija kadrova iz ovog područja ima svoje mjesto na tehničkim visokoškolskim institucijama. Potrebno je omogućiti studentima da već tijekom studija steknu osnovna znanja i kompetencije koje će im biti potrebne na tržištu rada.

Primjena Interneta stvari vrlo je široka, a projekti koji koriste koncepte IoT-a variraju od izrazito malih i jednostavnih do velikih i složenih. Na tržištu se može naći širok izbor alata za modeliranje i simulacije u IoT. Osnovne karakteristike ovakvih alata koji bi se mogli koristiti u edukacijske svrhe trebale bi se odlikovati u mogućnosti kreiranja praktičnih IoT scenarija, koji bi uključivali niz raznih senzorskih uređaja, usluga i drugih resursa iz različitih područja primjene pametnih objekata (kuće, institucije, gradovi), industrije, prometa, zdravstva i sl. Kao pedagoški model pristupa izrade i izvođenja praktične nastave za IoT rješenja u simulacijskom okruženju predlaže se STAR Legacy ciklus, koji se prema potrebi može i modificirati. Ovaj model zagovara najučinkovitija okruženja za učenje koja su utemeljena na stvarnim realnim i praktičnim problemima u čija se rješavanja aktivno uključuju studente kroz najvažnije korake, a to su:

- aktiviranje prethodnog iskustva, generiranje ideja i prikupljanje informacija koje mogu pomoći u rješenju problema,
- istraživanje prikupljenih informacija, izrade prototipskih simulacijskih rješenja čime se demonstrira primjena stečenih znanja i vještina,
- razmjene iskustva i javno prezentiranje simuliranih modela, te preispitivanje i evaluaciju prezentiranih rješenja.

Ipak na kraju odluka koji nastavni model ili simulator koristiti ovisit će o nastavnicima ili institucijama u kojima se izvodi ovakav oblik nastave.

Na TVZ-u će primjena STAR Legacy modela biti predmet daljnjih istraživanja, u cilju unapređenja timske eksperimentalne praktične laboratorijske nastave na pojedinim stručnim i specijalističkim studijima.

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STEM i obrazovni sustav u Bosni i Hercegovini

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***Sažetak* - Posljednjih godina, vlade velikog broja zemalja posebno naglašavaju neophodno poboljšanje kvaliteta obrazovanja iz oblasti znanosti, tehnologije, inženjerstva i matematike - STEM. Ovo implicira važnost navedenih disciplina u modernom društvu. Sve više obrazovnih institucija širom svijeta svoje nastavne planove usmjeravaju ka izučavanju navedenih oblasti kao jednog multidisciplinarnog predmeta sa kohezivnim paradigmama učenja temeljenim na rješavanju stvarnih životnih problema. Znanja iz ovih disciplina omogućit će ciljani ekonomski rast kroz usmjerene projekte, podržavaju inovacije i daju osnove za daljnji razvoj društva u cjelini.**

U radu je analizirano stanje STEM obrazovanja u Bosni i Hercegovini, te je dat pregled implementiranih projekata iz STEM područja u zemlji. Načinjena je usporedba provedenih STEM aktivnosti u domenu obrazovnih sustava drugih država sa sličnim aktivnostima u BiH, te je ukazano na moguća poboljšanja u sustavu obrazovanja.

Ključne riječi - STEM; obrazovanje; Bosna i Hercegovina; obrazovni sustav; cjeloživotno učenje;

I. UVOD

Informacijske tehnologije (IT) su sveprisutne u današnjem društvu. Danas ne postoji grana ljudske djelatnosti koja na neki način nije povezana sa IT industrijom. Ubrzani razvoj i promjene koje sa sobom donosi tehnologija i nauka zahtijevaju poznavanje informacijskih i telekomunikacijskih tehnologija.

Obrazovni sustavi širom svijeta sa više ili manje uspjeha pokušavaju uhvatiti „korak“ sa sve bržim razvojem i promjenama koje sa sobom donose informacijske tehnologije u sve segmente ljudskog društva. Pored poznavanja informacijskih i telekomunikacijskih tehnologija (digitalna pismenost), studenti i učenici moraju se prilagoditi novim uvjetima i načinima rada koji se odnose na međusobnu suradnju i rad u timovima. Kompetencije budućih generacija u područjima informacijskih tehnologija pružaju nove mogućnosti za razvoj novih proizvoda i usluga koji će, nadamo se, značajno unaprijediti kvalitetu života.

S time u vezi, teško je trenutno predvidjeti i precizno definirati utjecaj IT na razvoj društvenih zajednica u budućnosti, dovoljno je istaći njen neminovno sve veći značaj.

Pored ovoga, obrazovni sustav u velikom broju zemalja (među kojima je i Bosna i Hercegovina) još uvijek je fokusiran na upotrebu i primjenu informacijsko-komunikacijske tehnologije umjesto na usvajanje osnovnih informatičkih znanja ili pravila.

Upravo iz navedenih razloga, ukazala se potreba da se na adekvatan način odgovori postavljenim izazovima u obrazovanju mladih na koje obrazovni sustav u brojnim državama ne mogu adekvatno da odgovore.

STEM je engleska skraćenica za znanost – *Science*, tehnologiju – *Technology*, inženjering – *Engineering* i matematiku – *Mathematics*, i predstavlja akademsko polje izučavanja svega navedenog. Ovaj akronim je postao prepoznatljiv i veoma korišten u cijelom svijetu kao nova paradigma u obrazovanju mladih. STEM edukacija predstavlja, zasada, vid neformalnog obrazovanja najčešće mladih u oblastima suvremene digitalne tehnologije. Ali na jedan drugačiji način nego što to nudi klasično obrazovanje. Kod djece se prvenstveno razvija kreativnost i mašta, kritičko promišljanje, logika i želja za usvajanjem novih znanja kroz igru i oblik učenja koji kombinira klasičnu edukaciju sa *online* sadržajima (multimedija, interaktivni obrazovni sadržaji) i praktičnim aktivnostima u kojima se vrši integracija znanja iz različitih STEM oblasti kroz primjere projekata i zadataka iz svakodnevnog života.

Ovaj rad je kritički osvrt na trenutnu situaciju u oblasti STEM obrazovanja na području Bosne i Hercegovine. Prikazani su neki od svjetskih državnih projekata za STEM obrazovanje kao i aktuelne aktivnosti iz ove oblasti u BiH.

II. OBRAZOVNI SUSTAV U BOSNI I HERCEGOVINI

Obrazovni sustav u Bosni i Hercegovini je izuzetno složen, decentraliziran, nerijetko ne komplementaran, s odsustvom adekvatne vertikalne i horizontalne odgovornosti i koordinacije. Institucionalna slika obrazovnog sektora u Bosni i Hercegovini je odraz uređenja države, definiranog Ustavom BiH, ustavima entiteta i kantona, te Statutom Brčko distrikta.

Punu i nepodijeljenu nadležnost u obrazovanju imaju Republika Srpska, deset kantona u Federaciji BiH i Brčko distrikt BiH. Na nivou BiH usvojena su četiri okvirna zakona:

1. Okvirni zakon o visokom obrazovanju u Bosni i Hercegovini,
2. Okvirni zakon o predškolskom odgoju i obrazovanju u Bosni i Hercegovini,

3. Okvirni zakon o srednjem stručnom obrazovanju i obuci u Bosni i Hercegovini, i
4. Okvirni zakon o osnovnom i srednjem obrazovanju u Bosni i Hercegovini.

U Bosni i Hercegovini obrazovanje je organizirano u četiri osnovna nivoa, a to su:

- Predškolski odgoj i obrazovanje, prema Okvirnom zakonu o predškolskom odgoju i obrazovanju u BiH, je sastavni dio odgojno-obrazovnog sustava u BiH. On je prvi, poseban i specifičan stupanj odgojno-obrazovnog sustava koji se bavi odgojem djece predškolskog uzrasta.
- Osnovno obrazovanje, prema Okvirnom zakonu o osnovnom i srednjem obrazovanju u BiH je obavezno za svu djecu. U Federaciji Bosne i Hercegovine proces uvođenja obaveznog devetogodišnjeg osnovnog obrazovanja je završen početkom školske 2009./2010. godine, dok je u Republici Srpskoj devetogodišnje obavezno osnovno obrazovanje uvedeno školske 2003./2004. godine. Prema Okvirnom zakonu obavezno obrazovanje je besplatno i ono se osigurava svoj djeci. Međutim, zbog nedostatka financijskih sredstava, ta se odredba provodi selektivno u ovisnosti od financijske moći, a najčešće po kriteriju socijalnog statusa djeteta ili pripadnosti nacionalnim manjinama, najčešće Romima, kako bi se osigurao potpun i jednak pristup redovnom obrazovnom sustavu. Samo Brčko distrikt sprovodi ove odredbe, odnosno osigurava svim učenicima besplatne udžbenike i prijevoz do škole.
- Srednje obrazovanje, prema Okvirnom zakonu o osnovnom i srednjem obrazovanju u BiH, je svima dostupno, u skladu sa postignutim uspjehom u osnovnoj školi, ličnim interesom i sposobnostima.
- Visoko obrazovanje, prema Okvirnom zakonu o visokom obrazovanju u BiH, je obrazovanje nakon srednje škole koje vodi do međunarodno priznatog stepena visokog obrazovanja. Pristup visokom obrazovanju imaju svi oni koji su završili četverogodišnju srednju školu.

Stanje školskih objekata u Bosni i Hercegovini u ovom trenutku nije povoljno. Veliki broj školskih objekata građen je prije trideset i više godina. Objekti koji su uništeni u ratu uglavnom su obnovljeni korištenjem kredita i donatorskih sredstava međunarodne zajednice, ali se pritom nije vodilo računa o opremanju škola suvremenim nastavnim sredstvima. U pogledu školskih sportskih dvorana i terena stanje je također loše. Sigurno je da to negativno utječe na fizički razvoj školske populacije u Bosni i Hercegovini. Izuzetak čini Brčko distrikt, gdje svaka osnovna i srednja škola ima sportsku dvoranu.

U školama dominira predavačko-frontalni pristup i memorijsko-reproduktivno učenje. Glavni razlog tome su nedostatak odgovarajućih učila i nedovoljna obučenost i stimuliranost nastavnika za primjenu modernih nastavnih tehnologija.

Što se tiče suvremene informatičko-komunikacijske opremljenosti škola, stanje je veoma loše. Relativno mali broj škola ima suvremene računalne učionice sa softverskom podrškom koja se može koristiti u svakodnevnoj nastavi.

U ovom trenutku obuka nastavnika nije standardizirana. Oni nisu sustavno licencirani kao profesionalci u svom domenu, niti su razvijeni financijski i drugi instrumenti koji bi bili u funkciji poticanja unapređenja kvaliteta njihovog rada na osnovu konkurencije. Izmjene bilo koje vrste unutar obrazovnog sustava mora proći veliki broj nivoa vlasti, što je dugotrajan i u nekim slučajevima nemoguć proces u ovakvom ustavnom okruženju.

Na državnom nivou Ministarstvo civilnih poslova Bosne i Hercegovine (MCP) organ je uprave koji je, između ostalog, nadležan i za obrazovanje na nivou Bosne i Hercegovine. Državni nivo ima tri segmenta: Brčko distrikt, Republika Srpska (RS) i Federacija BiH, koji posljedično imaju svoje organe za obrazovanje i to:

- Odjel za obrazovanje u Vladi Brčko distrikta BiH odgovoran je za organizaciju i funkcioniranje obrazovnog sustava u Brčko distriktu.
- Ministarstvo prosvjete i kulture Republike Srpske ima odgovornost za obrazovnu politiku, legislativu, administraciju i financiranje obrazovanja u entitetu Republike Srpske.
- Federalno ministarstvo obrazovanja i nauke vrši upravne, stručne i druge poslove, te suradnju i koordinaciju aktivnosti sa 10 kantona. Nadležnost za obrazovanje imaju kantonalna ministarstva obrazovanja (od kojih su mnoga nadležna za obrazovanje, nauku, kulturu i sport). Njihova veličina i kapacitet za obavljanje funkcija razlikuju se od kantona do kantona.

U Bosni i Hercegovini postoje tri nastavna plana i programa (NPP) – NPP za osnovne škole u Republici Srpskoj, Okvirni NPP Federacije BiH te Plan i program za nastavu na hrvatskom jeziku. Međutim, ako gledamo sadržaje NPP-ova onda se govori o tri različita obrazovna sustava. Tri različita NPP-a posljedica su zakonom propisanih nadležnosti u okviru obrazovanja - u entitetu Republika Srpska obrazovanje je na nivou entiteta i njime upravlja resorno ministarstvo preko Republičkog pedagoškog zavoda. U Federaciji BiH nadležnost je u rukama kantona, ali Zavod za školstvo iz Mostara brine o svim školama koje rade po NPP-u za nastavu na hrvatskom jeziku, a kantoni u kojima su Bošnjaci većina koriste Okvirni NPP Federacije BiH koji prilagođavaju, mijenjaju i dopunjavaju.

U različitim nastavnim planovima i programima broj predmeta koji su osnova STEM obrazovanja, su različito zastupljeni, što je direktna posljedica ranije opisanog obrazovnog sustava u Bosni i Hercegovini.

Prema NPP-u u Kantonu Sarajevo trenutno se predmet Informatika izučava od prvog razreda osnovne škole, što

nije slučaj u drugim kantonima Federacije BiH niti u entitetu Republike Srpske.

Trenutno u Kantonu Sarajevo NPP za prvi razred devetogodišnje osnovne škole ima jedan nastavni čas Informatike u toku sedmice, dok okvirni NPP za prvi razred devetogodišnje osnovne škole u Tuzlanskom kantonu nema uopće zastupljenu Informatiku kao predmet.

Slično je i sa drugim predmetima, poput Matematike i Fizike koji su također nesrazmjerno zastupljeni u različitim NPP-ovima koji se trenutno provode na području BiH.

Pa tako u entitetu Republike Srpske u petom razredu osnovne škole, učenici imaju pet nastavnih časova Matematike sedmično, dok u Kantonu Sarajevo i Tuzlanskom kantonu imaju po četiri nastavna časa u sedmici. Za Fiziku situacija je slična: u entitetu Republike Srpske dva nastavna časa sedmično, Kanton Sarajevo i Tuzlanski kanton po jedan nastavni čas sedmično.

U toku 2013. godine završen je veliki popis stanovništva u Bosni i Hercegovini [1]. Iz ovog popisa možemo vidjeti obrazovnu strukturu stanovništva, također i informatičko obrazovanje stanovništva. Navedeni podaci na nivou države Bosne i Hercegovine prikazani su u tablici I.

TABLICA I. RAČUNALNA PISMENOST STANOVNIŠTVA PREMA REZULTATIMA POPISA IZ 2013. GODINE

Područje	Stanovništvo staro 10 i više godina prema računalnoj pismenosti i spolu, nivo BiH, F BiH, RS i BD		
Spol	UKUPNO	MUŠKI	ŽENSKI
Ukupno	3.180.115	1.551.947	1.628.168
Računalno obrazovano stanovništvo	1.152.353	593.012	559.341
Osobe sa djelomičnim poznavanjem rada na računalu	758.800	395.395	363.405
Računalno nepismene osobe	1.229.972	545.075	684.897
Nepoznato	38.990	18.465	20.525

Na osnovu ove tabele može se zaključiti da približno jednak broj muškog i ženskog stanovništva poznaje ili djelomično je upoznat sa radom na računalu. Međutim, ovo nas ne smije dovesti do zaključka da je spolna zastupljenost i zainteresiranost djece za predmete iz STEM oblasti ista.

Kao i svuda u svijetu tako i u BiH, podaci govore da veći je broj učenika i studenata muške populacije koji za svoje stručno usavršavanje biraju predmete iz STEM disciplina u odnosu na žensku. Zbog toga, sve veći broj STEM projekata se bazira na popularizaciji ovih predmeta među ženskom populacijom.

III. PRIMJERI SVJETSKIH AKCIONIH PLANOVA ZA STEM OBRAZOVANJE

Potrebno je napomenuti da je dugi niz godina poticanje iskustvenog učenja prisutan u velikom broju zemalja. Pa tako, je Velika Britanija jedna od zemalja koje intenzivno rade na reformama obrazovnog sustava, a istovremeno u obrazovanju ostvaruju rezultate iznad rezultata većine drugih zemalja. Kroz razvijanje različitih projekata, kreativni pojedinci, učitelji i učenici rade zajedno kao partneri kako bi postavili kreativnost u sami centar procesa učenja.

U Velikoj Britaniji od 2000. godine škole rade s fleksibilnijim nacionalnim nastavnim planom i programom [2], koji posvećuje više pažnje kreativnom i kulturnom obrazovanju. U ciljevima NPP-a eksplicitno je naglašen značaj kreativnog i kulturnog obrazovanja, uz poticanje učenika da koriste svoju maštu i tragaju za inovativnim rezultatima. Kreativnost se promovira kao integralni dio svih nastavih programa, uz jasno identificiranje karakteristika kreativnog razmišljanja i ponašanja. Stav je da učitelji mogu promovirati kreativnost učenika uz minimalne promjene u planiranju i praksama.

U Sjevernoj Irskoj međuministarska radna grupa je 2000. godine izdala dokument [3] u kojoj je definirala koordiniranu strategiju za puni razvoj kreativnih i kulturnih resursa stanovništva Sjeverne Irske. Tri ključne preporuke ovog dokumenta su:

- Razviti kontinuitet i napredak u kreativnom i kulturnom obrazovanju kroz cijeli proces učenja, obuke i rada s mladima
- Razviti metode i principe ocjenjivanja i ispita koji prepoznaju i vrednuju ciljeve i rezultate kreativnog i kulturnog obrazovanja
- Osigurati da sve profesionalne i akademske kvalifikacije promoviraju značaj kreativnog i kulturnog razvoja.

Navedene aktivnosti provedene u prethodnom periodu prethodile su nastanku strategijskog okvira za STEM obrazovanje, pa su tako u studenom 2016. godine u Irskoj izdate analize i preporuke za STEM grupu predmeta na svim nivoima obrazovanja mladih [4].

Osnovna preporuka ove radne grupe je da se poboljša matematičko obrazovanje u osnovom obrazovanju, budući da je matematika predmet koji podupire sve STEM predmete. Predložene aktivnosti na razvoju STEM grupe predmeta su sljedeće:

- Kontinuirano obrazovanje kvalificiranog nastavnog kadra, tzv. STEM nastavnika, na svim nivoima obrazovanja.
- Potrebno je poticati razvoj specijalista u STEM području, STEM učitelja u osnovnim školama. Ti učitelji bi radili zajedno sa kolegama iz raznih znanstvenih područja, kako bi se širila najbolja STEM praksa na nivou osnovnog obrazovanja. Ovo osposobljavanje je potrebno osigurati nastavnicima u osnovnim školama.

- Nakon osnovnog obrazovanja, ovo školovanje također trebaju nastaviti obučeni STEM nastavnici, u daljnjem školovanju učenika.
- Podržati sav nastavni kadar u proširenju znanja iz znanosti, matematike i tehnologije kako bi prošili svoj stručni portfolio, i primijenili stečena znanja na projekte koje će raditi.
- Podržati aktivan angažman škola sa industrijom i potrebama iste.
- Stalno stručno usavršavanje nastavnog kadra kroz cjeloživotno učenje u STEM disciplinama. Potrebno je osigurati kvalitetan, kontinuiran, i održavajući model cjeloživotnog učenja, potencirano na STEM kadrove.

Ministarstvo obrazovanja SAD-a, je u rujnu 2016. godine izdalo dokument [5] kojim se ukazuje na potrebu za kvalitetnim i relevantnim STEM znanjima baziranim na iskustvu za svako dijete i mlade osobe. Prema ovoj strategiji, STEM i cjeloživotno učenje se sastoji od formalnog i neformalnog obrazovanja koji se provodi kroz obrazovne institucije škole, znanstvene centre i ostale institucije koje potiču razvoj STEM disciplina. Navedeni dokument uključuje šest međusobno povezanih komponenti:

- Stvaranje zajednica koje će činiti: nastavnici u školskom i predškolskom obrazovanju, učitelji u vrtićima i uzori u društvu i školi. Ovi mentori bi trebali da potiču djecu da uče o svijetu koji ih okružuje, da identificiraju lokalne, nacionalne ili svjetske izazove, da iskoriste naučeno i viđeno kako bi razvili inovativna rješenja ovih izazova. Ovdje se cilja na dječju znatiželju kao osnovu edukacije i daljnjeg istraživanja.
- Dostupne aktivnosti učenja kroz igru i rizik. U strukturi formalnog obrazovanja danas je često odsutan akademski faktor da je iskustvo veoma bitno, koliko iskustvo uspjeha toliko i iskustvo neuspjeha. STEM obrazovanje u formalnim školskim okruženjima promovira neke od temeljnih vrijednosti znanstvene i inženjerske prakse kao što su traženje netočnosti, prepoznavanje dvosmislenosti i učenje iz neuspjeha.
- Obrazovna iskustva koja uključuju interdisciplinarne pristupe rješavanju problema. Glavna značajka integriranih i interdisciplinarnih pristupa STEM obrazovanju je upotreba situacija i problema iz stvarnog života, tzv. "velikih izazova" (engl. *Grand Challenges*) kao temelj stjecanja obrazovnih iskustava, koja povezuju pojedine discipline unutar STEM oblasti ili povezuju najmanje jednu STEM disciplinu sa ne-STEM disciplinama.
- Fleksibilni i inkluzivni prostori za učenje sa inovativnim tehnologijama. Koncept *flipped classrooma* je u osnovi STEM obrazovanja. U ovom konceptu učenici o novim nastavnim sadržajima stječu znanja ne direktno od nastavnika, već kroz unaprijed pripremljene materijale (od strane nastavnika) kojima pristupaju izvan škole a kako bi se bolje pripremili za aktivnije učestvovanje kada se nastavni sadržaji budu obrađivali na času ili bili im u prilici pristupiti kada su odsutni sa nastave.
- Inovativni i dostupni načini učenja. Težiti ka smanjenju vremena provedenog na testovima a povećati broj projekata kroz koji će učenici iskazati svoje vještine, a koji su bazirani na ishodima učenja. Iako će u budućnosti, kao i danas, biti važan faktor do koje mjere učenici razvijaju znanja iz temeljnih predmeta, u budućnosti se trebaju vrednovati trajne vještine i osobine koje učenici iskazuju u sklopu cjeloživotnog učenja, a koje će ostati relevantne i nakon 10 do 20 godina.
- Socijalna i kulturna raznolikost i okruženje koje potiče promoviranje raznolikosti i mogućnosti u STEM disciplinama. Do sada pojam STEM-a nije shvaćen na pravi način i samim tim neophodno je povećati svijest za prihvaćanje raznolikosti. Zato je neophodno ideju STEM-a širiti kroz različite medije koja su prihvatljiva mlađim generacijama poput video igrica.

Prema ovoj studiji snažno STEM obrazovanje počinje veoma rano još u predškolskim aktivnostima, gdje se primjenjuje istraživački pristup i praktične aktivnosti. Nejednakosti u STEM obrazovanju su izražene kod različitih etničkih, jezičnih, kulturnih skupina. Izražena je rodna nejednakost unutar ovih disciplina.

Nedavne analize u Americi pokazuju da će u sljedećih pet godina velike američke kompanije trebati 1.6 miliona radnika, od toga 94 500 koji posjeduju osnovnu pismenost iz STEM područja i 635 000 koji posjeduju napredna znanja iz ovih STEM područja. Drugi podaci sugeriraju da 20% poslova u SAD-u zahtjeva visok nivo znanja iz barem jedne oblasti koju pokriva STEM područje. Čak i izvan područja tradicionalno povezanih sa STEM oblastima izučavanja, postoji velika potreba za kompetencijama i vještinama iz ovih oblasti. Pa tako, podaci potvrđuju da kognitivno znanje, vještine i sposobnosti koje su povezane sa STEM-om su neophodne u svim sektorima i zanimanjima.

IV. POJEDINAČNI PROJEKTI NA PODRUČJU STEM OBRAZOVANJA U BOSNI I HERCEGOVINI

Ni na jednom nivou nadležnosti obrazovanja u BiH nema konkretnih projekata čija je osnova razvijanje i poticanje izučavanja predmeta iz STEM područja. Ipak, još polovinom 2008. godine Vijeće ministara BiH usvojilo je dokument [6] koji u svojem sadržaju ima dodirnih tačaka sa preporukama svjetskih akcionih planova za razvoj i implementaciju predmeta iz STEM oblasti.

Preporuka ovog dokumenta je da obrazovanje u BiH do 2015. treba biti: „*otvorenije, fleksibilnije, i omogućit će pojedincima da upražnjavaju svoje individualne načine i stilove učenja koji su prilagođeni njihovim potencijalima, potrebama i interesovanjima*."

Dokumentom je obećano da će do 2015. godine postojati „*sistem vrednovanja i mjerenja kvaliteta rada, što će istovremeno poslužiti i kao temelj profesionalnog razvoja svakog nastavnika"*.

Uvest će se i licenca za nastavničko zanimanje, koja će se obnavljati, pa bi prema ovom dokumentu "*Glavni uvjet za produžavanje licence, osim uspjeha u tekućem radu"*, navedeno je u dokumentu, "*bit će i uključenost pojedinaca u sistem profesionalnog usavršavanja i razvoja*. *Sadržaji učenja bit će rasterećeni od nepotrebne faktografije i više povezani sa životom i razvojem nauke, tehnike i tehnologije",* podsticat će "*razvijanje kritičkog mišljenja"* kod učenika, i oni bi nakon završenog osnovnog i srednjeg obrazovanja trebali biti sposobni rješavati probleme i primjenjivati stečeno znanje.

Sve navedeno važilo je za cijelu BiH, bez obzira koji NPP se primjenjivao. Čitav proces trebala je nadzirati Konferencija ministara obrazovanja (svi ministri obrazovanja), a Agencija za predškolsko, osnovno i srednje obrazovanje (APOSO) pri Vijeću ministara BiH voditi i koordinirati najavljene obrazovne reforme. Konferencija ministara se vrlo rijetko održavala, tako da većina najavljenih reformi nije nikad ni počela.

U travnju 2008. godine, Europski parlament i Vijeće Europske Unije usvojili su Europski kvalifikacijski okvir za cjeloživotno učenje, s ciljem poticanja mobilnosti i cjeloživotnog učenja svih građana Europe. U svibnju 2013. godine predložena je dopuna i proširenje uloge Europskog kvalifikacijskog okvira, na osnovnog kojeg je i donesen ovaj dokument. Dokument se odnosi na cjeloživotno učenje, što je i jedna od karakteristika STEM akcionih planova, ali je to i jedina dodirna tačka.

Nakon ovog dokumenta Vijeće ministara Bosne i Hercegovine usvojilo je novi dokument [7] sa ciljem definiranja kvalifikacijskog okvira u skladu sa istim koji je usvojen od strane Evropske Unije.

Kvalifikacijski okvir u Bosni i Hercegovini (KOBiH) ima za cilj pružiti svakom građaninu mogućnost za stjecanje prepoznatljivih, pouzdanih i priznatih kvalifikacija koje su usporedive s Europskim kvalifikacijskim okvirom (EQF), pristup cjeloživotnom učenju, povećati konkurentnost i socijalnu uključenost pojedinca, povezivati ga s europskim tržištem rada i prostorom obrazovanja. Isto tako, doprinijeti razvoju obrazovnog sustava, te gospodarskom i društvenom razvoju BiH. Jedan od glavnih ciljeva kvalifikacijskog okvira jeste reforma obrazovnog sustava u Bosni i Hercegovini, koja uključuje izradu i uvođenje ishoda učenja u nastavne programe, uspostavu i unaprjeđenje sustava osiguranja kvalitete, povezivanje s potrebama tržišta rada, mobilnost, te druge potrebe pojedinca i društva.

Jedan od važnih projekata koji se trenutno provodi u BiH je: "*Unapređenje osnovnog učenja i obrazovanja u Bosni i Hercegovini 2016. – 2018."* tzv. ENABLE-BIH [8]. Opći cilj projekta jeste doprinijeti unapređenju ishoda učenja u osnovnom i općem srednjem obrazovanju.

ENABLE-BiH namjerava kroz edukaciju nastavnika u STEM oblastima osigurati da učenici i učenice u BiH ovladaju ključnim kompetencijama neophodnim za učešće u ekonomiji zasnovanoj na znanju, te postanu nosioci ekonomskog razvoja u budućnosti.

Jedna od ključnih komponenti ovog projekta je prepoznata potreba za mijenjanjem obrazovne paradigme, na način da se krajnji rezultat učenja (ishod učenja) očituje sa konkretnim, mjerljivim pokazateljima – opisima onoga što su učenici i učenice u stanju uraditi nakon što je proces podučavanja na različitom uzrastu u okviru različitih školskih predmeta završen.

Ključni dokumenti koji su razvijeni kao rezultat rada STEM radne grupe u ovom projektu su:

- Nacrt Operativnog nastavnog plana i programa (ONPP) za STEM kompetencije zasnovanoj na zajedničkoj jezgri nastavnih planova i programa (ZJNPP) definiranoj na ishodima učenja
- Operativne smjernice za implementaciju ONPP-a za STEM kompetencije
- Priručnik za obuku nastavnika i nastavnica u primjeni ONPP-a za STEM kompetencije.

Ovi dokumenti razvijeni su kroz kolaborativan proces rada profesora i profesorica sa univerziteta u Sarajevu, Mostaru, Banja Luci, Zenici i Tuzli, eksperata iz Sjedinjenih Američkih Država – *"21 Century Partnership for STEM Education",* predstavnika svih ključnih institucija u BiH – Ministarstva civilnih poslova BiH, svih 12 entitetskih i kantonalnih ministarstava obrazovanja u BiH, kao i Odjeljenja za obrazovanje u Vladi Brčko distrikta.

Važnost ovog projekta je upravo u tome da se radi na saradnji svih institucija koje su direktno odgovorne za NPP i za usvajanje istih. Polazna osnova za razvoj svih dokumenata bile su upravo ZJNPP definirane na ishodima učenja za sve školske predmete koji se tiču STEM-a i koje učenici u BiH uče od prvog razreda osnovne škole do četvrtog razreda gimnazije. Nacrtom Operativnog nastavnog plana i programa za STEM kompetencije predložene su poveznice između definiranih ishoda učenja školskih predmeta iz STEM oblasti na kraju 3., 6. i 9. razreda osnovnog obrazovanja i na kraju 4. razreda općeg srednjeg obrazovanja. Operativnim smjernicama za implementaciju ONPP-a za STEM kompetencije i Priručnikom za obuku nastavnika u primjeni ONPP-a za STEM kompetencije nastojalo se ukazati na efikasnije načine kreiranja NPP i pružiti neophodne smjernice i alate nastavnicima, kako za planiranje i realizaciju nastavnog procesa, tako i za praćenje i procjenjivanje učeničkih postignuća.

Izrada svih dokumenata je u završnoj fazi i u narednom periodu bi se trebale održati edukacije nastavnika koji će raditi daljnje edukacije (engl. *Train The Trainer*). U inicijalnoj fazi obuhvaćen bi bio određeni broj škola u kojima bi bila realizirana edukacija, koja bi se potom proširila i na ostale škole u BiH. Na kraju projekta trebala bi biti izdata preporuka od strane APOSO-a za primjenu svega navedenog.

V. KORACI UNAPRIJEĐENJA STEM EDUKACIJE U BIH

Ni na jednom nivou obrazovanja nema razvijenih obavezujućih strategija za poticanje razvoja i usmjeravanja učenika na predmete iz STEM obrazovanja. Ono što je važno naglasiti i što je očito iz prethodno navedenih činjenica jeste da ne postoji ni materijalna osnova za razvoj ovih interdisciplinarnih aktivnosti. Sve aktivnosti se svode na entuzijazam i ličnu aktivnost nastavnog kadra uključujući i financijsku stranu. Financije predstavljaju veliki problem prilikom odvijanja nastave jer nema suvremenih naučnih pomagala, u nekim školama čak nema ni osnovnih pomagala za odvijanje redovnog školskog procesa. Velika većina nastanih aktivnosti ukoliko zahtijevaju suvremeni pristup, osim smjernica, su prepušteni nastavnom kadru, i samim tim i različiti pristupi nastavnog kadra dovodi do različite startne pozicije učenika u daljnjem obrazovanju iz pojedinih oblasti.

Iz svega naprijed navedenog, proizlaze osnovni koraci koji trebaju dovesti do unapriječenja STEM edukacije u BiH:

- Osnovati krovnu instancu na nivou države ili dati ovlasti postojećoj APOSO agenciji koja će biti nadležna za sve nenacionalne predmete a koji pripadaju STEM-u (Matematika, Fizika, Biologija, Hemija, Informatika itd..) kako bi se što lakše mogle implementirati promjene u sve obrazovne sustave u BiH.
- Kreirati strategiju za kontinuiranu edukaciju nastavnog kadra u STEM disciplinama, i implementirati već postojeće planove na nivou države a koji su još uvijek u fazi preporuke. Ojačati saradnju sa nevladinim sektorom koji rade na poboljšanju obrazovanja kroz zajedničke projekte poput trenutno aktualnog ENABLE-BIH projekta.
- Aplicirati na IPA fondove vezano za obnovu infrastrukture u školama, kao i edukaciju nastavnog kadra. U tu svrhu obučiti administrativne uposlenike za apliciranje za ove fondove kroz stručne seminare i/ili radionice.
- S obzirom da mladi ljudi predstavljaju budućnost i nosioci su promjena u društvu, za jednu državu bitno je imati educirani nastavni kadar koji će biti motiviran i entuzijastičan u radu kroz materijalne nagrade ili kroz povećanje plaća. Ovakav vid stimulacije nastavnog kadra je veoma efikasan što je i dokazano kroz sljedeća istraživanja.

Istraživanje koje su proveli Anthony Noremore i Lynn Iion [9] ukazuje da smanjenje veličine razreda nije troškovno najefikasnije sredstvo za unapređenje kvalitete obrazovnog sistema i poboljšanje rezultata koje učenici ostvaruju na testovima. Glavni zaključak istraživanja je da će ulaganje u kvalitetu nastavnog osoblja dati iste ili bolje rezultate uz značajno manje investicije i troškove nego kada je u pitanju investiranje u smanjenje veličine razreda.

Naime, u Južnoj Koreji, vođeni rezultatima istraživanja o ovisnosti rezultata obrazovnog procesa o veličini razreda, su se umjesto povećanja broja nastavnika, odlučili upotrijebiti novac za više plaće postojećeg nastavnog osoblja te tako dobiti kvalitetnije i motiviranije nastavnike. Zbog ovakvog pristupa i potrebe za manjim brojem nastavnika, Južna Koreja je u poziciji biti selektivnija u izboru tko može postati nastavnik. Krajnji rezultat je jedan od najkvalitetnijih sistema osnovnog obrazovanja.

VI. ZAKLJUČAK

Sustavno rješavanje problema unutar obrazovnih struktura Bosne i Hercegovine vezano za edukacije, usavršavanje nastavnog kadra i neophodne opremljenosti nastavnih prostorija i opreme za STEM bazirane predmete, postoji ali se ne provodi. Sve aktivnosti se svode na individualne slučajeve gdje roditelji insistiraju i iniciraju STEM edukaciju kod svoje djece upisujući ih u privatne ustanove koje se bave ovom edukacijom, kao što je prva STEM akademija u BiH za djecu i mlade pri Visokoj školi računarstva i poslovnih komunikacija eMPIRICA u Tuzli, ili se to sporadično dešava u pojedinim školama ukoliko postoji dovoljno motivirani nastavni kadar koji je spreman preuzeti inicijativu i sa ličnim sredstvima osigurati sve neophodno za podučavanje u domenu STEM disciplina.

BiH obrazovni sustav koji radi po više različitih NPP-ova, u osnovi je jednak po principu rada. Struktura svih navedenih NPP-ova propisuje sadržaj koji nastavnici prenose djeci, a ne polazi od toga da nastavnici trebaju voditi đake do određenih postignuća na kraju osnovne ili srednje škole.

Akcioni plan za izradu i provedbu Kvalifikacijskog okvira u Bosni i Hercegovini bio je zamišljen da to promijeni jer je još 2015. godine bilo planirano uvođenje domena ishoda učenja (znanja, vještine, kompetencije) u NPP, kao i izrada web portala KOBIH, što ni do današnjeg dana nije učinjeno, a informacije vezane za povjerenstvo koje bi trebalo biti zaduženo za provedbu ovog akcionog plana, nismo uspjeli pronaći. Neprovođenje u djelo donesenih uredbi i planova, što je već godinama ustaljena praksa, je veoma veliki problem prilikom implementacije bilo kakvog poboljšanja obrazovnog sistema u BiH.

Međutim, uspješnost kreativnih programa edukacije prvenstveno je bazirana na kvaliteti nastavnog osoblja, a manje na propisanom NPP-u. Kreativnost i učenje kreativnosti zahtijeva slobodu, fleksibilnost i eksperimentiranje ali također postavlja zahtjeve i na opremljenost i edukaciju nastavnika za što ne postoji nikakva državna niti entitetska strategija u BiH.

U svakom slučaju, nastavni kadar morao bi proaktivno djelovati u STEM edukaciji mladih, tako da za sada ne mogu očekivati pripremljene NPP-ove i nastavne sadržaje, nego potrebno znanje stjecati kroz seminare, bili oni organizirani od strane pedagoškog zavoda ili nevladinih organizacija koji imaju podršku nekog nivoa vlasti, ili

kroz samostalnu edukaciju. Nastavni kadar mora se , u svakom slučaju, opredijeliti na cjeloživotno učenje i prenošenje znanja kroz aktivnosti koje će poticati razvoj kritičkog razmišljanja i primjenjivanje stečenog znanja na konkretne probleme kod učenika, a pri tome uklapati se u postojeći NPP.

S tim u cilju, potreban je jedan viši nivo organizacije nastavnika koji dijele ovu viziju obrazovanja i entuzijazam za ovakvim radom sa mladim generacijama kako bi razmijenili iskustva, znanja i obrazovne materijale kojima bi im olakšali izvođenje ovakve nastave. Ovdje je potrebno voditi se iskustvima zemalja koje imaju kvalitetnije obrazovanje, u onoj mjeri koja se realno može primijeniti u BiH.

Ovakav vid organizacije nastavnika bi ubrzao realizaciju aktuelnih akcionih planova [7] [10], te bi mogao vršiti pritisak na vladajuće i odgovorne strukture za preuzete obaveze iz prethodnog perioda. Ovdje se prvenstveno misli na Ministarstva obrazovanja i Vlade pojedinih nivoa vlasti da investiraju, kako u opremanje zastarjelih obrazovnih institucija suvremenom naučnom i tehničkom opremom, tako i u odgovarajuću edukaciju nastavnika u svrhu realizacije suvremenog (klasičnog i STEM) obrazovanja.

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PAPERS

VIRTUAL AND MICROSERVICE ARCHITECTURES

Virtualization in Multicore Real-Time Embedded Systems for Improvement of Interrupt Latency

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***Abstract*—This paper investigates the possibilities of using virtualization in multicore real-time embedded systems based on combination of general-purpose and real-time operating systems running on separate processor cores. The research is focused on ARM processor architecture due to its widespread usage in numerous application domains. The paper describes the concepts and practical considerations of using virtualization to achieve better interrupt latency both in Linux, as a typical representative of commonly used general-purpose operating system in applications requiring real-time response, and real-time operating system running on separate cores. In the proposed approach we demonstrate how to use virtualization mechanism to decouple cores responsible for real-time and non real-time tasks in a multiprocessor system with real-time requirements. Xen Hypervisor is used as a virtual machine monitor with default credit and new experimental null scheduler. The aim of research was to study the system response time characteristics and to assess practical usability of such approach in applications with hard real-time requirements.**

I. Introduction

In recent years, there is a noticeable trend of growth in processing power of embedded systems while maintaining the low power consumption at the same time. Following this trend, the preconditions for using virtualization in low-power embedded systems are now present for many cases, which was not a case until recently. Although the usage of general-purpose operating systems (GPOS), such as Linux, has become a popular choice for easier and faster development, such operating systems cannot guarantee out-of-the-box a performance required by hard real-time low latency deterministic restrictions. In this paper we investigate an approach to provide a deterministic real-time response of a hard real-time subsystem by separating it from the GPOS by using virtualization. The whole system is divided into two basic parts: GPOS and a subsystem with hard real-time requirements. The latter can be either bare-metal application or real-time operating system (RTOS), such as FreeRTOS. In such configuration Linux can be used for non-critical soft real-time tasks which require high data throughput or feature-rich functionality while RTOS is used for handling critical tasks with hard real-time requirements [1]. We developed such system to test the validity and characteristics of the proposed approach using Odroid-XU4 hardware platform based on Exynos 5422 SoC and by employing Xen Hypervisor as a virtual machine monitor. The system was experimentally tested to determine the usability of the proposed configuration to achieve real-time and low latency response and to compare the predictability of response of such a system compared to Linux alone. For testing purposes both the default and the experimental `null` Xen schedulers were used [2]. The motivation for testing interrupt latency comes from performance requirements of hard real-time and safety embedded systems. Standards require temporal and spatial independence of software with different level of criticality [3]. Additionally, it is worth noting that there are many Linux extensions such as Xenomai, RTAI and similar projects that enable real-time operation in Linux and improve interrupt latency, but this paper is focused on improving latency through virtualization.

The main contribution of this paper is the interrupt latency benchmark of Xen Hypervisor with different schedulers. Results are compared to Linux interrupt latency and other similar Xen benchmarks [4], [5].

II. Related work

Need for the software partitioning in systems with different criticality levels in industry lead to the development of many hypervisor systems such as PikeOS, XtratuM [6], Jailhouse [7] etc. Design of these hypervisors was driven by hard real-time requirements of industrial embedded systems. Although there is a theoretical basis for determining spatial and temporal independence in such systems [8], there is lack of testing of these mentioned properties on different platforms in the context of hard real-time systems. However, there are tests and comparisons of different embedded hypervisors [9], but they are focused on properties such as CPU overhead, memory bandwidth and lock synchronization. Authors in [7] put an emphasis on duration of virtual machine exits during interrupt execution and propose similar methodology of measuring interrupt latency as it is proposed in this paper.

III. System overview

A. Xen Hypervisor

Xen is a bare-metal hypervisor which is mostly used in server applications. Xen implementation uses paravirtualization as well as hardware virtualization extensions [10]. Xen creates a virtualization layer between hardware and guest operating system. In the Xen context guest operating systems

are called domains [11]. The first domain is typically Linux, which contains a set of libraries for control of Xen system.

Xen was originally developed for Intel processors but nowadays it is also ported to ARMv7-A and ARMv8-A processor architectures [12]. Xen portable layer takes advantage of ARM Generic Timer, ARM Generic Interrupt Controller (GIC) and ARM Memory Management Unit. Therefore, Xen can be easily ported to any SoC which implements these features, such as Exynos 5422 or Xilinx UltraScale+ MPSoC. It cannot be easily ported to platforms without GIC interrupt controller (e.g. Raspberry Pi).

IV. Proposed System Architecture

By using Exynos 5422 or similar heterogeneous multicore SoC and Xen Hypervisor it is possible to statically assign virtual CPUs (vCPU) to physical CPUs (pCPU). Unlike the systems where virtualization is used when virtual CPU count is greater than a physical CPU count and where virtual CPU scheduling is required, in embedded applications it makes sense to have a smaller number of virtual CPUs than physical CPUs because in most cases tasks in embedded systems are known in advance. The configuration of the proposed system is shown in Fig. 1. In all software configurations mentioned in this paper Cortex-A7 runs at 1.4 GHz and Cortex-A15 runs at 2.0 GHz.

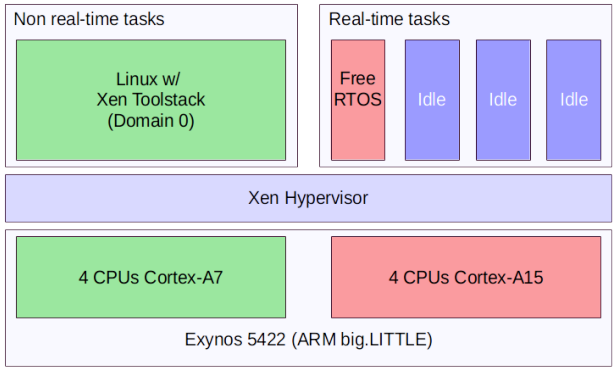

Fig. 1. Configuration of proposed system

The software of the overall proposed solution is divided into three separate layers:

- Xen Hypervisor running on top of Exynos 5422,
- Linux running as domain 0 using four Cortex-A7 cores,
- FreeRTOS running as domain 1 using one Cortex-A15 core.

Linux uses Cortex-A7 cores because it is the first operating system that boots after Xen and it is pinned to Cortex-A7 cores due to Xen boot command line parameter `dom0_vcpu_pin`.

Xen typically uses paravirtualized interfaces for device drivers in the guest domain. This means that only *domain 0* has right to access the hardware directly while other guest domains have access to the hardware through the *split device driver* interface. This approach can deteriorate the latency in *domain 1* because such indirect hardware access can be potentially expensive in terms of time. In order to overcome this problem, another *device passthrough* mechanism is used. Using *device passthrough* mechanism in Xen external interrupt can be injected into guest domain. Virtualization extensions of GIC interrupt controller make hypervisor interrupt injection overhead minimal. To ensure that vCPUs are never migrated from the assigned pCPUs, a vCPU pinning technique is used. Virtual machine scheduler overhead can be minimized through the Xen Toolstack available for *domain 0*, which allows for vCPUs to be pinned to predefined pCPUs.

V. Reference System and Testbench

A. Reference system configuration

Fig. 2 shows a reference configuration which uses only a single instance of Linux operating system (without hypervisor) on the top of Exynos 5422. The latencies measured for a system based on our proposed virtualization approach shown in Fig. 1 are compared to this reference system configuration. Kernel module `exti_kern_irq.ko` is used for detecting

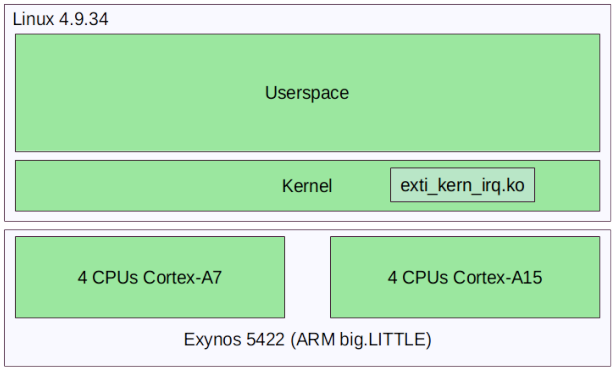

Fig. 2. Reference system configuration

and reacting to the interrupt. This reference system configuration was chosen as the most common application scenario when using Linux alone on a multicore SoC for various SoC designs.

Kernel module implementation is simplistic, and it only registers interrupt service routine for required interrupt number. Part of implementation is shown by listing 1.

```
static int __init exti_irq_init(void){
  ...
  result = request_irq(irq_no,
           (irq_handler_t) exti_irq_handler,
           IRQF_TRIGGER_RISING | \
           IRQF_TRIGGER_FALLING,
           "exti_irq_handler",
           NULL);
  ...
}
static irq_handler_t exti_irq_handler(unsigned int
    irq,
   void *dev_id, struct pt_regs *regs){
```

```
    gpio_set_value(gpio_out,gpio_get_value(gpio_in));
    return (irq_handler_t) IRQ_HANDLED;
}
```

Listing 1. `exti_kern_irq.ko` module implementation

B. Testing interrupt latency

The interrupt latency is one of the most important parameters in real-time embedded systems. Response time of the system depends greatly on the interrupt latency among other factors. In the context of this test case, the interrupt latency is defined as the time difference between the time instant when the external interrupt source was asserted (e.g. logical voltage level changes to trigger the GPIO interrupt) and the time instant which represents the finished reaction on the event that triggered the interrupt. The test configuration is shown in Fig. 3. In the test configuration the STM32F4 microcontroller

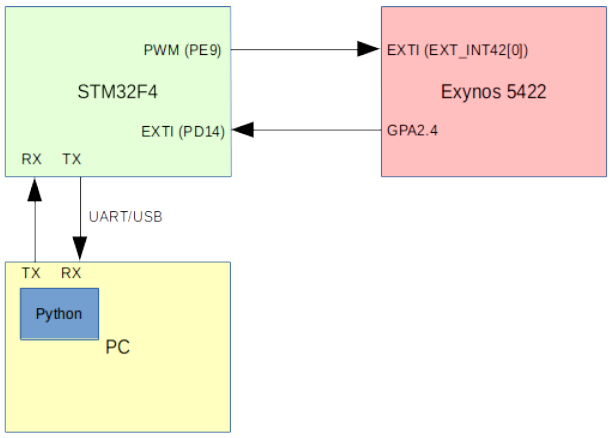

Fig. 3. Test configuration

is used to generate PWM signal that is fed to the EXTI input of Exynos 5422 system. The Exynos 5422 system generates a response to the external interrupt trigger by changing the logical level on GPA2.4 pin. The time difference between these two signals represents a time delay t_d, which is considered as a latency of interrupt reaction and this time corresponds to the above noted interrupt latency definition. Similar measuring method is used in [7]. This time delay is measured precisely by a STM32F4 microcontroller as the time difference between the falling edge of the input PWM signal and the falling edge of the response signal from Exynos 5422. The measured interrupt latency can be considered as a stochastic variable which statistics depends on the software configuration of the Exynos 5422 system. The aim is to minimize the standard deviation of the interrupt latency by using different software configurations in order to achieve as deterministic system response as possible in terms of interrupt latency. An example of input and output signals measured on oscilloscope is shown in Fig. 4. The time delay t_d can be described by equation (1):

$$t_d = t_{irq} + t_{user} \tag{1}$$

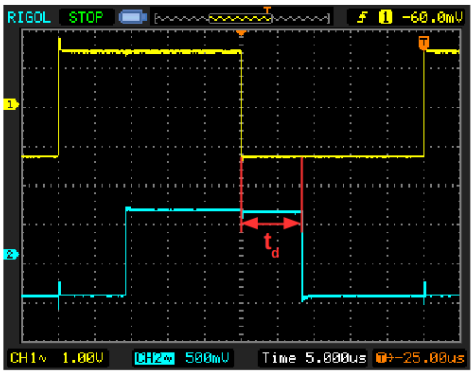

Fig. 4. Time delay t_d between input and output signal shown on oscilloscope

where t_{irq} is a part of time delay related to the time necessary for hardware to process interrupt source and call the interrupt service routine, and t_{user} is a time in which a reaction to interrupt is executed as a response (in this case changing the level of the output test pin GPA2.4). The equation (1) does not take into account the OS overhead and therefore it must be extended by an additional term in case of using OS in the system configuration:

$$t_d = t_{irq} + t_{os} + t_{user} \tag{2}$$

where t_{os} represents a time delay introduced by internal mechanisms of the OS. Moreover, in case of our proposed system architecture, we also need to furthermore extend the equation (2) to take into account the influence of the hypervisor layer to the interrupt latency:

$$t_d = t_{irq} + t_{hyp} + t_{os} + t_{user} \tag{3}$$

where t_{hyp} is a time delay introduced by hypervisor.

Generic interrupt controller (GIC) architecture supports injecting interrupts by using a special set of registers (*list registers*), which are maintained by the hypervisor [13]. This mechanism is implemented in `arch/arm/gic.c` and `arch/arm/vgic.c` in the Xen hypervisor. After IRQ interrupt is trapped, it is emulated by modifying the *list registers* (see function `do_trap_irq` in `arch/arm/traps.c`) and injected into to the guest. The deviation of t_{hyp} is the most significant term in interrupt latency equation (3) as it depends on states and utilization of all virtual machines and physical CPUs. Interrupt latency and deviation also directly affect the scheduling latency in FreeRTOS virtual machine as the scheduling depends on the arrival of the system tick interrupt. In this case, virtual timer was used for generating a system tick interrupt in FreeRTOS operating system (a part of ARM Generic Timer architecture [14]).

The tests were performed for two system configurations shown in Fig. 1 and Fig. 2. To simulate a workload in Linux operating system, a `stress` application was used. `Stress` is a simple Linux application which allows user to spawn workers that consume processor time and memory depending on the given parameters. CPU and memory allocation operations

in Linux operating system will affect the interrupt latency of Linux. Furthermore, they will also affect the interrupt latency in the FreeRTOS virtual machine for the configuration shown in Fig. 1 when virtualization is used. Therefore, to experimentally test both system configurations and different load conditions, we conducted three different test scenarios:

- no intensive CPU or memory utilization,
- intensive memory utilization (`malloc` and `free` workers - `stress -m $N --vm-bytes 64M`,),
- intensive CPU utilization (`sqrt` workers - `stress -c $N`),

where N is the number of cores available to Linux.

It is worth noting that intensive memory utilization as defined here is not similar to the traditional definition of memory utilization which implies high load on the CPU to RAM data path and high rate of cache misses. Instead, our interest is testing how locking mechanisms in memory allocation can cause interference between Linux and FreeRTOS operating systems. Therefore, from now on we will refer to this kind of utilization as lock-intensive.

Because these tests can yield results that are very variable depending on architecture, platform and hardware implementation, their usability is very limited. However, some qualitative properties of Xen interrupt processing can be asserted. To resolve this issue, we ran additional interrupt latency test on bare-metal FreeRTOS. Furthermore, additional profiling of Xen internal interrupt processing was done. Based on the mentioned measurements the ratio of t_{irq}, t_{hyp}, t_{os} and t_{user} was determined. This enables comparison to similar measurements in other papers.

Before presenting the benchmark of various software configurations, we present baseline scenario which provides us with the estimation of time t_{irq}. Time t_{irq} is estimated with application which runs on bare-metal FreeRTOS and uses ARM Generic Timer to determine latency of the interrupt response. Similar procedure is used in TBM application [15] by Xen developers [5]. Basically, we configure physical timer to deliver interrupt after 1 ms and in the interrupt handler read difference between subsequent interrupt arrivals (by reading `CNTPCT` register). Considering frequency of timer (24 MHz), we devise interrupt latency mean and standard deviation which is shown in table I. Additionally, results are also shown in Fig. 5.

TABLE I
INTERRUPT LATENCY ON BARE-METAL FREERTOS

Minimum (ns)	Average (ns)	Maximum (ns)	Standard deviation (ns)
588	642	672	31

VI. RESULTS

The following software configurations for systems shown in Fig. 1 and Fig. 2 were experimentally tested:

1) operating system Linux 4.9.34 without Xen Hypervisor (configuration shown in Fig. 2)

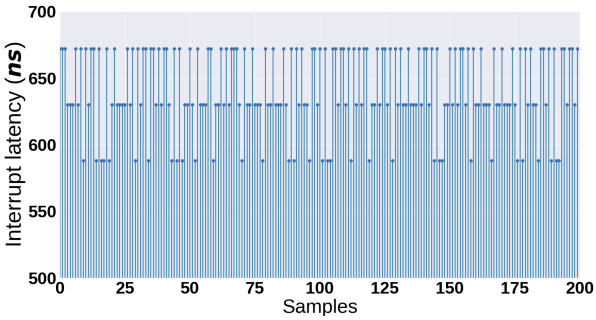

Fig. 5. Interrupt latency on bare-metal FreeRTOS

2) operating system FreeRTOS 9.0.0 in Xen 4.10 virtual machine with Linux 3.10.82 in other Xen virtual machine with `credit` virtual machine scheduler (configuration shown in Fig. 1)
3) operating system FreeRTOS 9.0.0 in Xen 4.10 virtual machine with Linux 3.10.82 in other Xen virtual machine with `null` virtual machine scheduler (configuration shown in Fig. 1)

The first configuration is considered as a reference test case because it resembles the most common and practical configuration in use for the Exynos 5422 and similar SoCs. Second and third software configuration represent a proposed system software architecture where the virtualization is used. The main difference between second and third software configuration is in the used Xen virtual machine scheduler. The second test case uses a default `credit` scheduler, which allows more vCPUs than pCPUs. The third configuration uses an experimental semi-static `null` scheduler [2], which removes the unnecessary scheduling overhead. The results obtained by the test procedure explained in the section V are shown in Tab. I-III and Fig. 6-8. For each test a series of 20000 interrupt latency samples was acquired. Every sample in series represents the time difference t_d between falling edges of input and output signals, as described in section V.B, which corresponds to the interrupt latency of the system configuration under test. Each test samples series was analyzed by calculating average, maximum and standard deviation of the observed interrupt latency. Each table I-III contains summary for three measurements obtained under different load test scenarios, as described in the section V. The sign "-" in the first table row means that there was no intensive CPU or lock-intensive utilization. Each table contains average, maximum and standard deviation of the interrupt latency measured in microseconds. The Fig. 6-8 visualize time series of the acquired interrupt latency samples under lock-intensive utilization as it causes the most significant deviation.

Results of the first software configuration are shown in table II and in Fig 6. These results show how interrupt latency in Linux becomes nondeterministic under lock-intensive utilization. This is not acceptable behaviour in hard real-time and low latency systems. Results of the second software configuration

TABLE II
INTERRUPT LATENCY IN OPERATING SYSTEM LINUX

Utilization	Average (μs)	Maximum (μs)	Standard deviation (μs)
-	7,63	23,57	0,56
CPU	7,33	69,60	5,18
Lock-intensive	9,99	157,29	7,24

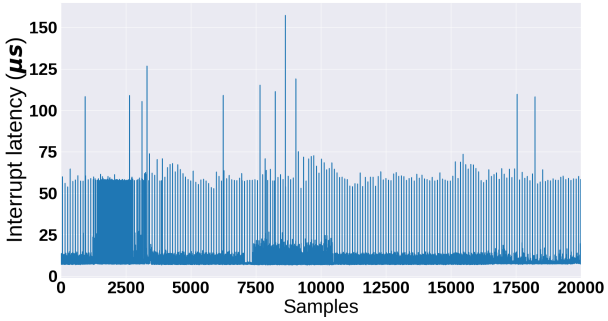

Fig. 6. Interrupt latency in operating system Linux with lock-intensive utilization

with Xen and default `credit` scheduler are shown in table III and Fig 7. In this test case, standard deviation of interrupt latency under different utilization conditions is significantly smaller than in the first reference test case.

TABLE III
INTERRUPT LATENCY IN FREERTOS (XEN - `CREDIT` SCHEDULER)

Utilization	Average (μs)	Maximum (μs)	Standard deviation (μs)
-	8,68	23,38	0,39
CPU	8,77	22,95	0,38
Lock-intensive	9,20	62,38	1,37

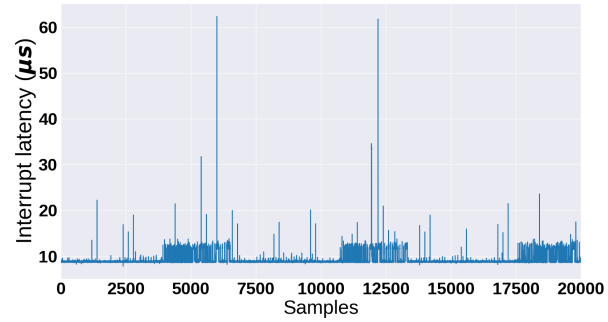

Fig. 7. Interrupt latency in FreeRTOS (Xen - `credit` scheduler) with lock-intensive utilization in Linux

Results of the third software configuration with Xen and experimental `null` scheduler are shown in table IV and Fig 8. Interrupt latency deviation in this software configuration is significantly smaller than in other two cases.

TABLE IV
INTERRUPT LATENCY IN FREERTOS (XEN - `NULL` SCHEDULER)

Utilization	Average (μs)	Maximum (μs)	Standard deviation (μs)
-	8,66	11,95	0,11
CPU	8,76	14,02	0,10
Lock-intensive	9,17	13,90	1,07

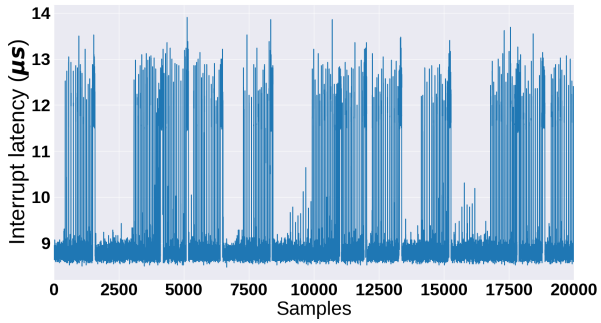

Fig. 8. Interrupt latency in FreeRTOS (Xen - `null` scheduler) with lock-intensive utilization in Linux

Finally, we present results of profiling every part of interrupt processing in case of the second and the third configuration for average case. Results are shown in table V. Time t_{irq} is a delay caused by hardware latency. Time t_{hyp} is caused by Xen and for purpose of determining its value execution time of function `do_trap_irq` in `arch/arm/traps.c` was measured. Times t_{os} and t_{user} depend on implementation of FreeRTOS port and user application. Our FreeRTOS port [1] for Xen on ARM enables user to register interrupt handler for the external interrupt or any other interrupt in an application. This is different approach from [7] where authors embedded interrupt response for the external interrupt in assembly which is not practical, but enables elimination of overhead created by guest operating system and application.

TABLE V
AVERAGE CASE INTERRUPT LATENCY t_d FOR FREERTOS VIRTUAL MACHINE

t_{irq} (μs)	t_{hyp} (μs)	t_{os} + t_{user} (μs)
≈0,6	≈6,8	≈1,0

VII. DISCUSSION

By analyzing the results obtained by experimental measurements of system behaviour under different system configurations and load tests, it is clear that a minimum interrupt latency deviation for a real-time subsystem (i.e. virtual machine running FreeRTOS) is achieved for the third case in which experimental Xen `null` virtual machine scheduler was used. The `null` scheduler reduces virtual machine scheduler overhead and provides the most deterministic behaviour of

[1] FreeRTOS port repository: https://github.com/dumpram/odroid-xen-rtos

the RTOS cores, even under the high CPU and lock-intensive load of the cores assigned to Linux. One can notice periodic high values of interrupt latencies in Fig. 7 caused by Xen `credit` scheduler. Periodic interrupt latency deviations while using `null` scheduler observed in Fig. 8 are caused by lock-intensive utilization. It can be noticed that these latencies for `null` scheduler are almost absent in the case without high memory utilization as shown in Fig. 9. This is the result of the fact that Xen manages the memory and therefore interrupts are delayed because of the critical sections that cannot be preempted. This problem could be resolved if the memory could be statically assigned among virtual machines.

Final results of average case t_{irq} profiling show that the virtualization layer is responsible for significant part of the total latency (about 70%). However, out-of-the-box performance of Xen with bare-metal application in virtual machine has lower interrupt latency deviation than Linux, which is shown by previously elaborated results.

Xen interrupt latency results in [4] and [5] are significantly smaller, but these measurements were executed on different platform (Xilinx UltraScale+ MPSoC) with different processor architecture and profile (ARMv8, Cortex-A53), although GIC architecture is equal (GICv2). It is unlikely that the difference in results is caused by different methodology. In [5] ARM Generic Timer was exploited to determine interrupt latency (with TBM application [15]). Our results with methodology elaborated in section V.B are consistent with results we obtain using ARM Generic Timer as proposed in [5].

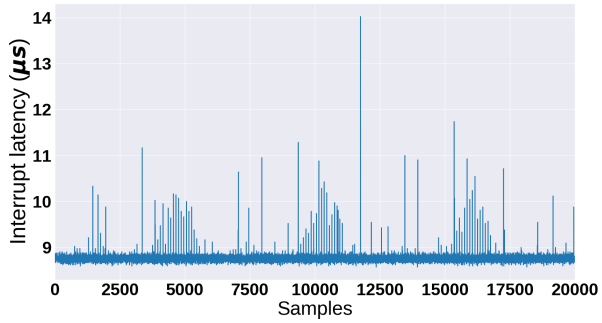

Fig. 9. Interrupt latency in FreeRTOS (Xen - `null` scheduler) without lock-intensive utilization in Linux

VIII. Conclusion

Although general-purpose operating systems such as Linux gained significant popularity as a platform of choice in many embedded systems applications, due to the nondeterministic latency they are not considered as an optimal choice for applications with hard real-time requirements. This paper investigated a possibility of using Xen Hypervisor to provide an elegant solution that can bring acceptable real-time performance in multicore SoC, without a need for modifying Linux kernel. The results of research showed that although the hypervisor layer introduces additional latency in a system response time, it can increase the predictability and reduce variability of interrupt response time for a real-time subsystem. The proposed approach achieved the best results by using static assignment of vCPUs to pCPUs with experimental Xen `null` scheduler. Lock-intensive utilization has much greater impact on a system response time predictability than CPU load. The research lead to the conclusion that even better results regarding the system response time predictability could be achieved by using static assignment of memory resources as hypervisor can significantly increase the statistical variation in response time while performing memory allocating operations. Such approach could be viable for solutions in embedded systems due to the fact that task and memory assignments could be in most cases determined in advance. The goal of future research is to investigate hypervisor schedulers in the context of temporal and spatial isolation in mixed-criticality systems.

Acknowledgement

This work has been supported by the European Regional Development Fund under the project "System for increased driving safety in public urban rail traffic (SafeTRAM)".

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Monolithic to Microservices redesign of event driven integration platform

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***Abstract* – With this paper we presented architectural redesign of SOA (service oriented architecture) integration platform by following principles of microservices design. Presented SOA platform is currently in use for Real estate sector. Number of messages which need to be processed by platform is growing as well as number of new integrations which requires redesign of platform. Redesign should provide ability for scalability, better resource management, maintenance and deployment. To support this, it is necessary to transform integration platform to be microservices based.**

***Key words* –Microservices, SOA, integration platform, Real estate**

I. INTRODUCTION

SOA (service oriented architecture) is approach used for designing software products based on services. Business functions are implemented in form of services. Every service independently handling different set of business functions [1]. Services have standardized definition for service consummation in form of service contract. Service can be consumed anywhere within public or private network where infrastructure or security restrictions are allowing that. Service is designed to be *long lived* to serve clients 24/7 for business requests [2].

Benefits of SOA architecture are:

- Business functions are exposed in form of independent services.
- Service reusability.
- Message exchange – services are passing messages by invoking each other.
- Message monitoring, control, transformation, security.
- Complex event processing.
- Service composition.
- Service discovery [3].

Disadvantages and reasons why the current platform SOA implemented needs to be replaced with something else are:

- Further updates are no longer easy to accomplish. Components are huge and complex.
- Daily maintenance and deployment become too risky and business affected since almost whole platform is down until deployment is done together with post deployment validations.
- Resources are not properly utilized since current platform implementation includes huge and complex components. We need to have small services and scale only where it is needed. Platforms which are not properly handling resources are not ready for cloud hosting.

Microservices approach is mostly filling these gaps but is not only one solution for our issues. Scope of this paper is not to compare possible solutions, it is presentation of one solution example from real world and microservices redesign approach was already taken.

Microservices are new architectural approach which requires to break up distributed applications (mostly implemented as monolithic services by using SOA) into small independent services. Each service is running in its own process and communicating with other services by using lightweight mechanisms [4].

These services are implementing separate business capabilities and implementation can done by using different programming languages and different data storage technologies. They are usually supported by automated deployment, for example, in the cloud, enabling each service to be deployed often or on scheduled time, with a bare minimum of centralized management [5], often following industry-proven DevOps practices [6].

The aim of this paper is to describe the disadvantages of current design, give proposal of how to fill gaps, approach of platform transformation and result presentation.

Paper is organized in 5 sections. First section will give the short introduction. Second section will give an overview in related work so far. Third section will give an overview of Real estate platform where it will be described all platform disadvantages. Fourth section will present platform redesign pattern where it will be given proposal in form of pattern for platform redesign with transformation steps. Fifth section will present results where it will be described what was accomplished with redesign. Sixth section contains conclusions.

Next section will give the overview of related work publish so far for the same topic.

II. RELATED WORK

Since microservices architectural approach has significant growth, it is published a lot of papers where it is presented similar topic of transition SOA architecture to microservices.

In paper [9] author has recognized and analyzed following items: (i) the identification of the key properties of microservice architectures, (ii) the identification and investigation on a description language for designing and analyzing architectures, (iii) the identification of the factors that impact the process of migrating existing applications towards Microservice Architecture.

Authors in paper [10] present a set of recommendations and best practices on the effective use and management of enterprise software components,

drawing upon the best of SOA, API and Microservice concepts and practice.

Authors in paper [11] illustrated how distributed systems evolved from the traditional client-server model to the recently proposed microservices architecture.

Authors in paper [12] presented a microservice based reference architecture model with clear understanding and definition of the concept of microservice and key architectural components and building blocks for implementation and management of enterprise microservices in the context of enterprise architecture.

Authors in paper [13] have done analysis and testing of the microservice architecture pattern, used during the last years by large Internet companies like Amazon, Netflix and LinkedIn to deploy large applications in the cloud as a set of small services.

Next section will give the overview of Real estate platform with disadvantages related to it.

III. An Overview of Real Estate Platform

Integration platform which we are presenting is currently in use in Real Estate sector and is one example how this kind of platform can be implemented, how platform can be organized and which parts are most important. This is not general design for all integration platforms, this is practical real example. This platform is implemented by following SOA principles. SOA is architectural style that leverages services as functional building blocks of distributed software systems.

Integration platform can be defined as a computer software or just a set of tools which have main goal to integrate applications and services of different companies with different set of heterogeneous entities and data formats [7].

Figure 1. is showing the building blocks of integration platform for Real estate sector. Platform components can be divided into 4 groups:

1. Feeding components.
2. Core components.
3. Provider components.
4. External components.

Feeding components group contains RestAPI, Front end application components and MQM (multiple queues monitors) component.

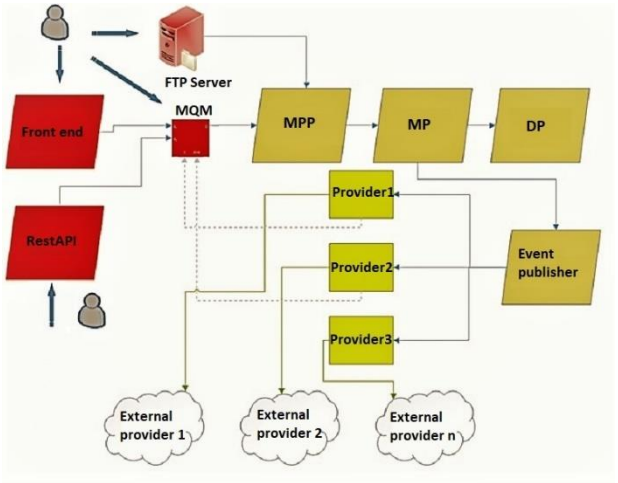

Figure 1. Building blocks of integration platform

Purpose of RestAPI component is to enable external consumers to enter the platform with specific messages. It is configured who can enter the platform. Output of this component is message queue. Front end application component is set of applications for feeding platform with messages. Output of this component is message queue. MQM component is set of configured message queue monitors which are taking off messages and sending them to the next component in pipeline – MPP (message preprocessor).

Core components group contains MPP (message preprocessor), MP (message processor). DP (delivery processor) and EP (event publisher). Purpose of MPP is to finish some preprocessing activities to prepare message for regular processing. Some of these activities are: message transformation to internal format, document registration, message validation etc. Purpose of MP is to process message. This requires message parsing and storing all relevant information to database. DP component is delivering message to folder, queue, ftp, URL, email, or to somewhere else. EP is determining to which service provider message needs to be forwarded after processing. Core components are regular WCF services implemented by following approach one service one component.

Provider components group is set of the components implemented for specific business purpose. Every provider is handling specific business workflow which is related to the external provider platform is integrated with. Business logic is fully implemented in this group.

External components group is basically direct communication with external providers. For this particular integration platform external providers are all external parties (which are not buyer or seller of property) included in process of buying / selling properties like bank (for credit ensuring), insurance agencies, agencies which are doing property appraisal, fraud detection etc. For some cases preprocessor is included to prepare message for external provider. All these components are targeting only one database.

Real estate platform has some of the disadvantages which are related to the number of messages which need to be processed by platform as well as number of new integrations which need to be supported. It is necessary to do platform redesign to support following:

1. We should be able to identify services which require more resources.
2. We should be able to increase resources only for services which require that, not for whole components.
3. We should have improved logging and issue troubleshooting.
4. Bug identification and fixing needs to be fast with fast deployment without platform turn off.
5. Only services which have updates should be redeployed, not whole platform.
6. Platform needs to be live 24/7 although some parts of platform are *down.*
7. We should have more ability regarding hosting since we want to have our platform (or just part of it) hosted in cloud.
8. Platform needs to be less technology dependent. There needs to be more selections regarding implementation, deployment and hosting of platform.
9. We should be capable to include multiple companies in platform maintenance.

Next section will describe the proposal for platform redesign in order to fix disadvantages.

IV. PLATFORM REDESIGN PATTERN

Figure 2. is showing the redesigned platform in form of microservices groups.

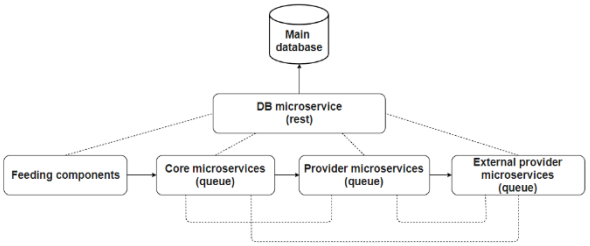

Figure 2. Integration platform redesigned into microservices groups

Since common transaction processing database is something what cannot be decomposed, it is added DB microservice component as a wrapper around DB which is handling DB actions like get, add, update, delete and ensuring transaction consistency, rollback and cleanup activity. This microservice can be used through REST API interface to ensure easier way for DB consumption. Feeding components are kept as it was.

Core components are decomposed to the microservices which are logically independent and every microservice contains its own configuration to ensure ability for control of message flow passing and some other configurations related to the message processing. These microservices are *queue* based which means that every service has its own feeding queue. This group is consuming transaction database through DB microservice by using REST.

Provider and external provider microservices are kept in form like they were except common DB consumption which is replaced with DB microservice call. Every provider component is representing isolated business logic which meets microservices redesign requirements. Common transaction processing database consumption is switched to be DB microservice, so there is no direct call to transaction database at ALL across integration platform. Feeding microservices group is changed to be *queue* feeding so there is no direct service call, message needs to be created and dropped to the appropriate queue. Every microservice contains its own configuration.

Figure 3. is showing part of core components implementation (MP, DP, EP) and provider microservices.

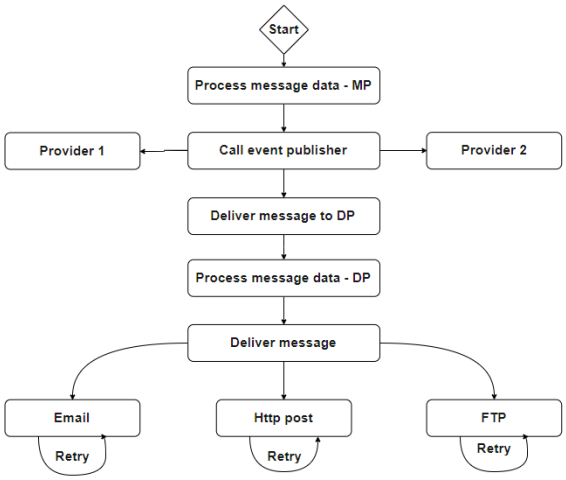

Figure 3. Core and provider microservices implementation

It is default that if microservice needs to communicate with central transaction processing database it will be done by calling DB microservice which has REST API interface and that communication is not shown on figure 3.

Since microservices are receiving messages by using queue so that requires that every microservice has its own queue monitor.

Process message data MP microservice will handle process activities related to the message processing and ensuring that information is stored correctly. *Call event publisher* microservice by using local configuration and information from message will determine which business provider can be utilized. Also, this microservice is passing message to the DP. *Deliver message to DP* is microservice which is delivering message to the next microservice in pipeline related to the DP. *Process message data DP* will determine where message needs to be sent. *Deliver message* is determining which delivery microservice will be utilized (email, http post, FTP). Microservices for delivery message have implemented retry logic in case that some locations are temporarily not available.

SOA transformation to the microservices based platform is done through following steps:

1. Recognized group of microservices (Figure 2).
2. Implementation of DB microservice with REST interface for main database utilization.
3. Component decomposition into small independent microservices.

4. Removing service contract dependencies.
5. Switching DB consumption to be by using created microservice for that purpose (#2).
6. Creation of local microservice configuration where it was needed.
7. Switching ALL configurations to be local.
8. Setting up queue monitors and queues per microservice [8].

Next section will describe what was accomplished with platform redesign.

V. Redesign platform benefits

With microservices platform redesign we have made ability for resolving issues which we had with our platform. Following items are resolved:

1. Maintenance is much improved since code changes can be done just on small microservice.
2. Deployment is improved since we are independently deploying only services which are changed.
3. Scalability is improved since we can have different number of instances for different microservices without code changes.
4. Resource management is much better since we can increase number of instances of microservices which were bottlenecks, not whole components.
5. Production deployment is improved since it is not necessary to turn off whole platform, just particular microservices. Messages will be stored in queues and after deployment, platform will continue with processing.
6. Future development is improved since different teams can work on different services and use different technologies.
7. Platform hosting is improved since now it can be done also in cloud.

All in all, mostly all our issues we had with platform are resolved.

VI. Conclusion

SOA approach is in use very long time with all mentioned benefits, supported technologies, tools and approved patterns. But microservice approach is giving us more agility and flexibility regarding software product maintenance, upgrade and deployment.

SOA integration platform which is in use for Real estate sector many years is presented in this paper. Technical model with building blocks is described as well. Disadvantages and limitations related to the maintenance of platform and ability for scaling are main reason for platform redesigned. Redesign pattern is microservices based and is fully described in paper as well as transformation steps. Microservices based redesign is chosen because it is fully resolving platform limitations but it is not only one approach.

Microservices approach is not only decomposition of software components it is also ability for software development organizations to be organize on the same way into small independent teams which have ability to select different programming languages and technologies for implementation and to work independently. All these redesign platform benefits which are described in paper are giving more agility to the platform maintenance teams and are key values why this approach is selected in comparison to the other approaches for platform redesign.

Further work related to the platform redesign is to investigate all microservices redesign platform patterns and compare theirs benefits for different sectors and try to have standardized form of those. Also, microservices based approach needs to be compared with other approaches while resolving issues like we had.

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Distributed Solvers of Applied Problems Based on Microservices and Agent Networks

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***Abstract* - In recent years, distributed computations based on the direct interactions of agents without using a central control node, is a subject of increased interest of many researchers in the field of computing technologies. We investigate the intellectualization of the collective management of the process of solving applied problems "given – find" by the agents network on the distributed computational model of the subject domain. In the distributed solver, we use a multi-agents service-oriented method of organizing computations based on the mechanisms of semantic interaction of applied solver agents. We propose the communicational model of the agents network and the model of agent functioning dynamics, providing the solution of the abovementioned problems using the distributed computational model of the subject domain. The problem solving technology based on offed approach is demonstrated on the example of the multiagent distributed computing system creating for solving qualitative analysis problems of autonomous binary dynamic systems having practical application in gene regulatory networks.**

Keywords - agents network; collective management; microservice; direct interactions of agents; binary dynamic system.

I. INTRODUCTION

In the past two decades, parallel and distributed computing has been actively used in applied scientific research. Therefore, there was a renewed interest in the use of applied program packages (APP), which necessitates, in its turn, a need to reconstruct the old methods and tools of parallel and distributed computing organization in APP, and to design the new ones. The APP is a set of interconnected modules for solving a particular class of problems within some subject area.

We offer a new approach to the intellectualization of decentralized collective management based on direct agents interactions for solving problems using the APP. The main subject is the APP intellectualization, while it lets an end user formulate the problem in meaningful terms without specifying the algorithm of its solving.

This algorithm (the abstract program and its procedural implementation) is designed automatically, while the computation details are hidden from a user. This way of organizing calculations is known as a structural synthesis of programs [1, 2]. It supposes an availability of the computational model of subject area (knowledge database, KB), which allows describing all APP calculation capabilities for problem solving of a particular class. The computational model KB is represented as an aggregate of significant values (parameters set *P*) of the subject area and functional relations between them. Every functional relation is realized by program module (from modules set *M*) that calculates the module output parameters values according to given values of the input parameters. Thus, the computational model determines the rules of modules usage and integration during the process of problem solving as: «according to given values of the parameters $A_0 = \{a_1, a_2, \ldots a_k\}$ calculate values of the parameters $B_0 = \{b_1, b_2, \ldots b_r\}$ » ("given – find"). Such non-procedural problem formulation is denoted as $T = (A_0, B_0)$. The program packages with capabilities mentioned above are further referred to as distributed solvers of computational problems.

We offer distributed solvers development technology based on the integrated application of the service-oriented approach, decentralized control, and self-organization mechanisms in agent systems. The group of intellectual agents (set *Ag* of local control programs for APP modules) forms all the control actions in this system.

We introduce the notion of the computational field (CF) as an aggregate of logical network nodes united by a network. Under a logical node, we understand some physical computing resource such as processor cores, computational clusters nodes, a personal computer, a virtual machine, a mobile computing device, etc. The program modules of APP, created as services are executed at the place of their installation on this nodes. The count of agents is not less than the number of modules. Backup agents provide reliability of the distributed solver in the failure event of the CF node. The concept of the CF is a productive and effective means of coordinating the actions of software agents for a wide variety of applications [3, 4]. In our very case, the CF is discrete, the numeric CF value is calculated in each node by the agent depending on its state, and according to the field propagation rule over the network. Zero value of the field is a trigger for corresponding module inclusion into the applied problem solving process. This approach is applied to the organization of distributed computing in the APP when the following conditions are met:

• The application software modules are implemented in the form of computational microservices [5, 6] installed on CF nodes. The use of microservices allows us to operate modularity properties under absolutely new conditions for organizing distributed computing when

inter-modular interaction is provided only through the mechanism of message transmission.

• The microservice developer delegates the execution of all necessary actions related to the solution of user problem on the KB model, to the solver's applied agent associated with the microservice installation node.

• The domain model is distributed the way that each agent has limited knowledge of both the capabilities of other system agents and the topology of the CF as a whole.

Thus, we use an agent-based, application- and service-oriented method of computations organizing in a distributed solver based on the semantic interaction of the solver's applied agents. The computational field and distributed knowledge base of computational problems are the necessary means of information support of such interaction.

II. Related Work

The complexity of many practical problems, possessing the features of unpredictable dynamics, openness, the mobility of components, etc. stipulates the activation of the development of service-oriented software tools for their solution based on self-organization and multi-agent approach [7, 8]. Distributions and decentralized management are indicated in [9, 10] as one of the main criteria for the quality and reliability of such software systems. In the same papers, poor scaling, lack of reliability and questions related to ensuring data confidentiality are noted by the authors as weaknesses in the use of the central control node.

In recent years, distributed computing based on direct interactions of agents without using a central control node is a subject of increased interest of many researchers in the field of computational technologies. In [11] the perspectives of various ways for agent interactions are discussed, and the significant advantage of direct ones is noted, which consist in an ability to design of specific self-organized behaviors with the required outcomes and robust properties. In work [12] authors noted good adaptability of direct interactions to a dynamic environment and higher reactivity to external changes in comparison with indirect interactions.

We focus on the dynamics of a heterogeneous distributed computing environment during the developing a distributed solver. We combine the advantages of multi-agent and service-oriented technologies, decentralized control with direct interaction of agents (unlike [13]) and use self-organization for creating a service-agents composition for a non-procedural problem formulation on distributed computing model of the subject domain without its explicit description (in contrast to [14]). The behavioral model of distributed solver agents is realized based on a discrete-event finite state machine.

III. The Communication Model of Agents Network

The communication model of the agents network assumes only paired (reflected in the KB model) interactions between agents at each stage of solving the T problem. In the decentralized management of the process of solving the problem formulated non-procedurally, there are two stages. The first one is the formation of the active group of agents that ensure the solvability of the problem (if possible) on the KB model. The second one is the joint actions of the active group of agents to solve the problem by running the necessary computational microservices. The only way to coordinate the behavior of agents on either the first or the second stages is to control the behavior of agents "by the readiness of input data" (event management). Thus, the process of distributed integration of Ready-made Modules Distributed Integration (RMDI) is carried out only due to internal interactions of the multi-agent system without explicit external control (decentralized control).

The experimental implementation of the RMDI process is performed using the HPCSOMAS 2.0 Framework, which automates the development of the multi-agent systems (MACs) for distributed computing.

IV. Framework for Microservices Building

The composition microservices control depends on the way the problem is formulated by the user (procedural or non-procedural formulation) for problem solving in a specific subject area. In the procedural formulation of the problem, system microservices are used to organize management based on API classes intended for explicit describing the logic executing the basic templates of calculating schemes. The architecture of MAS based on this interaction was given earlier in [15, 16]. For non-procedural problem formulation, we developed a new version of the HPCSOMAS 2.0 system, which includes new API classes for implementing the new type of computational agents based on the discrete-event behavioral model formed as a deterministic finite state machine (DFSM). For non-procedural problem formulation $T=(A_0,B_0)$ on distributed computational model KB, the control is performed using a self-organizing multi-agent system, which consists of only

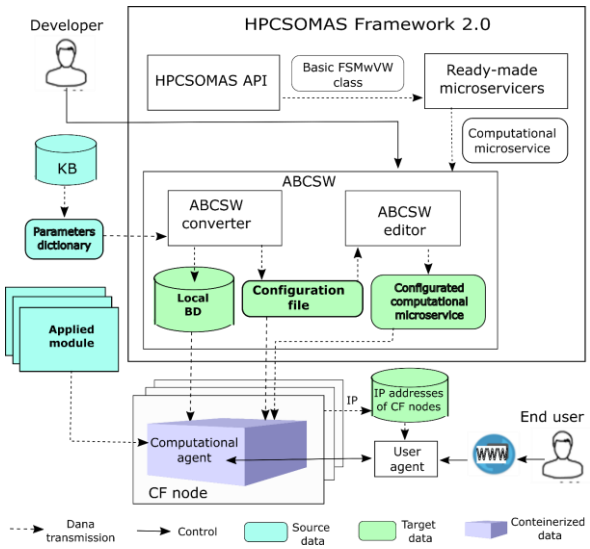

Figure 1. The scheme for creating microservices using HPCSOMAS Framework 2.0.

agents based on such classes. These agents are implemented as services, based on REST architectural style, and interact with each other using HTTP protocol. In the modern view of a service-oriented architecture, such services of a distributed software system are called microservices. The scheme for building computational microservices is shown in Fig. 1. Using APP knowledge base, ABCSW converter describes the scheme of the computing agent-microservice (here and below microservice) in JSON language and creates a computational model of the microservice formed as a local knowledge base. Using ABCSW editor, a microservice configuration file is created and edited.

As a result, the microservice has a description scheme, configuration file, local knowledge base and application module. Each microservice is autonomous, independent, reusable, and intended for performing a particular function. Microservices are created using similar data format determined by the specification of parameters and operations in the subject domain dictionary. Therefore, there are no incompatibility problems with creating a distributed solver based on this approach. Using HPCSOMAS Framework 2.0, the user agent database is created in which static links between the computing services and CF nodes are stored. Management of the user problem solving is transferred on the level of computing agents implemented as microservices.

V. Model of Agent Functioning Dynamics

We create new FSMwVW (Finite State Machine with Variables and Works) to describe the agent functioning dynamics. FSMwVW is the extension of FSMwV [17] by the set of input variables and the set of program works. The new model FSMwVW is following:

$$\text{FSMwVW} = (\Sigma, S, \delta, x, y, G, E, W, (s_0, y_0), s_m),$$

where $\Sigma = \{\sigma_1, \ldots, \sigma_{n_\Sigma}\}$ – the finite set of events; $S = \{s_0, s_1, \ldots, s_{n_S}\}$ – the finite set of conditions; δ: $\Sigma \times G \times x \times y \times S \to S \times y$ – the transition function; $x = (x_1, \ldots, x_{n_x})$ – the vector of binary input variables; $y = (y_1, \ldots, y_{n_y})$ – the vector of binary output variables; $G = \{g_1, \ldots, g_{n_G}\}$ and $E = \{e_1, \ldots, e_{n_E}\}$ – the set of predicates for accordingly input variables and events; $W = \{w_1, \ldots, w_{n_W}\}$ – the set of program works, which are performed by the agent during transition process from one state to another, also in some state before transition; s_0 and s_m – the initial and finite states, y_0 – the values of the variables in the initial state s_0. During the agents interactions, each message leads to corresponding event creation. These messages are processed in the order of their queue.

Unlike [17], the model is used for describing of program system functioning that is why we subdivided the variables to input and output and added the set of works W in the model. The usage of the predicates is also different from [17]. The predicates for the input parameters define

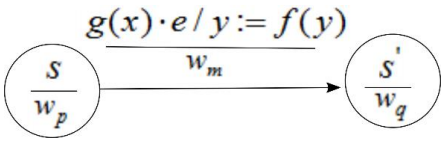

Figure 2. Transition function.

the agent type and regulate the arcs transition according to this type. Event predicates are responsible for the moment of transition.

The transition function (Figure 2) includes logical expression which contains the following constituents: the variables predicate $g(x) \in G$ and the events predicate $e(\sigma) \in E$, the function $f(y)$ of the y vector change and the agent work $w_m \in W$ (program actions), the running of which is performed during the transition process (in case of logical expression validity) to the next state.

The predicate $g(x)$ is a logical expression defined on the input parameters vector. For example, for the Boolean vector (x_1, x_2) with values (0, 1) the predicate $g(x) = \bar{x}_1 \cdot x_2$ would be «truth». The predicate of the event becomes "true" in case of the event appearance with number k, becomes "false" otherwise, and for brevity is denoted by e_k. For example, if the agent message comes from the message queue having number 5 (σ_5 event appearance), all the e_k predicates if $k \neq 5$ would be "false". At least one part of the logic expression ($g(x)$ or e_k) must present in the transition function. The symbol · indicates the operation of conjunction. In some states, particular program actions must be performed before the transition to another state independent of events appearance. This work is noted in the vertex of transition graph corresponding to this state (Figure2).

The graph of FSMwVW transitions of distributed solver agents is shown in Fig. 3. FSMwVW has seven states s_0, s_1, ..., s_6 described in Table. 1. The agent has an internal memory in which its state and working variables are stored. The state of the agent is encoded by three Boolean variables that specify the mode of operation: forward wave (d), backward wave (b), joint actions ($\bar{b} \cdot \bar{d}$) and activation flag (a) of the computational module associated with the agent. The local computational model of the module and the message queue are stored in the

TABLE 1. Agent States

State	Meaning	Component value of the state vector		
		a	*b*	*d*
s_0	Initial state	0	0	0
s_1	Direct wave mode state	0	0	1
s_2	Backward wave mode state	0	1	0
s_3	Input parameters waiting state	0	1	1
s_4	Module running state	1	0	0
s_5	Finite state	1	1	1
s_6	Backup agent	1	1	0

TABLE 2. MESSAGES RECEIVING BY THE AGENT

№ of message	Message	Message type
1	The criterion of computability	1
2	The parameter value	1
3	The completion of the module	0
4	Zero computational field valuation	0
5	The confirmation of message acceptance	1
6	The time of message acceptance t_1 has elapsed	0
7	The time of input data waiting t_2 has elapsed	0
8	The backup agent is required	1
9	No backup agents	0
10	There are reserve agents	0
11	Join the direct wave	0
12	Join the reverse wave mode	0
13	Join the action mode	0

internal memory as well. Messages (Table 2) are divided into external (sent by other MAS agents) and internal (generated by nested agent subprograms). Unity and zero symbols are the type of the message in Table 2, respectively. The variables t_1 and t_2 in the table are parameters of the agent model and determine the timing interval.

The input vector $x = (x_1, x_2)$ has two components (n_x = 2). The component values are (1, 0), (0, 1), (0, 0) and (1, 1) are defined by three types of agents – initial, target, computational, and backup correspondingly. The output vector $y = (y_1, y_2, y_3)$ has three components (n_y = 3). The first one is installing in 1 in case of problem solving process failure. The second is installing in 1, in case of extensive input parameters detection during the backward

TABLE 3. AGENT WOKS.

Name	Program actions
w_1	Agent initialization, assignment the initial values to output variables
w_2	Change of CF values
w_3	Including of the module into the M^* group, sending the message with the sign of computability
w_4	Completion of the group M^* formation, sending the message containing parameters values
w_5	Including of the target module into the M^* group, backward wave mode initiation, sending the message with the sign of computability
w_6	Reduction of A_0 set, performing the w_4 action
w_7	Running of the module
w_8	Sending the message containing module output parameters values
w_9	Transference of the problem solution results
w_{10}	Transference of the output parameter y
w_{11}	Set received state, reduction of A_0 set, request to resend messages
w_{12}	Repeated message sending
w_{13}	Verification of the availability of reserve agents
w_{14}	Transference the request to join reserve agent

wave mode. The third is installing in 1 if the problem solution is found. The initial value (zero) of the vector y components is setting on the stage of agent initialization.

The vector y conversion functions consist in assignment value 1 to one of the vector components. The predicates $x_1 \cdot \overline{x_2}$, $\overline{x_1} \cdot x_2$, $\overline{x_1} \cdot \overline{x_2}$, $\overline{x_1} \cdot \overline{x_2} \vee \overline{x_1} \cdot x_2$, and $x_1 \cdot x_2$ set the rules of the transition arc selection for, correspondingly, initial, target, computational,

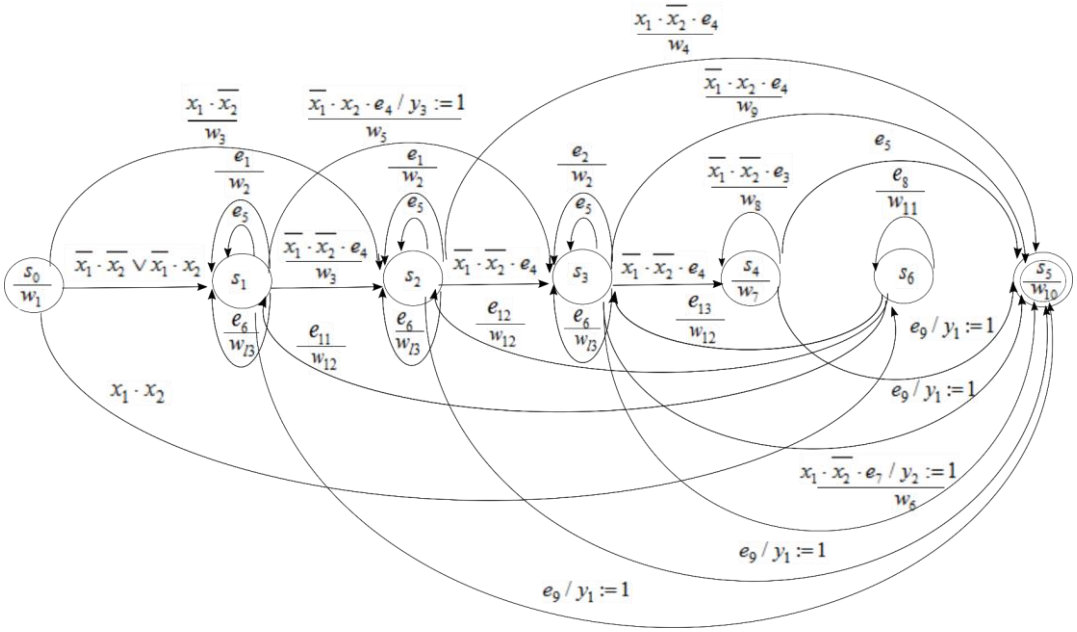

Figure 3. Transition graph FSMwVW of agent

computational and (or) target, and backup agents. The list of works performed at the transition process and at the vertexes of the graph is given in Table 3.

VI. THE SELF-ORGANIZED AGENTS NETWORK EXAMPLE

Let us demonstrate the offered approach to the organization of the process of computations decentralized management based on microservices and agent networks for the control synthesis in a binary dynamic system (BDS). This problem is important from the practical point of view and computationally difficult. The vector-matrix equation of this problem has the form

$$x^t = F(x^{t-1}, u^{t-1}), \qquad (1)$$

where $x \in B^n$ – the state vector, $B = \{0,1\}$, $u \in B^m$ – the input control vector, n and m – correspondently dimensions of state and control vectors, $t \in T = \{1,2,\ldots,k\}$ – discrete time (tact number), F (x) is a logic algebra vector function, called the transition function ($F : B^n \times B^m \to B^n$). For each state $x^0 \in B^n$ and finite sequence $u(t) = (u^0, u^1, \ldots, u^{k-1})$ of states of the control vector ($u^t \in B^m, t \in T$), we define the trajectory $x(t, x^0, u(t))$ of the system (1) as a finite sequence of states from the set.

Suppose two states $c^0, c^* \in B^n$ are given. We call c^0 – the initial state, c^* – the final (target) state. It is necessary to synthesize such control $u(t)$ (if it exists), which takes the system (1) from the initial $x^0 = c^0$ state to the final state $x^k = c^*$ in k tacts, i.e. c^* is attainable from the state c^0 after k tacts. It should be noted that this problem is currently one of the most important ones [18] to investigate the dynamics of the behavior of gene regulatory networks represented by a discrete time and state model (1).

From the theoretical point of view, the model (1) is essentially nonlinear, and existing methods of control theory are inapplicable to it. From a practical point of view, the control obtained can be useful for creating medicines for the treatment of diseases. Because of the essential nonlinearity of the system (1), we formulate of the control synthesis problem u (t) as the Boolean satisfiability problem. First, we note that the system of Boolean equations (1) is equivalent to one Boolean equation of the form

$$\Phi_k(x^0, x^1, \ldots, x^k, u^0, u^1, \ldots, u^{k-1}) = \\ = \vee_{t=1}^{k} \vee_{i=1}^{n} (x_i^t \oplus F_i(x^{t-1}, u^{t-1})) = 0, \qquad (2)$$

where x_i^t – is the i-th component of the vector x^t; $\oplus$ – addition modulo 2; F_i – the i-th component of the vector F. When $k = 1$ (only one-step transitions are considered), equation (2) takes the form

$$\Phi_1(x^0, x^1, u^0) = \vee_{i=1}^{n} (x_i^1 \oplus F_i(x^0, u^0)) = 0. \qquad (3)$$

Taking into account (3), we write equation (2) as

$$\Phi_k(x^0, x^1, \ldots, x^k, u^0, u^1, \ldots, u^{k-1}) = \vee_{t=1}^{k} \Phi_1(x^{t-1}, x^t, u^{t-1}).$$

Then the necessary control $u(t) = (u^0, u^1, \ldots, u^{k-1})$ (if it exists) is a solution of the Boolean equation

$$\Phi_k(x^0, x^1, \ldots, x^k, u^0, u^1, \ldots, u^{k-1})\Big|_{\substack{x^0 = c^0 \\ x^k = x^*}} = 0. \qquad (4)$$

We represent the conditions $x^0 = c^0$ and $x^k = c^*$ in the form of Boolean equations. Then (4) takes the form

$$\vee_{i=1}^{n} (x_i^0 \cdot \bar{c}_i^0 \vee \bar{x}_i^0 \cdot c_i^0) \vee \Phi_k(x^0, x^1, \ldots, x^k, u^0, u^1, \ldots, u^{k-1}) \vee \\ \vee [\vee_{i=1}^{n} (x_i^k \cdot \bar{c}_i^* \vee \bar{x}_i^k \cdot c_i^*)] = 0,$$

where the subscript i denotes the number of the components of the vectors x^0, c^0, x^k, c^*.

The considered problem in the illustrative example is solved for such systems (1), where vector-function F can be represented in the ".cnet" format [19]. Control sequence length is restricted by value five. Agents network of the distributed solver based on offered approach is shown in Fig. 4. To solve the problem $T = (A_0, B_0)$ on the distributed KB it is necessary to find the required for its solving set $M^* \subseteq M$ of modules installed on available CF nodes in dependency of relations fixed in the agent's local databases (black arrows) and to organize the decentralized management of their execution to obtain $B_0 \subset P$ parameter values from the set $A_0 \subset P$ of given parameters values. For the following non-procedural problem formulation $T = (\{\text{VFcnet}\}, \{\text{CSL2}, \text{CSL4}\})$ the self-organization-based active group of agents $Ag^* \subset Ag$ ($Ag^* = \{Ag_1, Ag_4, Ag_6, Ag_8\}$) are formed as result of the distributed logical inference method on the KB. Agents of this group run their modules using event-driven control ("on the readiness of data"). The correspondent set $M^* \subset M$ includes modules obtained as a result of the RMDI process:

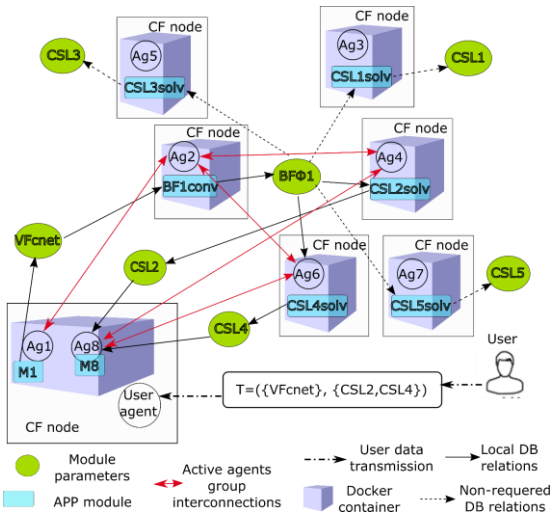

Figure 4. The distributed solver.

$$M^* = \{\text{Ml}, \text{BFlconv}, \text{CSL2solv}, \text{CSL4solv}, \text{M8}\}.$$

These modules intended for the following actions. Initial module M1 sends the vector-function F from (1) represented in the .cnet format (parameter VFcnet). CBF1conv module converts F to Boolean function Φ_1 from (3). CSL2solv and CSL4solv modules create Boolean functions Φ_2 and Φ_4 for $k = 2,4$ and solve the correspondent SAT problems for equations (4). Asynchronous parallel execution is possible for these modules. M8 receives the results that are the control sequences of required length k (parameter CSLk), if SAT problem is satisfiable and conclusion "No control" in another case.

We tested the distributed solver on examples [18, 19] and randomly generated examples of more dimensions. Computational experiments were conducted using computational resources [20] and confirmed the effectiveness of the developed approach. We compared the computational cost of solving the problem T on the computational model KB using centralized and decentralized control schemes for modules execution. The execution time of the computational modules is the same for both control methods, whereas the overhead for module intercommunications by messaging using the agent network is on average half as large as when using a central node to control the solution of the problem.

VII. Conclusion

We offered a new approach to the intellectualization of decentralized collective management based on direct interactions of agents for solving the non-procedural problem formulations on a distributed computational model of the subject area. We developed a new discrete-event model of the dynamics of the functioning of agents and created tools to automate the use of this approach. We demonstrated this approach using the example of creating a distributed solver for the problem of synthesizing control in a binary dynamic system. An example of such systems is a binary synchronous automaton, which is a model of many discrete devices in control systems, computer technology, telemechanics, etc. The widespread use of binary dynamic models in scientific and applied research determines the relevance and practical significance of the offed technology.

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DATA ENGINEERING AND PROCESSING

A Framework for Dynamic Data-Driven User Interfaces

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***Abstract* - A user interface tailored to the specific needs of individual installations and swift fulfilment of user requirements contribute to the level of user satisfaction. Both can be achieved using dynamic user interfaces. The proposed framework consists of a module for data structure definition and a designing module in which graphical components can be bound to the data and assembled into user interfaces using drag-and-drop, while a built-in rule engine enables additional operations. It allows the end user to define the data model and design the corresponding input forms and reports. It is especially beneficial in cases where there is a need for frequent changes in the data structure and the graphical layout. Such an approach saves time and enables the development and modification of application modules without the involvement of programmers. The framework has been applied successfully for report generation, creating the medical documentation and modeling business processes in several domains.**

Keywords - dynamic user interfaces; data-driven user interfaces; dynamic data models

I. INTRODUCTION

Most applications are developed to support a static data model because the structure of the data is known in advance and the changes in the database schema are relatively rare. However, there are cases when a static data model is not a feasible solution.

For example, if the structure of the data collected into certain database tables differs from one client to another, new fields need to be added for each client that requires the attributes not previously used. The user interface also needs to be altered to support the new fields. However, for the clients that don't use these additional fields, the user interface becomes cluttered with unnecessary elements. The usual solution is parametrization and the toggle of the elements' visibility based on the parameter value. In many cases, this expands to handling not only the visibility but also some other properties based on the parameters, such as whether or not the field is required for entry. With the increasing number of such fields, the complexity of the code increases, even though the table and the form were originally simple. Interventions on such code become complex and time-consuming, resulting in slow fulfilment of user requirements and, consequently, lower user satisfaction.

A static data model is also problematic when numerous classes of data need to be represented, but the number of instances of each class is small, or when data are sparse and have a large number of applicable attributes, but only a small fraction will apply to a given entity [1]. Static models are also ineffective in scenarios which require frequent changes in the data structure or a large number of similar database tables.

Biomedical data are an example of data which are difficult to maintain using conventional database tables because they are highly diverse, sparse, heterogeneous and require frequent schema changes [2, 3]. In addition, database architectures are often designed to support single clinical applications and are not easily modified to meet the needs of all end-users [4].

An efficient way of solving these issues is to develop a dynamic data model which allows the end user to define the structure of the data.

Such a data model also implies the need for a dynamic user interface. Any changes in the data structure need to be reflected in the user interface in order to enable the input and output of the data.

Dynamic user interfaces solve another problem. In development of medical information systems, it is usually necessary to create a large number of different, but somewhat similar, graphical user interface forms and database tables corresponding to different medical data, which can be inefficient and time consuming [5]. The use of dynamic user interfaces expedites this process as well as simplifies customization. User interfaces that support customization and data validation play a decisive role for user acceptance and data quality [6]. Customization is desirable in medical information systems because of the specifics of the processes in different healthcare organizations as well as country-specific differences in the administrative parts of the system [5].

The proposed framework for dynamic data-driven user interfaces consists of a module for data structure definition and a designing module in which graphical components can be bound to the data and assembled into user interfaces using drag-and-drop.

II. DATA STRUCTURE

In order to support a dynamic data model, one database table is needed for storing the definitions of custom data structures, and another for storing their fields. The term "data source" is used for these custom data structures which replace conventional database tables.

Data source fields often represent a reference to another table or a custom data type with its own set of rules. For this reason, instead of defining fields by the usual data types, fields are defined by custom field types

called items. A similar approach is used in [7], with archetypes which represent specific clinical concepts with constraint rules, used to ensure data quality.

Fig. 1 shows the main database tables used.

A. *Items*

Items are the basic elements of the data structure. The first step of the process is the creation of items so that they can be assembled into more complex data structures, the data sources.

Predefined items are the ones that represent the basic data types such as integer, decimal, datetime, character, string and richtext. In addition to the predefined items, users can define their own items.

The main features of an item are a code, a name, a data type, an item type, a size and a description. Item type can be basic, external or universal codebook. *Basic type* means that the item is one of the predefined items. *External type* means that the item references a database table from the business system in which the framework is integrated. It enables the data sources to contain data from the other parts of the system. Universal codebooks enable the user to define a list of possible values for the item, making the item an equivalent to a codebook table.

Universal codebook database table contains definitions of different codebooks, while the universal code table contains all the codes and their names with a reference to the codebook they belong to. This allows the user to easily input new codebooks and codes, without the need for adding new tables into the database or creating new input forms. Codes and codebooks can be arranged hierarchically, meaning that a code may be assigned a base code from its codebook's base codebook. In that case, a field's possible values are restricted by the value of the field bound to the base codebook. Codes and codebooks can be deactivated if they are no longer used.

It is possible to input referent values for a specific item, which is commonly used in medical applications, as well as to define any other additional data. Items can be grouped into classes as well as deactivated if necessary.

B. *Data Sources*

The basic attributes of a data source are a code, a name and a description. Each data source consists of several fields. A field, with its code and name, is defined by the item it is associated with, so the items act as field types. The same item can appear in the same data source multiple times, as long as the field code is different, and the same item can be used in multiple data sources.

Records that are created based on the data source structure, called documents, are all stored in the same table, with a reference to the data source they belong to. Another table holds the documents' fields and their values, with a reference to a specific document. Like in the entity-attribute-value (EAV) model, each row contains an attribute and its value for a certain document, while attributes with empty values are not stored. The EAV model is increasingly used for knowledge representation for complex heterogeneous biomedical databases [8]. It allows for highly sparse data to be stored in a compact way [9].

In this context, data sources can be viewed as document types or schemas, defining which attributes a document may have and providing a way to validate the

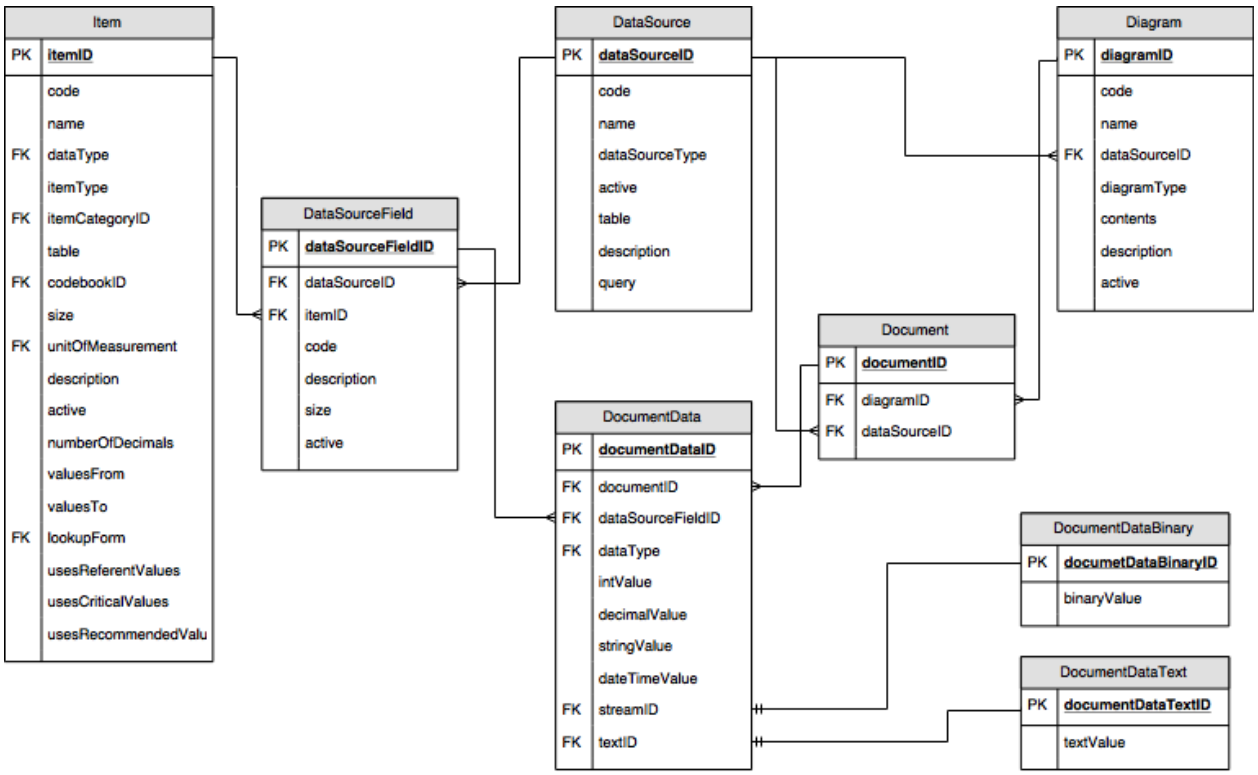

Figure 1. Database diagram

contents of the documents tables.

The database table with documents' fields' values usually has a large number of rows because it contains data from all of the data sources. It also has a vertical schema, with fields in rows instead of the columns. As a result, the queries directed at it are complex and slow. In particular, queries in which the criterion is based on the value of a field are most likely to show impaired performance [3]. In order to solve this issue, when a data source is created, a new table is automatically generated in the database. The columns of the table correspond to the fields of the data source. These tables provide a quicker and easier access to data and are used in queries instead of the document data table.

In addition, SQL data sources can be created. An SQL data source contains an SQL query and its fields are generated automatically based on the columns in the select list. Database tables are not generated for these data sources as they are only invoked in order to fetch the data and not to store it. It is possible to include parameters in the queries.

III. USER INTERFACE

A. *Designing*

The designing module enables the creation of user interfaces for the input and output of the data, called diagrams. The module is shown in Fig. 2. The screenshot is in Croatian and it displays the work surface with a palette of symbols on the left and a property editor on the right.

A code, a name, a type and a data source are specified when creating a diagram. The type of a diagram is either a form or a report, while the data source specifies the data structure that is to be input and/or output using the diagram. A diagram may use several data sources along with the main one. The same data source can be used in multiple diagrams.

The center of the designing module is the work surface which represents the user interface. It is derived from the Diagram control and consists of a model, a view and a controller. The model is a collection of the diagram's nodes, the view handles the visualization of the model and the controller handles user interaction.

A PaletteGroupBar control contains various icons representing graphical components of the user interface, including labels, checkboxes, buttons, radiobuttons, textboxes, grids, graphs, etc. Each icon is bound to a specific component upon initialization. A component is a platform-independent representation of a graphical control.

The icons can be added to the work surface via drag-and-drop. When an icon representing a specific component is dropped onto the work surface, the action is handled by the diagram's controller and the corresponding node is added to the diagram's model. The correlation between components and nodes is defined in the diagram generator class, as well as the correlation between nodes and the controls displayed on the work surface to represent them. When a node is selected, its properties can be edited in the PropertyEditor control. The properties are synchronized with the component's properties.

A component is usually bound to a specific data source field. It is also possible to drag-and-drop the fields of the chosen data source, in which case the graphical component is generated based on the field type and automatically bound to the field.

Groups of components, such as panels and tab controls, can be assigned their own data source, different to the data source of the diagram. That data source may be an SQL data source which retrieves data and displays them as the values of the components contained in the group based on the field they are bound to. The grid and the chart components are always assigned SQL data sources so that they can display the results of the query at runtime. Parameters that the query requires can be bound to the fields of other data sources used in the diagram so that, for example, the query fetches only the records that

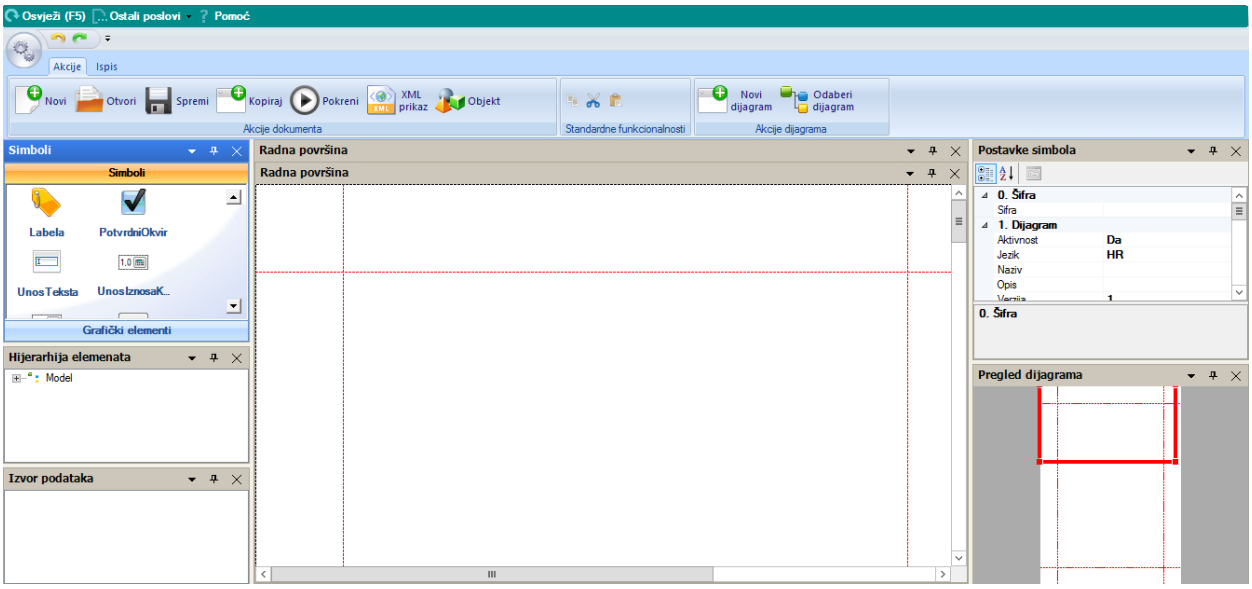

Figure 2. The designing module

reference the current document. The grid component also supports drilldown tables, so a different data source may be assigned to each table in the grid.

If it is necessary to define what happens when certain events are raised, the built-in rule engine can be used. It allows the creation of rules with conditions, "then actions" and "else actions". For example, a rule can be created in order to compute the value of a field based on the value of another field. A ruleset can contain several rules with priority indicating the order of execution. The rule engine also supports loops.

The grid can be used for data entry as well. The way the data are stored into the database is defined through the rule engine. This means that the same diagram can be used for input into multiple data sources, which are usually in a hierarchical structure, with the main data source representing the header of the document and the subordinate data sources representing the records of the document.

When a diagram is saved, an XML document describing the diagram's contents is generated and saved into the database as its attribute.

Existing diagrams can be loaded into the designing module. XML is deserialized into components and nodes are generated and added to the work surface based on the components. Diagrams can then be edited as well as copied so that a new version with alterations can easily be created. Diagrams can be exported into an XML file along with all related data, which enables them to be imported into another database.

B. Usage

Diagrams are independent of the platform and can be invoked on both the Web and the Windows platform. Based on the currently used platform, the corresponding generator handles the generation of graphical controls based on the components listed in the diagram's XML.

A document object is generated first, whether it is an existing document retrieved from the database or a new one that hasn't been saved into the database yet. When creating a new document, a data source must be specified in the constructor. A document object contains a collection of fields with their values.

The report generator class handles the report diagrams. It receives the document object as a parameter, refreshes the used data sources, executes the rules defined for the before print event and deserializes the diagram's XML into components. The next step is the generation of the corresponding report controls based on the location, size and other properties of the components. The result is a report object which can be shown in a print preview screen, sent to a printer or exported into a file.

Documents associated with form diagrams are hosted in the diagram display control. They can be embedded into existing forms or included into the system as separate forms, in which case a host form, which contains only the diagram display control, is invoked. When a document is passed to the diagram display control, the form generator is invoked. Like the report generator, it refreshes the used data sources and deserializes the diagram's XML into components. Based on the components and the current platform, graphical controls are generated and displayed.

If SQL data sources are used in the diagram, the query is executed upon loading the diagram and data are populated into the corresponding components and then into the controls. Calling the refresh method on a group of components results in another query execution.

The values of the document's fields are synchronized with the components' values and the component's values are synchronized with the controls' values. The synchronization works both ways when it comes to form diagrams, so when the user changes the control's value, the change is reflected in the component's value and in the document's field's value.

When the document is saved, the values of the fields are saved both in the general database table for document field values and the table that belongs to the corresponding data source. Log tables enable tracking the changes in the data.

Documents can be integrated into the existing documentation system by defining a new document type and binding it to the corresponding data source. This allows the defining of a form diagram for input and a report diagram for output, as well as using the standard documentation configuration such as defining organization units in which the document type can be used, its statuses, status transitions, required authorization, field configuration depending on document status, etc.

IV. FRAMEWORK APPLICATION

The framework has been applied successfully for the creation of medical documentation. It was developed within the company Laus CC, Dubrovnik, Croatia, using C# on the .NET platform, and integrated into the company's business system. Syncfusion's Essential Diagram Controls were used to create the designing module. The lead author of this paper was a member of the development team.

The motive was the large influx of user requirements regarding the development of medical documentation [10]. A large number of database tables, forms and reports needed to be created to support different types of documents. There was also the need for frequent changes and additions in the data structure and the graphical layout and their adaptation to specific installations. The framework, named DoRa, provided an effective way to handle these requirements.

Without the framework, a separate database table, input form and report would have to be created for every type of medical document and, in most cases, for each item within the document. The framework enables the end user to create new data structures and modify the existing ones, without the need for direct interventions in the database. The large quantity of diverse and sparse data is stored in an efficient way. The user can also create and modify the user interfaces directly through the application. This approach has proven to be significantly faster, with the development of the original set of document types being completed in under two months, while the earlier

development which used the conventional approach lasted for a year.

The framework has since been expanded and optimized. While [10] describes the initial version, this paper provides a more detailed view and describes additional features such as SQL data sources, the rule engine, platform independence, the ability to add multiple data sources to the diagram to support more complex data structures, and the automatic generation of database tables that provide a quicker and easier access to data.

An example of a document created using the framework is shown in Fig. 3. The document is used for the input of the gynecological medical history of the patient and it is a part of a module for monitoring medically assisted reproductive treatments.

User requirements for new document types and alterations on existing document types are fulfilled more quickly and without the involvement of programmers. Programmers can focus on more complex tasks while other employees handle the creation and modification of simple data structures, forms and reports.

The framework provides an effective way of developing multiple versions of forms and reports in order to adapt to the needs of specific installations. Additionally, since the diagrams are platform-independent, the need for developing separate forms for different platforms is eliminated.

All of the elements created within the framework are fully integrated with the rest of the system, without visible differences to the end user. New features are easily transferred to the clients without the need for the release and the delivery of new software versions.

Another advantage is that all data are structured, which makes it possible to search and analyze them. A search module was developed which enables the user to create query conditions by choosing fields and required values in order to retrieve the documents that match those conditions. It is used for extracting data from the medical documentation for the purpose of research.

V. Conclusion

In this paper, a framework for dynamic data-driven user interfaces is described. The framework not only simplifies the process of creating, modifying and customizing data structures and user interfaces, but also provides a platform for executing these actions without the knowledge of programming. It saves time and resources, and as a result, user requirements are fulfilled rapidly, contributing to user satisfaction.

The framework was also used extensively for report creation in other domains, allowing for quick generation of numerous reports without programming. Examples include the generation of sales recapitulation reports and export of procurement documents. In these cases, the data structures are not contained within the framework. The framework is integrated into the existing business system and SQL data sources retrieve data from standard database tables in order for the diagrams to display the data. This allows the framework to be used for report generation in any domain.

Regarding the platform-independence, the framework was used for the export of student administration documents for academic institutions on both the Windows and the Web version of the application. The same diagrams are used on both platforms.

Other than documentation creation, the framework is successful in the production of complete application modules with complex data structures and modeling various business processes. Examples include a surgery

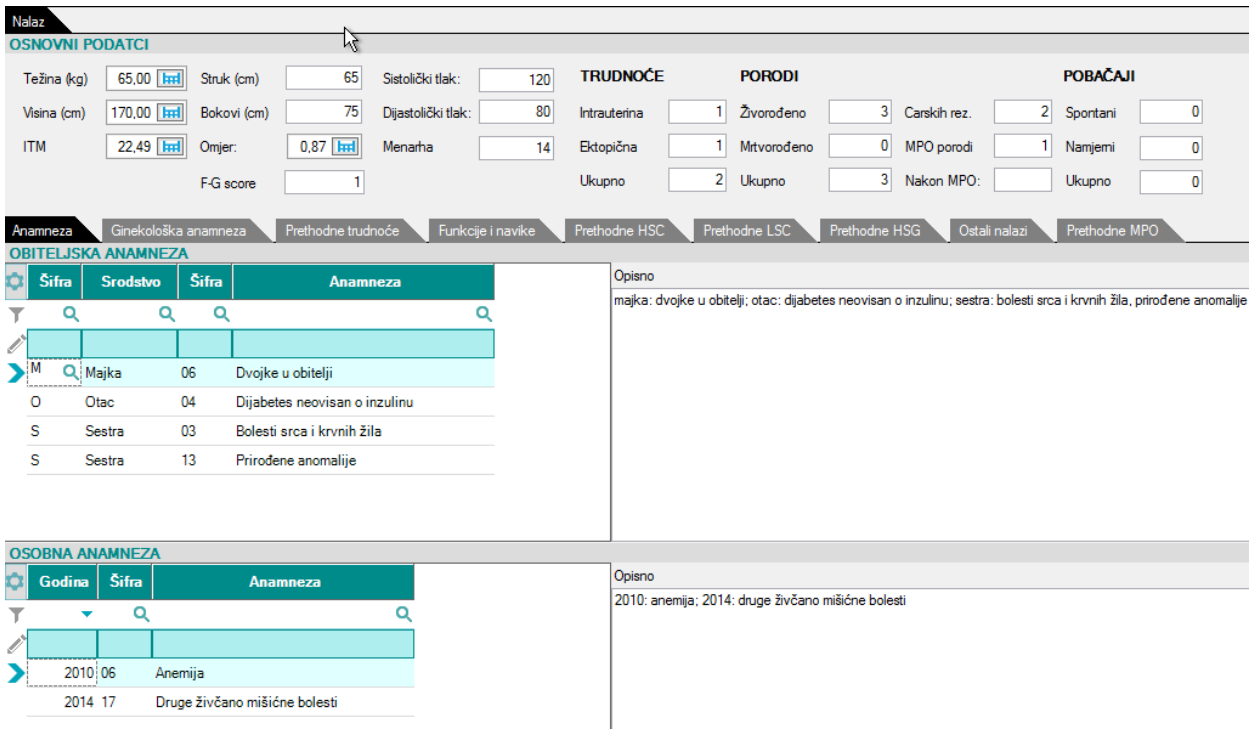

Figure 3. Medical document created using the framework

management module, a module for monitoring medically assisted reproductive treatments and a human resources module for candidate selection.

The speed and simplicity of the development also make the framework efficient for the creation of prototypes.

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NoSQL Approach for Sensor Data Storage and Retrieval

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***Abstract* - The sensor data is heterogeneous, redundant, real-time, massive, streaming and is generated in high frequency. The increasing use of sensors leads to a rising demand on sensor data storage platforms. Appropriate data management is therefore, a key factor in making sure that the sensor data storage system becomes a reality. In this article we will focus on finding a data storage solution that is capable of storing huge amount of sensor data. The storage models in SQL and NoSQL databases are analyzed and compared, thus seeking an appropriate type of database for sensor data storage. Hypertable is identified to be the database that best suits the system requirements. It is therefore investigated how to implement the sensor data insertion and retrieval services. Query processing over distributed databases is more challenging than doing so in a centralized environment. Because NoSQL databases do not work with SQL, they require manual query programming which can be fast for simple tasks but time-consuming for others. This paper considers the extension of Hypertable query language with aggregate operations and describes the implementation of the query language interpreter.**

Keywords - sensor data; data storage; NoSQL data models; database management system; data insertion and retrieval services

I. INTRODUCTION

Sensors are used to monitor certain aspects of the physical or virtual world and databases are typically used to store the data that these sensors provide. To provide raw data for information systems, sensors regularly collect signals of heat, power, light, sound, speed etc., thus revealing the status of the surrounding environment. These signals are sensor data, which in the real-time applications has the following four characteristics [15]:

- *Sensor data is heterogeneous*. The type and functions of sensors are diverse and different type of devices monitor various indices;
- *Sensor data is redundant*. The state of the sensor-monitored environment is unstable. I.e., the temperature of a room may remain unchanged or float a little (5 minutes in common situations). Since sensors collect information in seconds, storing this data in database will cause quick growth, heavy load and disrupted performance;
- *Sensor data is real time data* and is collected over time. Processing the sensor data in time can bring benefits to the IoT. I.e., a timely detected exception can help operators make faster decision hence reducing the loss.
- *Sensor data is massive and streaming*. As the production cost of sensors comes down, more and more sensors are applied to detect complete environmental information. Meanwhile, sensors are set to collect large amount of data in seconds, generating and streaming it to the Internet.

The surveys presented in [8], [13], [19] demonstrate different visions of sensor data storage paradigm and enabling technologies. Meanwhile, the storage models in SQL and NoSQL databases are analyzed and compared, trying to seek an appropriate type of database for sensor data storage. These studies consider the challenges brought by the need to manage vast quantities of data across heterogeneous systems therefore, discussing the areas of querying, indexing, process modelling, transaction handling and the integration of heterogeneous systems. The studies also discuss the key enabling technologies and application domains which are likely to drive sensor data storage research.

The main objective of the current analysis is to propose an approach, which can handle heterogeneous workloads with structured, semi-structured and unstructured data from many and dissimilar sources. To that purpose, we focus on the challenges addressed to the sensor database management and the implementation of insertion and retrieval services. In this article we will focus on finding a data storage solution for storing huge amount of sensor data, along with identifying an extension of the query language to both insert and retrieve this data in a fast manner.

The rest of this work includes the following: Section 2 presents some use case examples of sensor data. Section 3 surveys sensor database management issues. The architecture of insertion and retrieval services, as well as the extension of Hypertable query language with aggregate operations are considered in Section 4. Some related to Hypertable DBMS projects are discussed in Section 5. Finally, we conclude our work in Section 6.

II. USE CASE EXAMPLES OF SENSOR DATA

The goal of an Energy Management System is to monitor energy consumption of household and store energy consumption data in a database [16]. The system aims to aggregate measures collected by sensors in a

specific environment (i.e. a home) and to share them in a bigger context. The data is used for various purposes ranging from displaying households' current energy consumption to providing intelligent advice on efficient energy use based on historical data. The development of an Energy Management System lays on smart metering energy performance models, which analyze the way of consumption and the level of power usage. To achieve these performance models, energy monitoring brings together sensor data from critical areas, such as appliance performance. As sensor readings are expected to occur from various sources, it is expected that the generated data collection is essentially a very large database that supports storing and generating statistical measures on sensor data. Sensor reading data comes from various sources: energy meter systems and supporting sensors or directly from appliances and services in the building. This data must be stored and analyzed against business intelligence to provide statistical and practical information to the managers. Extensive use of sensors for thermal, lighting, and appliance energy use will deliver granular measurement, establishing a prospective business case for sensor deployment. These cases demonstrate the level of savings enabled through more accurate measurement, balanced against the costs of deployment and operation.

In order to attain effective collaboration, the information about the product life cycle must be captured and administrated in a way that supports the decision taken during the product development. In this context, the manufacturing process information needs to be shared between manufacturers. The moulding process is quite complex involving many variable process parameters like pressure, temperature and time settings [17]. These process parameters must be optimally set in order to improve part quality and maximize the production capacity of the injection moulding machine. All activities along the value-adding chain can be supported by a web-based platform to coordinate all forms of forward and backward collaboration. At the same time, the platform accesses the data collected by the smart tools and the customers' production facilities. Smart tools are injection moulds equipped with state-of-the-art sensor technology that delivers real time data from the production process. The on-line analysis of the gathered data enables an optimized mix of both condition-based and preventive maintenance services. This directly leads to an increase of the overall operational availability of the production cell. To monitor the production process, algorithms and methods for the intelligent interpretation of the gathered data are developed. Thus, allowing the simulation of different scenarios forecasting the tool's further behavior in operation. Based on those forecasts, the toolmaker can interpret in real time errors and downtimes.

Inferring air quality in urban areas, i.e. cities, has become recent success in sensor data systems. Air pollution is a widespread problem in many cities as poor air quality poses risks to human health. Particularly to people suffering from cardiovascular illnesses and to young children whose lungs are still developing. The aim is to provide real-time and fine-grained air quality information to people, therefore guiding their daily decision-making. This problem is very challenging especially in urban areas, where air quality is affected by multiple complex factors. These include meteorology, traffic volume, land use, and urban structures [11]. Another growing trend for sensor data systems are mobile healthcare applications with increased appearance of various wearable sensors to measure types of health conditions i.e. temperature, heart rate, blood pressure, pulse oximetry, electrocardiogram. This use of sensor-based technology is progressively seen as a solution to support assistive living.

III. Sensor Database Management Issues and Query Processing

The rapid increase of sensor usage nowadays leads to high demand on sensor data storage platforms. The vast quantity of data provided by the sensors is essential feature of the sensor monitoring applications. Appropriate data management is therefore, a key factor in making sure that the sensor data storage system becomes reality [10].

A sensor data management system is divided into an online real-time front end that interacts directly with the interconnected sensors and an offline backend that handles the mass storage and in-depth analysis of sensor data [3].

Relational database management systems (RDBMS) work best with structured data. Query operations are usually local, with execution costs bound to processing and intermediate storage. Transaction management mechanisms guarantee the atomic, consistent, isolation and durable (ACID) properties to enforce overall data integrity. Even if the database is distributed over multiple sites, query processing and distributed transaction management are enforced. The execution of distributed queries is based on the transparency principle, which dictates that the database is still viewed logically as one centralized unit, and the ACID properties are guaranteed via the two-phase commit protocol. The sensor data that needs to be stored is immutable. This eliminates the need for transactions to keep values consistent when updating. Thus, an ACID compliant database is not needed. The sensor data is also simple, i.e. there are no complex relations or inheritances between different entities, so a relational or object-oriented database is not warranted either.

RDBMSs cannot meet the challenges of the next generation real-time applications for the following reasons [7], [18], [19]:

- With RDBMSs, users must convert all data into tables. When the data doesn't fit easily into a table, the database's structure can be complex, difficult, and slow to work with;
- RDBMSs don't work easily in a distributed manner because joining their tables across a distributed system is difficult. RDBMSs don't scale out when joins are required;
- Sharding over many servers can be done but requires application code and will be operationally inefficient. It can be difficult to store high-variability data in tables.

In response to the growing awareness of relational databases' limitations, vendors and users are increasingly turning to NoSQL systems. NoSQL systems provide storage of data on multiple processors and maintain high-speed performance. Most of them leverage low-cost commodity processors that have separate RAM and disks, this way supporting linear scalability. NoSQL systems allow users to extract data using simple interfaces. They store and retrieve data from many formats [1], [4], [7], [21]:

- *Key-value stores* are the simplest NoSQL data stores that use a key to access a value. The value is a blob that the data store just stores, without caring or knowing what is inside; it is the responsibility of the application to understand what was stored. Since key-value stores always use primary-key access, they generally have great performance and can be easily scaled.

- *Column-family databases* store data in column families as rows that have many columns associated with a row key. Column families are groups of related data that is often accessed together. Each column family can be compared to a container of rows in an RDBMS table where the key identifies the row and the row consists of multiple columns. The difference is that various rows do not have to have the same columns, and columns can be added to any row at any time without having to add it to other rows.

- *Document databases* store hierarchical data structures directly in the database. Documents are the main concept in document databases. The database stores and retrieves documents i.e. XML, JSON, BSON etc. These documents are self-describing, hierarchical tree data structures which can consist of maps, collections and scalar values.

- *Graph databases* provide means to store entities and relationships between these entities. Entities are also known as nodes, which have properties. Think of a node as an instance of an object in the application. Relations are known as edges that can have properties.

Many of the NoSQL databases are based on the Distributed Hash Table (DHT) model [9], which provides hash table access semantics. To access or modify any object data, the client is required to supply the primary key of the object, then the database will look up the object using an equality match to the supplied key. Although, query processing and indexing technique is quite common in RDBMS world, it is seriously lacking in the NoSQL world because of the very nature of the "distributed architecture" underlying most of NoSQL databases [24]. Some of the NoSQL DBMSs provide indexing and query processing mechanism within the local database. In this case, the query processor broadcasts the query to every node in the DHT where a local search is conducted.

B+Tree is a common indexing structure used in relational DBMS [12]. A distributed version of B+Tree can also be used in a DHT environment. The basic idea is to hash the searchable attribute to locate the root node of the B+ Tree. The "value" of the root node contains the id of its children node. So the client can then issue another DHT lookup call to find the children node. Continuing this process, the client eventually navigates down to the leaf node, where the object id matching the search criteria is found. Then the client will issue another DHT lookup to extract the actual object. Trie is an alternative data structure, where every path (from the root) contains the prefix of the key. Basically, every node in the Trie contains all the data whose key is prefixed by it. This mechanism is described in [24].

Aggregations in column-oriented NoSQL DBMSs (BigTable, Hypertable and CouchDB) can only be implemented with the usage of MapReduce functions. BigTable and Hypertable allows to use Google's MapReduce framework on it, which can use BigTable and Hypertable as data input source and output target [23]. In contrast to this, CouchDB's incremental MapReduce system stores the results of MapReduce tasks as index which is incrementally updated whenever a document is written. A MapReduce task on something like BigTable might not be well suited for real time tasks. That is why the typical use case of non-incremental MapReduce is batch processing, which can be done periodically. This kind of MapReduce is more suitable for large data warehouses, with more complex calculations, which do not require to be always up to date.

IV. Using Hypertable as a Sensor Database Management System

The column-family data model is the best NoSQL data format to store time series data in a sensor data storage system. This allows the structuring and semi-structuring of the collected dataset. In record-oriented (relational) storage systems, the attributes of a tuple are placed in contiguous storage. With row-store architecture, the writing of a single disk is sufficient to push all the fields of a single record out to disk, thus achieving high performance writes. A DBMS with row-store architecture is called a write-optimized system [7], [21]. However, systems oriented toward querying a large amount of data should be read-optimized. In column-store architecture, values for each single column (or attribute) are stored contiguously, which is more efficient. A DBMS with column-store architecture needs only to read the values of columns required for processing a given query, thus avoiding bringing irrelevant attributes to memory. In data warehouse environment, where typical queries involve aggregates performed over large numbers of data items, a column-store system has a sizeable performance advantage.

Therefore, in a sensor data storage system, the implementation of a distributed data warehouse would be better based on a column-oriented NoSQL DBMS. We offer the use of Hypertable DBMS as a real data warehouse implementation. This decision was based on the requirements of the data model, the types of requests, the amount of data to be stored and the benchmarking results [5]. Hypertable DBMS offers the largest number of insert operations per second (on average) and a reasonable rate of scan operations. Considering that scan operations are supposed to be performed at a lower rate than are insert operations, Hypertable exhibits good performance; indeed, it could be considered as an option for the

distributed data warehouse implementation in the sensor data storage system.

Hypertable (see http://hypertable.com) is an open source, high performance, scalable DBMS modelled after Google's BigTable [4], [18]. Hypertable is designed to manage the storage and processing of information on a large cluster of commodity servers and is resilient to machine and component failures.

Hypertable stores data in a table sorted by primary key. Data is not typed into cells, but rather is stored as un-interpreted byte strings, as in BigTable [6]. Scaling is achieved by breaking tables in contiguous ranges and dividing them among different physical machines. Data is stored as **<key,value>** pairs. All revisions of the data are stored in Hypertable, so timestamps are an important part of the keys. The Hypertable data model is column-oriented, consisting of a multi-dimensional table of information that can be queried using a single primary key. The first dimension of the table is the row key. The second dimension is the column family. This dimension is somewhat analogous to a traditional database column. The third dimension is the column qualifier. Within each column family, there can be a theoretically infinite number of qualified instances. The fourth and final dimension is the time dimension. This dimension consists of a timestamp that is usually auto-assigned by the system and represents the insertion time of the cell in nanoseconds since the epoch.

The sensor data storage system is intended to work as a platform that provides access to the data for external third-party applications. The applications that will be built on top of the platform are not known in advance. It is therefore necessary to be able to provide the data in a general way that can be used for any kind of application that might want to use it.

The insertion and extraction Web services are based on Apache Web server using *mod_wsgi* package. The aim of *mod_wsgi* is to implement a simple to use Apache module which can host any Python application that supports the Python WSGI interface. The services were developed using ReSTful standard and latest innovative technologies. The architecture of the data insertion and retrieving Web services is presented in figure 1, where the outer layer of these services are the scripts *insert.wsgi* and *select.wsgi* implemented in Python.

The *ThriftBroker* provides an interface for applications written in any high-level language (Java, PHP, Ruby, Python, Perl, and C++) to communicate with Hypertable. The *select.wsgi* script translates the query in Hypertable Query Language format, starts the process ***Extended_hql_interpreter*** and returns the accomplished result of the query. The application ***Extended_HQL_Interpreter*** is an extension of the standard Hypertable HQL query language with added ability to react on data, most specifically in the SELECT statement.

It takes as an argument a query in ***Extended_HQL*** format, extracts the needed data from Hypertable DBMS, processes and returns the result in one of the following three formats: tsv, csv, json.

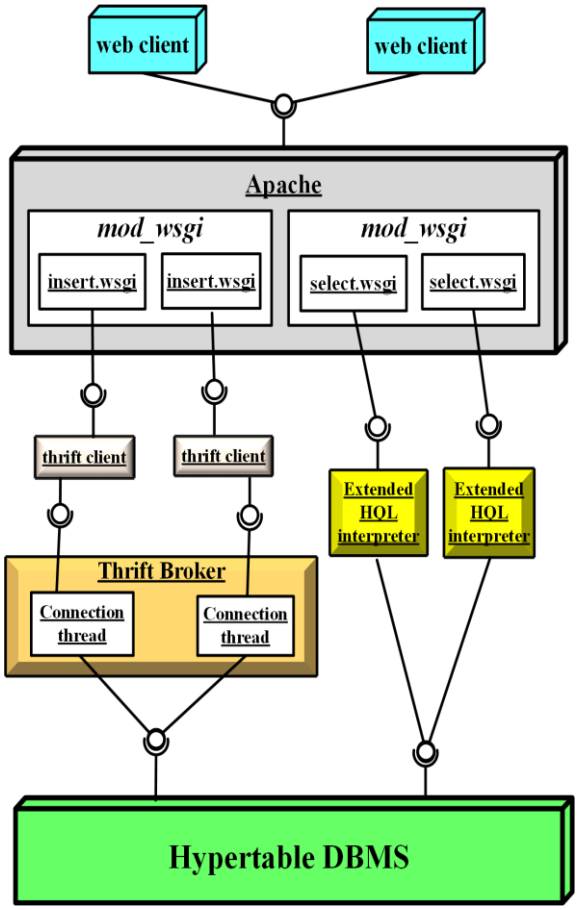

Figure 1. Architecture of the insertion and extraction services

The quantity of the simultaneously started entities of this process is constrained only by the operating system settings and the hardware potential.

The standard Hypertable Query Language (HQL) allows the user to create and modify tables, to query them, and to execute administrative commands. Extended Hypertable Query Language (EHQL) is an extension of the standard HQL. EHQL syntax allows the forming of queries with aggregate operations, therefore adds the aggregate functions SUM, MIN, MAX, COUNT, and AVG. Each of the functions takes two parameters – the column name for all columns (column qualifiers allowed) and the type of the data in the column (because the data in Hypertable is stored as uninterpreted byte strings). The number of the aggregations in one query is unlimited. The aggregating can be performed in groups by certain criteria – row key, timestamp, column (or column: qualifier) or time periods. The criteria can be combined.

The query processing implementation uses the Spirit interpreter, which is part of the Boost C++ library [22] and consists of four parts: lexical analyzer, scanner, match module and semantic action module. The parser is central to the framework and does the actual work of recognizing a linear input stream of data read sequentially from start to end by the scanner. The parser attempts to match the input following a well-defined set of specifications known as grammar rules, therefore it reports the success or failure to its client through a match object. When successful, the

parser calls a client-supplied semantic action. Finally, the semantic action extracts structural information depending on two things: The data passed by the parser and the hierarchical context of the parser it is attached to. Like the parser, the scanner is also an abstract concept. The task of the scanner is to feed the sequential input data stream to the parser. The scanner is composed of two STL conforming forward iterators, first and last, where first is held by reference and last, by value. The first iterator is held by reference to allow re-positioning by the parser.

The EHQL interpreter has the same conceptual model, as the Hypertable Query Language interpreter (figure 2). The interpreter creates and uses an instance of the *Ehql::Parser* class, which is basically the same as the *Hql::Parser* class. The *EhqlCommandInterpreter* class is used from the *CommandShell* class to process the parsed query. The *CommandCallback* instance holds a reference to the command interpreter and user methods that correspond to the events, triggered by the interpreter (on return, on progress, on finish, etc.).

The both objects of the *EhqlInterpreter* and *EhqlCommandInterpreter* classes hold reference to the Hypertable client object, which is used for multiple purposes, such as connection to the DBMS, management of the namespaces, etc. The client class uses objects from numerous classes from the Hypertable namespace, like *ConnectionManager* (builds and maintains TCP connections), *RangeLocator* (finds the range server, which contains the proper cell, identified by row key), *Comm* (provides communication services via message exchange), *Mutex* (provides synchronization means), *MasterClient* (provides access to the Master service).

The *EhqlParser* class inherits the public interface of the Spirit grammar and defines an inner structure named definition, in which all the rules, of which the grammar consists, are described. The aggregation of the scanned cells is implemented in the aggregator class, which provides two overloaded interface methods – one for accumulating data, one for printing the results.

The instance of the aggregator is a member-field in the *Ehql::ParserState* class, which serves for storing the current state of the translation process. The aggregator receives the cell, extracted from the table scanner via reference, then gets the data in it and places it according its primary key and its timestamp in the appropriate aggregating primitives. The aggregating primitives are represented as specialized template accumulator structures, implementing the different aggregating algorithms – AVG, MAX, MIN, SUM and COUNT with a template parameter as the type of aggregation – INT, UINT, LONG, ULONG, FLOAT, DOUBLE.

Since one aggregating operation may consists of lots of sub aggregations, respectively of lots of primitives (i.e. aggregating by timestamp with time resolution), a more sophisticated structure is needed to place the elemental aggregators. This container is implemented as an STL map with a key type consisting of: aggregating type, data type, column and qualifier name (if there is one); and value type – another map with a key type – primary key, timestamp and column key; and value type – elemental accumulator.

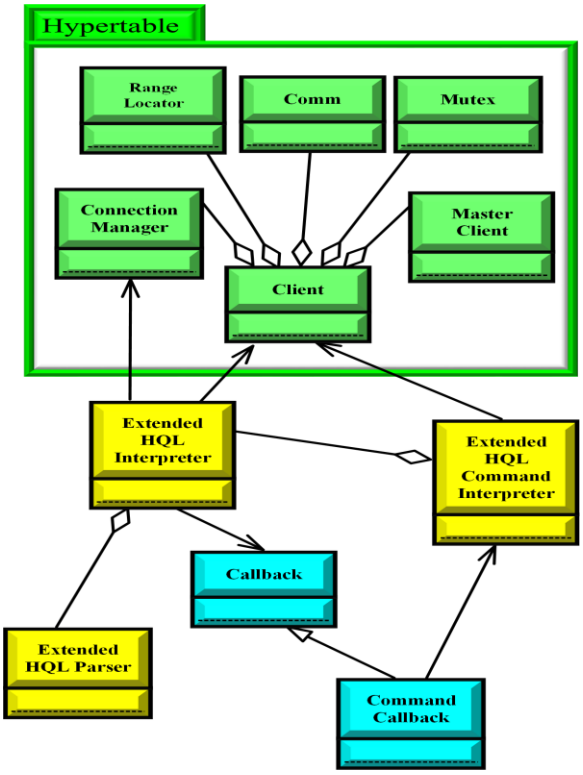

Figure 2. High level class diagram of Extended HQL interpreter and Hypertable DBMS

To increase the performance, another composite map is added, containing other maps with virtual constructors for the different types of primitives.

V. Related to Hypertable Projects

Several projects are based on Hypertable. Book Abacus [2] is a data science project that crawls the web to discover readily available for purchase books. These books are presented to users via recommendation pages generated by using human-interests gathered from the Linked Open Data cloud. The project stores its data in a Hypertable data repository.

The HyperArchiver [14] is an Experimental Physics and Industrial Control System (EPICS) Archiver implementation driven by Hypertable. EPICS provides the infrastructure with distributed control systems and is a set of open source software tools and applications. Many particle accelerators, large experiments and major telescope facilities use it to build complex control systems. These structures are made of hundreds of computers, networked together to communicate and provide control and feedback from various locations. The HyperArchiver is configured to insert 10K samples/sec and to extract 1K samples of 4 PVs Control System Studio. Hypertable is used to store the channel data: *channelName Status*, *TimeStamp*, *Severity*, *Simple Mode*, *SimplePeriod*, type, and value.

One of the goals of DEHEMS (Digital Environmental Home Energy Management System) project [20] is to work with vast number of households and preserve a huge amount of data while extracting information. This happens due to system's capability to provide a chance for request

formulating on the accumulated data. There are three key-moments which influence the problem of data storage and processing - the data model, the type of requests, and the amount of data. The data processing system should be able to write down data flowing in with high intensity, to store vast amounts of measured data values, to provide chronological information and to register special requests to data currently stored and filed. In the DEHEMS project the implementation of the distributed data warehouse is based on the Hypertable DBMS. For scalability purpose, the Web Service stores data into Hypertable time series database. Energy data stored in the time series database is summarized and parameterized in order to be abstracted according to the definition in a household model database.

VI. CONLUSION

NoSQL databases are becoming an increasingly important part of the database landscape and when used appropriately, can offer real benefits. The emerging popularity of NoSQL databases for the storage of large data sets, such as web logs and sensor readings, has relied on Map Reduce and other external summarization methods. These aggregation and summarization methods do not persist results and are communication heavy in their approach. They also do not have easy to use query semantics that are either descriptive or portable.

The column-family data model is the best NoSQL data format to store time series data in a sensor data storage system, allowing the collected datasets to be structured or semi-structured. We offer the use of Hypertable DBMS as a real data warehouse implementation. Our approach has been based on modifying the insertion and extraction Web services, therefore establishing a purpose-fit, high-performance query language benefited from persisted and local aggregation.

The authors' further efforts will be aimed at extending the functional capabilities of the insertion and extraction Web services.

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Using R with different types of databases: An overview

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Abstract - R is a working environment and computer language used in statistical computing. It is widely used as a tool in knowledge discovery and big data analytics as it provides an environment in which different statistical methods can be applied efficiently. As the size of analyzed data grows different data sources may be added to enrich statistical models and improve analysis quality. However, with R there is no need to store those datasets into the database. At the same time, R as environment support different data structures that make design and development of the information systems even more complex. R data structures could be divided into two main categories, homogeneous data such as atomic vector, matrix or array, and heterogeneous such as list and data frame. Additionally, we are witnesses to new trends in database design such as NoSQL, New SQL, graph database, in memory data storage, columnar and different application of SQL. Aim of this paper is to give an overview of different databases types in the context of R, covering concepts from navigational databases, to rational and post relational databases and how they are suited to host data for the purpose of access, storage and manipulation by statistical procedures in R.

Keywords: R, Database, Big Data, Data Science, New SQL

I. INTRODUCTION

There is evidence of several different trends that are having impact on information system design. The first trend is evident in more and more data being collected as the ratio between stored data and analyzed data decreases [1]. Another trend is an increase of frequently used data sources. This new situation imposes a question about what data sources could be leveraged and what data infrastructure is required to support data processing [2]. The third trend is a design of information systems being built on one or more clouds [3]. Those trends are creating new requirements for future information systems design and adoption of existing ones. These requirements are (based on [3]): *i)* use of machine learning and statistical techniques to enable automatisation of data processing scalability, *ii)* as the size of data and their sources increase there is need to clean data using efficient algorithms, *iii)* as more jobs depend on data there is a need to design end user interfaces in a way that they are able to perform data combining and analysis tasks without using computer code, and *iv)* information systems should be designed in a way that new data sources can be incrementally integrated. To meet those requirements information system designers have to look for the database and data processing techniques that are beyond data warehouse concepts. Some of the ideas discussing these issues could be found in [5,6,7] just to name a few. One of the possible direction in research is to investigate the use of computer statistical languages, in particular R, as a component in the design of information systems. Overview of the potential use is presented in Figure 1.

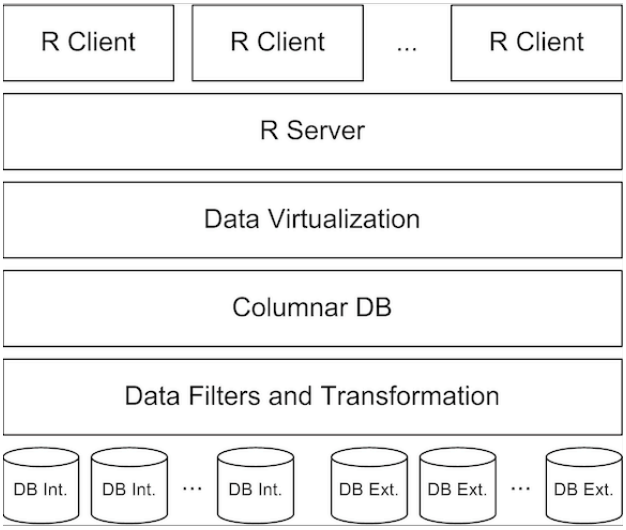

Fig. 1. Application of R in data processing procedures.

At the bottom tier of the scheme there are different types of databases used by information system. They can be internal or external. Directly above the databases there is a layer responsible for filtering the data for further analysis in terms of detecting anomaly. For example, filters could be set up to automatically analyze the number of returns (of goods sold), data collected that represent the customer satisfaction with shop assistants and the sentiments of the social media content relevant to company brand. If anomalies are detected, relevant data from different databases is "pushed" into the column-oriented database systems for temporary analysis. This system is connected with R server that manages access to the data for further analysis by data scientists with R clients based on data virtualization approach. From the R server access to data can be given to numerous clients

and they may use different statistical techniques to simultaneously analyze detected anomalies. Data processing tasks can also be divided into smaller tasks and run asynchronously on a single client. By using this combined approach analysis time can be drastically reduced and different insights into same datasets can be concurrently generated. Datasets can be accessed by data scientist that are the part of the organization and others that are only temporarily employed. This could be useful if analysis is domain specific and there is no inside expertise in the organization. Except the above described "push" process, "pull" process could be used so that data scientists can access the data stored in different databases and "pull" them through different layers (filter, columnar, virtualization, R server) to their R clients' statistical environments. But to implement and apply the proposed process there is a need to first understand R data structures and how well they fit with different data models and databases. This paper first elaborates R, its data types and structures, following with the brief overview of different types of databases. In the discussion synthesis of those two in terms will be presented together with outlined benefits and limitations in using R.

II. R

R is a working environment and computer language used in statistical computing. It is a GNU package and is available freely under GNU General Public Licence. It was created at the University of Auckland (in New Zealand). Its creators are Ross Ihaka and Robert Gentleman. The initial work of the beforementioned two authors appeared at Statlib as a binary copy of code in August of 1993. Receiving a good feedback from peer community (notably Martin Machler of ETH Zurich) the initial source code of R has been made available under Free Software Foundation's GNU general license in June of 1995. From the early beginnings many members of science community have been active in proposing enhancement to the core source code, and bug fixes through the established mailing list. All these efforts led to establishment of larger „core group" in 1997 whose responsibility was to make changes to the source code of R, in response to suggestions from community [8]. R has been created as a successor to S programming language (S was created by Jon Chambers) and was inspired by functional programming language Scheme. Development of R began by creating an interpreter for a subset of Scheme. The interpreter supported initial mechanism for symbol-table management and counted approximately 1000 lines of code written in C programming language [8]. R, referred to as a system, is written primarily in C, Fortran and R programming language. Even though there are similarities between R and S, there have been made some design time choices specific to R. The way memory is allocated is that it is set to some constant size. It is controlled with a built-in garbage collector resulting with the heap not getting too spaced up. There are substantially less paging issues in R design [8].

Another major difference in R implementation are scoping rules. Functions can potentially reach variables which were present in time when the functions were being defined [8]. The syntax of R has some resemblance with the syntax of the C programming language, even though it has functional programming language semantics [9] R is an interpreted language and is used widely by statisticians for the purpose of data analysis.

A. R Data types and Data Structures

Everything in R is an object. To elaborate on that statement, it is important to present main mechanisms in R which are used for efficient data representation as well as performing operations on supported data types. There are Object types which are internal types implemented in C. Another step was introducing vector structures which are closely related to vectors. S3 classes present another approach, that is objects which have no class definition, but can have attributes. With S3 classes there is a one-argument method dispatch. Formal (S4) classes have a class definition and support generic functions. S3 approach lacks some flexibility and S4 approach to programming is recommended [10].

Internally in C implementation of R language, all objects are pointers to a structure of type SEXPREC. In R looking at its low level implementation in the C programming language objects are pointers. They point to a structure of type SEXPREC. Also in C, SEXPTYPE is used to represent various data types from R language [9]. Various data structures will be presented summarizing all major types of objects in R, and later the main data structures will be presented more thoroughly. Vectors are one of the basic data types in R and can be thought as contiguous structures holding data. R has six basic (also referred to as 'atomic') vector types. These vector types are: integer, real, complex, logical, string (or character) and raw. Single numbers are vectors, and they have vector length of one. Lists are another basic data type and they can be thought of as 'generic vectors' meaning they can contain different elements which and each of them can be of a different type. In essence lists are vectors, but it is important to differentiate between atomic vectors and lists. Language objects are objects that are integral part of R language. They can be divided into: symbol objects, expression objects and function objects. There are also special objects (NULL type), built-in objects, promise objects (they are tightly coupled to lazy evaluation) [9]. These are not the only objects that exist but represent the most crucial types in R. There are also special compound objects: Factors and Data Frame objects. Factors are implemented using an integer array and are used to represent items that have a finite number of values. A data frame is a list of factors, matrices, vectors. What is common for them is that their length is identical [9]. General classification of R's data structures can also be made based on dimensionality and homogeneity. Homogenous data structures are atomic vector (one dimensional), matrix (2 dimensional) and array (many dimensional). Lists and data frames are heterogeneous data structures with list being one dimensional, and data frame being two dimensional [9]. Looking at the low-level implementation of R most elements of the language are internally represented by a special data structure. This

data structure is sometimes referred to as BLE (basic language element) and is composed of five machine words. The first element is a tag that contains information about the type. The second word contains a pointer and serves as a mean of associating attributes with an object. According to the specific type of object the content of the last three words can vary [8].

III. DATABASES

A database can be referred to as a collection of dynamic data which provides persistency and integration. It also provides operations to manipulate and access its data. A database management system(DBMS)presents languages and services which enable administrators and users to efficiently work with the underlying database [11]. When categorizing databases they are often distinguished by the underlying data model. A data model gives definition of the objects and operators enabling interaction for end users. It presents an abstract, self-contained definition. When talking about its implementation we are referring to its implementation on a physical machine. Knowing about implementation details of the model is not mandatory from a user's perspective, whereas knowing the data model is mandatory [11].

Database model consists of three components: a set of data structure types, a set of operators or inference rules and a set of integrity rules [12]. It is important to mention a well-known DBMS three-layer architecture consisted of the conceptual layer, the physical layer and the external layer. The physical layer is used for describing how data is organized and stored on a physical storage media. External layer presents data to the users, and the conceptual layer is used for describing the total data model [11] DBMS systems are being coordinated through usage of the data definition language (DDL), data manipulation language (DML) and data query. By describing schemas in DDL language data model of the DBMS is described [11]. When developing different data models there is a set of criteria which have to be taken into consideration. These are: the characteristics or structure of the domain to be modeled, the type of theoretical tools that are of interest to the expected users and the hardware and software constraints [12]. Before the introduction of relational data model two data models existed. They were the hierarchical model and network model. In the hierarchical data model, information is organized as a collection of inverted trees of records. The records contains fields and a field may contain simple data value, or a pointer. It is interesting that the pointer graph is not permitted to contain cycles [11]. Hierarchical databases could be explained, based on the hierarchical data model. In terms of storing, accessing and manipulating data represented in formal (S4) R classes if there is need to express complex models, hierarchical databases are impoverished in doing so, and it is not always suitable to form a parent-child relationship required to navigate in the database. Navigation in hierarchical databases starts from the root and continues in the opposite direction (from parents to children) until the desired record is found. Searching down the hierarchical tree is fast, but all other queries require sequential search techniques. It is also important to note that storing NULL values was implemented in only few concrete database implementations [11] In the network data model there are graphs of records. They can be accessed via pointers. Many individual fields constitute a record, and each field contains a simple value [11]. Some network DBMS doesn't allow NULL values which again limits the flexibility in storing certain objects from the R language data model. For the network model navigation in the database is implemented close to the physical storage structures (through pointers and indexes), implying that the network data model supports only limited data independence. Inevitably as the data model becomes more complex over time it is more difficult to maintain a network database. While providing more flexibility than hierarchical databases, network databases are not fit for efficiently persisting varying and changing data created by statistical computations. The relational database model was proposed by Codd in 1970's and proposed separation between physical and logical levels of the relational database, introducing them as different abstraction levels in design [12]. The relational data model finds its roots in relational algebra. Relational data model organizes data in two dimensional tables (relations). Every relation has a set of records (tuples). Additionally, tuples contain fields. A relation can be viewed as a truth predicate [11]. It defines attributes which are part of the predicate. An attribute has a name and a domain. Domains can be considered data types [11]. Most relational database management systems allow NULL values and that is accommodating the storage of R's NULL objects. Relational databases introduce a more logical view on data but it is also important to stress out that from the perspective of persisting R data structures it is often not desirable to adhere to relational constraints imposed by relational data model. In terms of efficient querying of the stored data it is also important to differentiate between traditional row-oriented database systems („row-stores“) and recent column-oriented database systems („column-stores“). As stated in [13]: “Column stores have been shown to perform more than an order of magnitude better than traditional row-oriented database systems on analytical workloads”. An object-oriented data model is based on concepts from object-oriented orientation. Objects are closely related to classes which serve a blueprint for object creation. Object orientated paradigm appeared as a result of joined effort in mitigating advanced systems [12]. It provides flexibility where each object has a number of attributes which can be simple values, complex values (a reference to another object due to composition) or methods. According to object-oriented database system manifesto, an OODBMS (object-oriented database management system) must satisfy two criteria, which are stating that an OODBMS must satisfy all the features of a DBMS system and it should be an object-oriented system. Implementing the second

criterion in OODBMS provides means for encapsulation, complex objects, inheritance, polymorphism and extensibility [14]. When evaluating benefits of object-oriented databases in storing R data it is important to point out that one of the key benefits in OODBMS is the possibility of modelling complex data models and extensibility via creation of new custom data types. These kinds of databases are suitable for persisting complex data structures from R's type system and since there is no impedance mismatch (due to object nature of both the object-oriented data model and R data structures). When listing the downsides of using an object-oriented data model, there are traditional setbacks in terms of no standard mathematical foundation via relational algebra. More importantly absence of a standard query language and nested queries may present a problem in efficiently accessing and manipulating persisted data in a standardized way despite the ease of manipulation via means of custom, more complex querying. There are other specialized forms of DBMS data models which emerged as a response to finding optimal ways of storing and organizing semi-structured data, or data that mainly depicts relationship between entities, or any other data for which these data models facilitate better means of database representation. The notion of graph database models is conceptualized with respect to three basic components. These components are basic data structures, integrity constraints and a transformation language. A graph database data model is a model where data is modelled as a directed, labeled graph. Graph oriented operations enable graph data manipulation. Type constructors and integrity constraints are defined over graph structures [12]. This text is referring to a full-fledged property graph model with all the benefits it introduces. A property graph is a directed multi graph. It consists of set of vertices (nodes) and edges (arcs) They are finite and mutable. [15]. The properties of vertices and edges (attributes) are simple name value pairs. If there is a need to uniquely identify a vertice, or an edge, dedicated property could be used. The graph database model gained a significant momentum in the early nineties, but its significance decreased to other database models being developed at that time (namely spatial and semi-structured data models). Taking into consideration flexibility and natural expressiveness of graph related structures, graph databases have been used lately in traditional business applications (where graph data representation proves to be more efficient) and in newer applications such as Social Media Analysis, Context aware search and social asset management [15]. R data structures which depict complex interconnections between objects are suited for storing in graph databases as they are suited for representing component interconnectivity. Retrieving complex data can be also significantly faster. Not all applications of statistical analysis in R produce complex interconnected objects and therefore suitability of using a graph database is limited to storing a subset of complex data types in R.

Further there are NoSQL (also referred to as not only SQL) databases which are supported by various data models such as key/value or documents. It is important to say that there is a distinction between traditional graph data model (and graph databases) from NoSQL underlying graph model. This text refers to graph databases as a separate entity separating it from the NoSQL class of databases. NoSQL databases as type of distributed database systems gained momentum in 2000's with the arrival of [16] applications that presented more resource requirements. Initial shortcomings of scaling the existing hardware infrastructure vertically and the impracticality of sharding middleware led to design of new distributed databases. This class of NoSQL databases focuses on availability and performance presenting eventual consistency of data [16]. This class of databases is suited for scaling out, and lacks strong transactional guarantees. As presented before they introduce alternative data models such as key/value and document [16] NoSQL databases try to solve three major problems which are not adequately addressed in relational databases [16]. These are growing data set size, growth of connectivity (as information is getting more connected) and semi-structurality of information which can be presented with few mandatory, but many optional attributes in the data model [17]. Considering the benefits of NoSQL databases when storing R data structures, R objects having few mandatory attributes which can present a basic data type or reference another object, and a handful of optional attributes which can be NULL, are suitable for persisting in document-oriented types of NoSQL class of databases. A major setback of using document databases with R data structures arises in need to write an additional code for handling inconsistent data when large quantity of data is being retrieved. There are also many applications that cannot give up strong transactional and consistency requirements making.

There is also emergence of different kinds of applications that are based on data stream processing. Mostly they could be found in the area of sensor generated data. Such data streams could be processed using R language in two ways, inbound and outbound. With inbound processing models of execution, possible streams of data could be pushed and processed as they fly by in memory, making reads and writes to traditional storage optional [18]. The main difference between inbound and outbound data processing is that former is explaining situations when data is processed before transaction and in the later model transaction appears first and then data stream is processed. At the heart of outbound processing is committing the transaction and only then processing data. This approach presents latency issues [18]. This „inbound processing“ model is employed by a stream processing engine such as StreamBas. There is also evidence in increase of the popularity of a new breed of DBMS systems collectively referred to as NewSQL DBMS that are also suitable for storing and retrieving R data structures. New SQL databases are modern databases that maintain ACID guarantees for transactions, while offering scalability of NoSQL databases for OLTP reads and writes [16]. Those systems could be categorized according to their nature of

development and for the purpose of actual use. Main categories proposed in are; new systems built from scratch, middleware reimplementing the sharding infrastructure developed from 2000s and database as a service offerings based on new architectures [16]. Analyzing systems with a completely new architecture there is a trend of storing the complete database in main memory. Thus, these systems can get better performance because traditional database components are simply left out (such as a buffer pool) [16].

Another difference with NewSQL Systems is its ability to move data from main memory to hard disc if there is an increased demand for random access memory [19]. These new types of databases are well suitable for working with R data, as in main memory data processing introduce large performance benefits. Being ACID compliant, and supporting storage of vast quantities of data due to increase in main memory price, they are suitable for data-intensive, fast workloads. In some cases there is a need to consolidate data from disperse data sources in order to do statistical analysis in R. There are technologies addressing this need enabling virtual connections to remote database objects where only metadata about remote sources is stored in virtual tables. Unification of disconnected sources presents a new approach in statistical analysis of data being present in different external databases [19]. Cell stores is also one among of new approaches in structuring a database model. The cell store data model organizes data at the cell level. Cells can be seen as atoms of data. Cell stores are associated with dimension data and a big collection of cell stores can be easily clustered, replicated or retrieved efficiently. Cells can also be assembled into data cubes or into spreadsheet views [20]. Structuring R data types into the cell store data model allows storing highly dimensional data.

IV. DISCUSSION

In Table 1 different types of databases (or streaming engines) and their suitability to store R data structures (in terms of key benefits and setbacks) are discussed. Streaming data processing is not directly related to a particular database but as more and more data from sensors is collected, processing it «on the fly» before it is stored in a database (or after transactions are executed) deployment of R language in those procedures is of a high importance.

TABLE I.
Properties of different database types in relation to R data structures storage ability

Database types and streaming engines	R usage key benefits and deficiencies
Hierarchical	Searching down the hierarchical tree is fast but there is no possibility to store NULL values
Network	Network databases are not fit for efficiently persisting varying and changing data created by statistical computations.
Relational	Imposed data relations and constraints are not very suitable for statistical computing because to be able to perform different analysis, data models should be easy to change. Column store database types could help to overcome such limitations, as data could be stored in one or few tables, making them more suitable for statistical computing. They also support storage of NULL values.
Object	Object-oriented databases are beneficial for processing R data as they give the possibility to analyze and process complex data models and are able to support data extensibility via provisioning of new custom data types. The limitations of using this type of database are that there is no standard mathematical foundation via relational algebra and there is an absence of standard query language.
NoSQL	Analyzing data sets with few mandatory fields but with a high velocity of additional attributes are the main benefits of using NoSQL for the purpose of storing and processing R data. The main setback is manifested in the need to write a lot of additional code for handling inconsistent data when a large quantity of data is being retrieved.
New SQL	Use memory to store data, utilize the opportunities of cloud computing based on data virtualization techniques and use different data sources stored in different databases.
Cell	Store and analyze highly dimensional data.
Streaming	Reduce the amount of data before transaction (inbound) and/or analyze data streams that are a result of a high number of transactions. In both cases, out of the large volume of data streams, systems use only those parts that are relevant to triggering a particular function (by using R scripts) and that data is stored in a database system chosen by a designer.

V. CONCLUSION

We have described new trends influencing the design of data processing information systems. The trends are: 1) decreasing ratio between continuously collected and analyzed data; 2) increasing number of available data sources; 3) accelerated introduction of cloud and multi-cloud information systems. These trends will have a significant impact on the development of current and future data mining systems. Knowledge discovery research will also have to adapt to the new situation and requirements from the IT industry. Incremental system integration and intelligent user interfaces regulated by information need will become a necessity [21] [22] [23]. The standard data warehouse paradigm will become inadequate and new concepts for acquisition, integration and analysis of heterogeneous data sources will have to emerge. The most immediate and efficient solution is the use of a standardized data model built on computer statistical language R. We believe that the importance of

R in the design of information processing systems will continue to grow.

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Real-time map projection in virtual reality using WebVR

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***Abstract* - In this paper, we present an implementation of a real-time web-based solution that projects pre-rendered map tiles onto a virtual reality plane. An interaction layer, that enables different ways of map manipulation including its surroundings, is developed. The implementation of the projection is described in detail. The main goal of our work is to show the advantages of the web-based map applications over the maps that currently exist and are being developed for native hardware and software support in virtual reality. We measure and analyze their performances and discuss possible future integrations of the already existing platforms with the proposed solution. The implementation leverages JavaScript with WebGL by extending the possibilities of the A-Frame framework based on WebVR. The results of the performance evaluation proved a high usability and interaction level of the proposed solution with already existing and widely available hardware and software support.**

Keywords - map; projection; virtual; reality; WebVR; A-Frame; WebGL

I. INTRODUCTION

Today, there is an abundance of hardware and software solutions available on the market that provide some type of virtual reality (VR) experience to their users [1], [2]. The largest companies in the industry, such as Facebook, HTC, Sony, Google and others, are entering themselves in this expanding market [3]. Almost all of their solutions, e.g. Facebook's Oculus Rift, HTC's Vive, Sony's Playstation VR, Google's Daydream, use different software platform to run their VR experience. Consequently, this approach prevents developers to create VR enabled solutions that are available to a wide number of users. Indeed, smartphones based on Android and iOS are making VR accessible to a wider audience more than ever before, although the hardware on these devices currently does not match the performance of the devices such as Oculus Rift or HTC Vive [4]. Nevertheless, consumer devices may perform on a par with expensive specialized hardware for certain tasks [5]. Also, one of the existing problems is the lack of a cross-platform solution for Android and iOS. Therefore, a separate development for each platform is required to approach most of the users. This could be changed with the development and use of WebVR.

Various incidents are happening around the world at any given moment, such as earthquakes, forest fires, terrorist attacks, car accidents, to name a few. On the other hand, population data, crime data, congestion of traffic routes, weather forecasts and their statistics varies depending on the time of the year and the time of the day. If we look at any of them, a need to associate these types of information to their location and visualize them, is required for any further analysis and presentation. Progress has been made in this field in previous years with solutions like MapBox, Google maps, OpenLayers and others. Also, a VR Geographic Information System (GIS) analysis platform is proposed in [6], which serves 3D digital city and supports integrated VR GIS functions offering 3D analysis and visualization of the concerned city's massive information.

The main idea behind this paper is to build a web-enabled real-time map that works in virtual reality. The motivation was the exploration of new possibilities for geospatial data analysis opened by introducing a new VR dimension. The solution is developed in response to the expansion of big data and the growing need to visualize large volumes of geospatial data on the web.

The solution that is presented in this paper explains how we enabled real-time map projection in VR using A-Frame framework that is based on WebGL and WebVR integration.

The paper is organized as follows. In section II, related work is presented. Section III describes how a scene was created in VR. Section IV introduces a map, while in Section V its projection is presented. Section VI describes the implementation of the interaction layer. A performance analysis of the proposed solution is done in section VII. The last section concludes the paper.

II. RELATED WORK

A modular web-based VR framework is presented in [1] that extends video conferencing capabilities with virtual and mixed reality functionality. One of the modules, that is in charge of displaying content in VR, utilizes the A-Frame framework linking the WebVR and Three.js. In this way, a VR enabled head-mounted display can present VR content in the Firefox web browser. In the paper [7], the authors explore the use of the WebVR and the Google Cardboard for low-cost immersive analytics. They focus on recreating known physical visualization designs in VR, exploring the performance trade-offs between fast and realistic rendering and stating that WebVR shows promising results.

An analysis of several Map APIs and evaluation of the most suitable API for interactive images regarding its usability, accessibility and performance is conducted in

[8]. The paper [9] identifies and compares the most capable libraries suitable for foundation of a web GIS client. The applied criteria include their GIS feature coverage and some quality metrics.

In paper [10] GPU power is used to accelerate data discovery and visual analytics in MapD solution, where the power of MapD database is leveraged in MapD's Immerse visualization platform for complex data visualizations (including detailed GIS representations).

A. WebVR

WebVR is an open specification that enables VR experience in the web browser [11]. Its goal is to facilitate VR experience to users, regardless of a device they have. The only two things that are required by WebVR are a headset and a compatible browser. The easiest way to get started is with a basic headset like Google Cardboard and a suitable web browser installed on the users' smartphone. WebVR can also be used on advanced headsets with a browser that supports this specification and can run on the chosen headset. Its development is led by major browsers' engineers, and some independent developers. Some of the web browsers that currently support this specification are Chrome for Android, Chromium, Firefox, Microsoft Edge, Oculus Browser and Safari [12], [13]. There are also WebVR emulators available that enable the API testing without any use of external hardware headsets.

WebVR has two base concepts. The first one sends stereoscopic images to both handset lenses. The other one receives positional data from the sensors that track a head movement. The API enables access to these data and their integration with already existing 3D solutions in web browsers. Certainly, one of the most used libraries for displaying 3D computer graphics in a browser is Three.js. This library allows for the creation of GPU-accelerated 3D animations using the JavaScript language with WebGL API. The projects running on Three.js can be made VR-ready by adapting them to use WebVR. In this way, many existing projects can be ported to VR without much additional work.

B. A-Frame

A-Frame is a web framework for building virtual reality experience. Originally developed by Mozilla, A-Frame was intended to be an easy but powerful way to develop VR content. A-Frame uses Custom Elements (a W3C's draft recommendation) to act merely as data containers and it does not trigger the layout engine. Hence, it overcomes 2D layout which is a primary performance concern for normal web applications. It uses in-memory 3D operations with minimal overhead which are rendered with WebGL leveraging OpenGL or Direct3D.

III. CREATING A SCENE IN VIRTUAL REALITY

A-Frame framework comes with a prepared set of components to use to order to create a simple 3D scene. A-Frame can be developed from a plain HTML file without having to install anything. All that is needed is to include the library in the <script> tag and to add a valid scene with <a-scene> tag which is shown in Listing 1. Components that are rendered in this scene are later used as a placeholder for map projection.

```
<html>
  <head>
    <script src="./aframe.min.js"></script>
  </head>
  <body>
    <a-scene>
        <a-box top color="#000"></a-box>
        <a-box left color="#000"></a-box>
        <a-box bottom color="#000"></a-box>
        <a-box right color="#000"></a-box>

        <a-entity position="0 0 3.8">
                <a-camera></a-camera>
         </a-entity>
    </a-scene>
  </body>
</html>
```

Listing 1. HTML used to render basic A-Frame scene

This HTML will render a VR-enabled 3D scene in the browser that is presented in Figure 1.

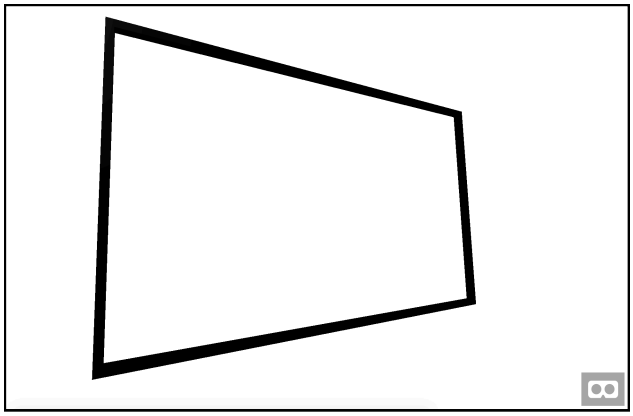

Figure 1. Basic A-Frame VR scene created as a placeholder

As it can be seen in Figure 1, A-Frame has rendered a scene that contains a frame in which a plane object is injected. The image in the bottom right corner, that represents glasses, designates that the scene is VR enabled in the browser.

Although the previous scene can be created in a simple way, integration of a map that can be interacted with, is not an easy task. A-Frame supports a custom component creation and this approach should be used to add any custom object to a scene.

IV. CREATING A MAP ENTITY

It would be a straightforward process to add a map to the scene, if the A-Frame allowed adding standard HTML elements. As this is not the case, the decision was to add our map as a canvas and then to project it as a texture onto a plane that will be added to the scene afterwards.

Since the subject of this paper is the projection of a map and not the creation of one, authors decided to use MapBox GL JavaScript library that renders maps from raster and vector tiles using WebGL. MapBox GL uses tileset sorting and ordering mechanism to properly load and cache tiles that are to be displayed. A tileset is a collection of raster or vector data broken up into a uniform grid of square tiles at 22 percent zoom levels.

MapBox GL library internally determines which tiles to load and show, based on different conditions such as the width and height of the container, zoom level and user actions such as panning, rotating or tilting. The map navigation controls were employed to create an interaction layer to enable the map manipulation in virtual space as there are no mouse or keyboard that could be used.

Although this solution relies on MapBox GL to render the map properly, this layer can be easily replaced with a similar library.

As the A-Frame is based on entity-component-system pattern, we created an entity, the element, that was added to the HTML as an A-Frame element. In the A-Frame Custom primitives (i.e. elements) are registered using *AFRAME.registerPrimitive(name, definition)* function. Parameter *name* is a string and it represents the name of a new element, while *definition* parameter is a JavaScript object that defines *defaultComponents* and *mappings* properties.

We named our element *a-mapgl* and registrated it with A-Frame as shown in Listing 2. This element represents an entity in the entity-component-system pattern.

```
AFRAME.registerPrimitive('a-mapgl',
extendDeep({}, meshMixin, {
  defaultComponents: {
    mapgl: {},
    geometry: {
      primitive: 'plane'
    },
    material: {
      color: '#FFF',
      shader: 'flat',
      side: 'double',
      transparent: true,
    }
  },
  mappings: {
    height: 'geometry.height',
    width: 'geometry.width'
  }
}));
```

Listing 2. Registering a-mapgl entity

This enables adding of <*a-mapgl*> element to the main HTML file, but it still does not have any logic implemented for it to project the map onto the plane. In order to do this we created a component named mapgl that is referenced in the defaultComponents property in the a-mapgl entity.

V. MAP PROJECTION

To register a component that can be used with the entity we used *AFRAME.registerComponent(name, definition)* function. The main functions that we redefined for this component are *init* and *update*.

A. Init function

Init function is used to set up initial state and instantiate variables. It is called once when the component is initialized. This function is used to dynamically create a container that MapBox GL uses to inject the generated canvas element into. The main problem with generating this container is that MapBox sets the width and height of the canvas based on the offset of the container. Because this canvas is hidden, MapBox GL is not able to properly render the map. One solution is to set the position of the container to be fixed and move it out of the visible part of the view in order that the map can be properly rendered and invisible for a user as shown in Listing 3.

```
element = document.createElement('div');
element.setAttribute('id', 'mapboxContainer');
element.style.position = 'fixed';
element.style.left = document.width;
document.body.appendChild(element);
```

Listing 3. Creating a hidden map canvas container

This element can now be referenced with the MapBox GL map constructor as a container for the canvas as show in Listing 4.

```
var map = new mapboxgl.Map({
    container: 'mapboxContainer',
    style: 'mapbox://styles/mapbox/streets-v9',
    ...
});

this.mapInstance = map;
```

Listing 4. Generating a map instance

After the constructor initializes the map variable, the canvas is added to the container and tiles are loaded. This variable is then exposed globally as a service instance that is used to build an interaction layer and update the map if a change occurs. Adding a texture that represents the canvas is now based on adding a source attribute that references the id of the canvas element. This id can be dynamically added after the map finishes loading as shown in Listing 5.

```
this.el.setAttribute('src', '#canvasId');
```

Listing 5. Adding the canvas element as a source of the element texture

A-Frame uses meters in a 1:1 ratio, since WebVR is also using meters. This means that 1 unit in A-Frame is equal to 1 meter in real world. Because the plane element requires these units to define width and height of the containers, a mapping needs to be implemented so that the rendered map can scale its width and height defined in pixels to fit onto the texture of a plane shown in Listing 6. We defined a multiplication scale factor. It is recommended that this calculation result be a power of two since older graphic cards process textures in this way.

```
mapWidth = geometry.data.width *
this.data.multiplyScaleFactor;
mapHeight = geometry.data.height *
this.data.multiplyScaleFactor;
```

Listing 6. Calculating map size based on a scale factor

If we include the *a-mapgl* element and place around it a frame-shaped object we get a VR scene as illustrated in Figure 2.

Figure 2. Real-time map projection in VR

B. Update function

Update function is triggered when at least one of the parameters passed with component registration has been changed. Since we can choose which parameters to include we decided to define similar parameters map instance uses to navigate the map shown in Listing 7.

```
schema {
  //The desired center (LngLatLike)
  center: {default: 0},
  //The desired zoom level (number)
  zoom: {default: 0},
  //The desired bearing, in degrees. The bearing
is the compass direction that is "up";
  //for example, a bearing of 90° orients the
map so that east is up. (number)
  //pitch The desired pitch, in degrees.
(number)
  bearing: {default: 0},
  //If  zoom is specified,  around determines
the point
  //around which the zoom is centered.
(LngLatLike)
  around: {default: 0},
}
```

Listing 7 - Registration component parameters

These parameters can be exposed outside of the *a-mapgl* element and used to control the map. For this to work, the update function will refresh the map with the new values.

VI. INTERACTION LAYER

In a similar way that we created a-mapgl element (entity) and added it to the solution, we have created an interaction element that hooks to the parameters that can update the map. As headsets do not have mouse or keyboard input, a gaze-based (fuse-based) cursor has been implemented to call the event handlers attached to this element. If we set a cursor to be gaze-based, the cursor will triggers a click when the user gazes at an entity for a predefined amount of time. It can be imagined as a pointing device, the direction of the user's sight is a straight line going from the camera position to an infinite target. When you gaze at the entity the line intersects with it. The disadvantage of gaze-based interactions is that they require the user to turn their head significantly. Figure 3. shows the component's appearance.

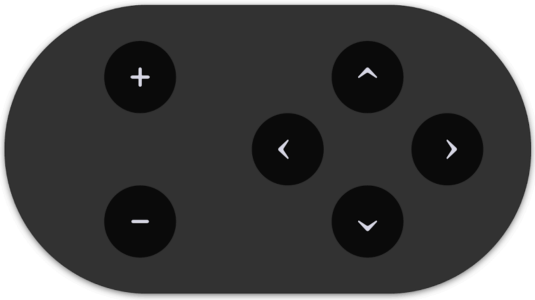

Figure 3. Interaction layer component

An example of an event handler attached to the interaction is presented in Listing 8.

```
var setComponentProperty =
window.AFRAME.utils.entity.setComponentProperty;
  entity.onGaze = function(handleType) {
    if (handleType === 'zoomIn') {
      setComponentProperty(mapEl, 'map.zoom',
zoomLvl+1);
    }else if (handleType === 'zoomOut') {
      setComponentProperty(mapEl, 'map.zoom',
zoomLvl-1);
    }
```

Listing 8. Interaction layer event handler

VII. PERFORMANCE ANALYSIS

The performance testing of this real-time map projection in virtual reality based on A-Frame and WebVR was conducted on a computer with an Intel Core i5 at 2.7 GHz CPU with 8GB of RAM and 128 GB SSD running macOS High Sierra and a VR emulator in Chrome for macOS version 64.

The testing and comparison was done in four different scenarios. The parameters that were monitored were frames-per-second (FPS) and the size of the JavaScript heap size. The results are presented in Table 1.

Scenarios that were analyzed include:

- Scenario 1 - Map rendering onto the canvas in 2D with zoom interaction for 20 zoom levels;
- Scenario 2 - Rendering a basic A-Frame scene described in Section II;
- Scenario 3 - Rendering the A-Frame scene with the included a-mapgl element described in Sections IV - V without the interaction layer. We are using WebVR API to change the camera position and navigate through the VR space;
- Scenario 4 - Scenario 3 with the interaction layer that is used to zoom the map for 20 zoom levels.

Tools used to measure these performances are: Stats.js JavaScript Performance Monitor developed by Ricardo Cabello, the author of Three.js (used to measure FPS) and Performance profiler from Chrome developer tools. Main reason why FPS meter from Chrome developer tools was not used is because FPS meter does not measure FPS performance properly when a canvas is used.

Profiling time for each test was set to 30 seconds, as this was a very intensive operation for the device on which the analysis was running. In Table 1. a range of FPS and memory values are presented for the given timeframe. The results of the tests are displayed in Table 1.

Scenario Number	FPS (higher is better)	JS heap size (MB)
1	19-61	19-64
2	58-60	7.9-10.4
3	31-39	20.8-26
4	10-39	21.3-67

Table 1. Performance analysis test results

As the range from 30 to 60 FPS is considered optimal for the human eye [14] it is noticeable that Scenarios 1 and 4 behave suboptimal in some cases. As Scenario 1 only contains a map rendered by MapBox GL library, there was nothing we could have done to optimize this performance. The main drop in FPS happens when the library starts loading and rendering new map tiles. As our solution depends on this rendering, it is clear that FPS rate cannot be higher. A drop below 19 FPS in Scenario 4 happens when the user starts changing the position of the camera while the loading of new tiles is still in progress.

CONCLUSION

The results displayed in the performance analysis suggest that interactions with the map in virtual reality can be bellow optimal level if a user decides to move around its surroundings (by changing camera position) while the map tiles are loading. A solution that disables camera movement until the tile loading is completed can be implemented to prevent drop in the performance. If we remove this scenario from our use case, frame rates are ranging from 31 to 39 fps which is considered optimal for the human eye to process [13]. The results of the performance evaluation proved a high usability and interaction level of the proposed solution with already existing and widely available hardware and software support.

The solution described in this paper showed a possible future of the map-based web applications using a component that can be easily integrated into already existing web 3D projects.

The next step in the development of this solution is its modification and adjustment to work with augmented reality so it can interact with the real world. A new interaction layer can be created to use new types of controllers such as Leap Motion that supports hand and finger motions as input, but requires no hand contact or touch.

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Visualization of smart specialisation process using QGIS tools

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Abstract - **Smart specialisation is identification of strategic areas for research and innovation within European countries, based on their specific strengths and potentials for growth. Smart specialization links together companies, state bodies, scientific world, and civil society and encourages them to work on implementation of European strategic documents. Only areas defined in smart specialization strategies of different countries or regions are financed through EU funds. This fact makes it very important for regions to clearly define their focus sectors, because only these sectors will be financed by the European Union. And, visa versa, for the development of the EU, it is significant to have correct sectors for smart specialization defined for each region. Any mistake in this procedure will cause slowing down of EU development process and will decrease EU capabilities to compete correctly and successfully with the rest of the world. Authors of this paper use GIS software to analyze correlations between selected smart specialization sectors for certain regions and some economic facts related to those regions. Such analysis should prove that each smart specialization sector was correctly chosen for a specific country or a region. Authors propose new methods to check starting points for smart specialization process and recommend methodology that should be implemented to avoid errors in decision making process.**

Keywords - QGIS; visualization; smart specialisation; decision making

I. INTRODUCTION

Smart specialization is a new business model. Philip McCann and Raquel Ortega-Argilés, in their work: "Transforming European regional policy: a results-driven agenda and smart specialization", define smart specialization concept and its use to facilitate a results-oriented policy agenda [1].

EU wants to become a smart, sustainable and inclusive economy. These priorities should help the EU and the member states to deliver high levels of employment, productivity, and social cohesion. Smart specialization concept is developed by European Commission based on methodology that is used in the USA to avoid fragmentation of innovation and research space and to concentrate investments into something that surely gives better outcomes and results. Its aim is to build an innovative approach to the growth of European economy that will improve its competitiveness on world level and increase number of jobs in Europe. It is based on a premise that available resources should be used more efficiently. Which methodology should be used to reach this? Regions in Europe don't need to do research and create innovative solutions in all sectors, but only in those that will bring the biggest effectiveness. Each region should be specialized for research and innovation in sectors where it has the greatest potentials and it must develop specific niches for products and services that will bring most comparative advantages.

Smart specialization encompasses analysis of strengths and opportunities of local economies and implements Entrepreneurial Discovery Process (EDP), which is a bottom-up process with wide stakeholders' involvement. This process has already made a big change in designing innovation strategies for European regions. It forced cooperation of all social groups. The process brings local authorities, scientific institutions, companies, and civil society to work together with aim to define focus sectors for research and innovation of a given region. The important fact is that this process is supported by EU programs for funding. European Commission has been providing, starting from 2011, knowledge support to regional and national authorities in defining and implementing regional and national level smart specialization strategies [2].

What is new is that the Commission proposes to make such strategies a pre-condition for ERDF (European Regional Development Fund) funding [3].

Thus EU member states and regions must have smart specialization strategies in place before their Operational Programmes supporting these investments are approved.

The Smart Specialisation Platform helps regional and national authorities to prioritise their efforts to create an innovative economy. Established by the European Commission in 2011, it facilitates mutual learning, data gathering, analysis, and networking opportunities for more than 170 EU regions and 18 national governments. The Platform has been instrumental in consolidating, disseminating, and implementing smart specialisation methodology across European regions. It has helped to

optimise the definition of innovation strategies on the basis of regional strengths and through an open and participatory process. It is an important means to improve EU investments in knowledge based territorial development.

It encourages regions and cities from all over Europe to adopt the Innovation Camps methodology. This methodology is a tool to address collectively and effectively societal and economic challenges concerning local societies in a European context. This is especially so in the field of Research and Innovation Smart Specialisation Strategies (RIS3) through an open, collaborative and inclusive Entrepreneurial Discovery Process (EDP) between Quadruple Helix actors (i.e. government, industry, academia, and civil society).

Defining right sectorial priorities is very important. It happens that some regions want to be specialized in sectors that are "fashionable" and not in traditional ones where they possess real strength and traditional advantage.

Some information-communication technology (ICT) tools should be used additionally to Entrepreneurial Discovery Process to prove weather sectors defined within EDP processes are correctly selected. These ICT tools are necessary to match EDP outcomes with economic, social, political, climatologic, and other facts. Of course, integration with emerging technologies defined by visionary scientists and artists must be included in this process.

Authors of this paper use QGIS software to analyze correlations between selected smart specialization sectors for certain regions and some important and relevant economic facts related to those regions. Such analysis should prove or disprove that each smart specialization sector was correctly chosen for a specific country or a region. Authors propose new methods how to start defining smart specialization priorities and how to check final results. They recommend methodology that should be implemented to avoid errors in the decision making process.

II. Methodology

GIS technology is working with georeferenced data and enables their collection, organization, manipulation, analysis, and visualization. It is suitable to find relationships between entities, to create patterns, find and follow time and space changes and trends. Its use started with public health patterns [4]. Demographics are spatial issues and GIS enables a lot of visualised discoveries [5]. GIS can be implemented as an ICT assistance tool in many different sectors of human activity. Some examples are: urban planning [6], [7], ecology [8], and analysis of transportation problems [9]. GIS is precious even for analysing social and human problems, e.g. in law [10] and resource management [11]. It is also useful for micro and macro analysis of many industrial problems. It includes different techniques linking databases, georeferencing, analysis, and visualization [12].

GIS as a software tool includes many geostatistical techniques for spatial analysis that have been extended over the years [13]. It offers raster analysis [14], it enables analytical methods for business [15] and it is often used in 3D analysis [16], network analytics [17], space-time dynamics [18], and techniques specific to a variety of industries [19].

Authors are using a user friendly open source geographic information system, QGIS, previously known as Quantum GIS. QGIS is an official project of the Open Source Geospatial Foundation (OSGeo). It works on Linux, UNIX, Mac OS X, Windows and Android platforms. Numerous vector, raster, and database formats and functionalities are supported by QGIS. QGIS is maintained by volunteer developers who regularly release updates and bug fixes and work volunteer. Developers have translated QGIS into 48 languages and it is used internationally in academic and professional environments [20].

III. QGIS for Visualization of Smart Specialization Process

In this paper authors analyzed agricultural sector as a defined priority sector for smart specialization of some countries and compared this choice with real economic data that show potential of their agricultural sectors. The authors used QGIS Desktop 2.0 to visualize different economic data related to agriculture and food production within EU member countries. They selected the following data [21]:

- Percentage of agricultural export within total export
- The size of agriculture labour force
- Percentage of agricultural gross value added.

Figure 1 presents countries that defined agriculture and food production as their priorities within smart specialization strategy. Agriculture and food production are declared as one of smart specialization priorities in: Hungary, Croatia, Czech Republic, Poland, Lithuania, and Ireland.

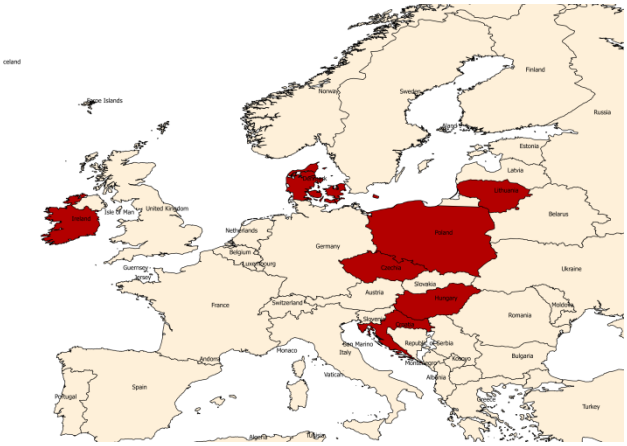

Figure 1. Countries that defined agriculture and food production as smart specialization strategy priority

Figure 2c presents data on percentage of agricultural export within total export in EU member states in 2016 in categorized style, so that countries with bigger export are

coloured in darker colours. Countries marked with number 1 have agriculture as their focus in smart specialization strategy. Such presentation is designed by overlapping of two layers:

- One with colour categorized presentation of percentage of agricultural export within total export (Figure 2a) and
- The other one with numbers 1 and 2 (Figure 2b)

.

Figure 2a. Percentage of agricultural exports within total exports in EU member states (2016), Source: Authors

Figure 2b. Labels 1 and 0 for countries with defined and not defined smart specialisation strategies

Figure 2c. Overlapped Figures 2a and 2b

The numbers from the second QGIS layer (Figure 2b) are added to the first layer (Figure 2a) and presented in Figure 2c. Numbers means the following:

Number 1: agriculture and food production are declared as one of smart specialization priorities

Number 0: agriculture and food production are not declared as one of smart specialization priorities.

It can be seen that some countries with weak agricultural exports have put agriculture as smart priority. On the opposite side, countries with significant exports like Spain, Greece. Netherlands, Lithuania, and Denmark, did not put agriculture as focus of their smart specialization. They did not recognize agriculture as a source of innovations.

Countries without any colour do not have yet created smart specialization strategy.

Figure 3 shows percentage of agricultural exports within total exports of EU member countries in categorized style with inscribed values of percentages of agricultural export.

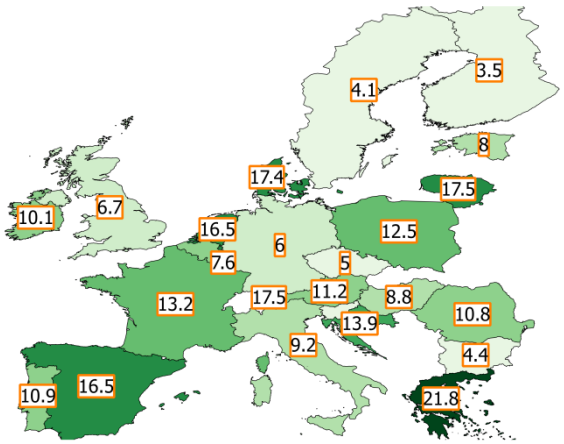

Figure 3. Percentage of agricultural exports within total exports in EU member states (2016), Source: Authors

Figure 4 presents the same as Figure 2c but with QGIS canvas with all its toolbars. All previous figures are made as QGIS maps and exported with export resolution of 256 dpi (dots per inch) in TIFF (Tagged Image File Format) format that is used for storing high-quality raster type graphics.

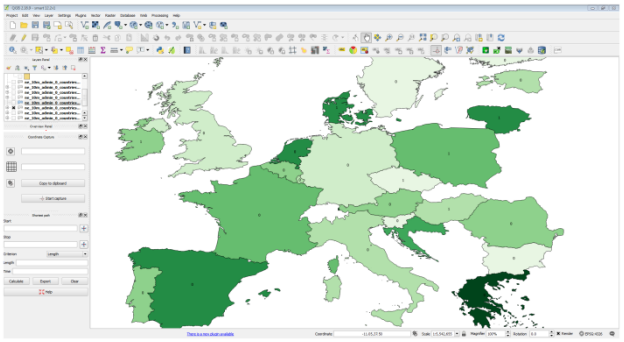

Figure 4. Percentage of agricultural exports within total exports in EU member states (2016) with QGIS canvas, Source: Authors

Figure 5 presents gross added value (GVA) in agriculture in 2016 of EU countries. Blue colour is getting darker for countries where GVA is being higher. Hungary, Greece and Bulgaria have the highest GVA and the lowest GVA is in Italy, followed by Great Britain and Germany. Numbers from the other QGIS layer are added to the previous one and presented in the same way as in Figure 2c.

When the two QGIS layers are overlapped, it can be seen that data on GVA and on smart specialization priority do not correlate. They do only in the case of Hungary.

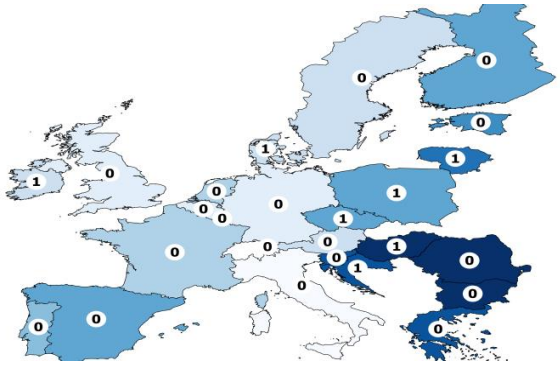

Figure 5. Percentage of agricultural GVA in EU member states in 2016 (intensity of blue colour) and agriculture in focus of smart specialization (ones and zeroes) Source: Authors

Figures 6 and 7 present another important factor; it is employed labour in agriculture and food production. Following the same principle, orange colour is getting darker where number of employees is getting bigger. Romania has the highest number of employed in agriculture, followed by Greece and Poland.

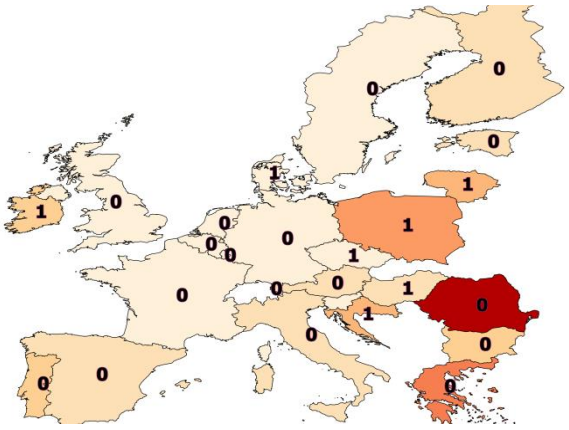

Figure 6. Employed labour in agriculture and food production in EU members states (2016), Source: Authors

Figure 7 presents the same data, with added names of the countries.

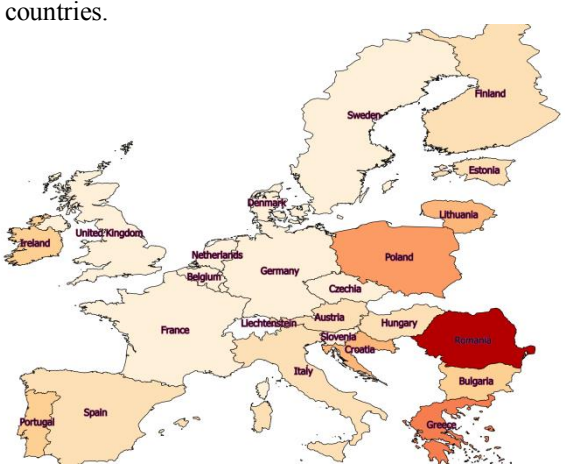

Figure 7. Employed labour in agriculture and food production in EU member states with names of countries (2016), Source: Authors

Figure 8 has two overlapped layers:

- The numbers of employed labour in agriculture (in millions)
- Visualization of these data in shades of orange colour.

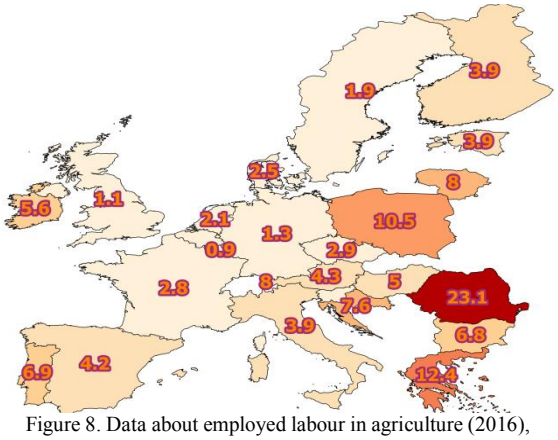

Figure 8. Data about employed labour in agriculture (2016), Source: Authors

Figure 9 shows visualized data about GVA. Values of GVA are added in each country.

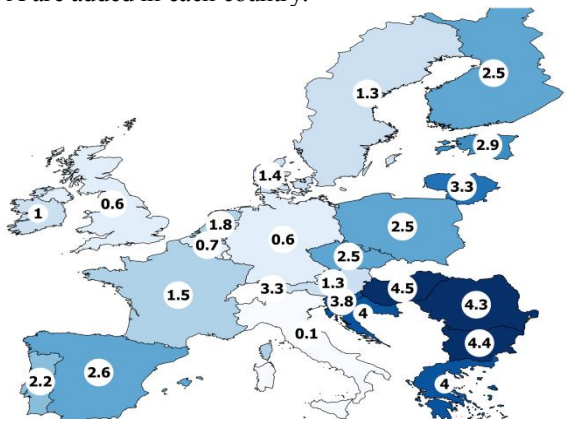

Figure 9. Visualized data GVA (shades of blue) with added values of GVA for each country (2016), Source: Authors

Figure 10 as the previous one, contains visualized data on exports of agricultural products within total country exports (shades of green) with inscribed values of exports.

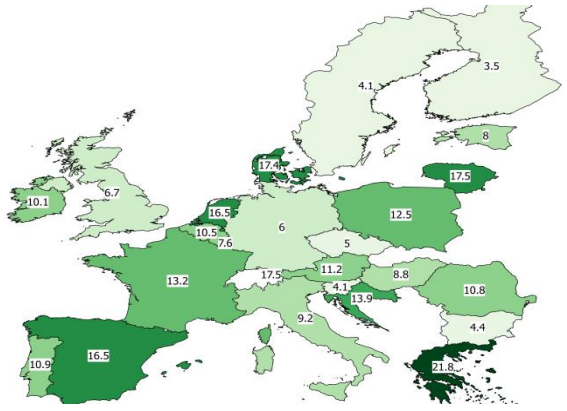

Figure 10. Visualized data on exports of agricultural products with percentage of agricultural exports within total exports in EU member states (2016), Source: Authors

IV. New Method for Decision Making Process of Smart Specialization

Identification of smart specialization priorities for each region and country is of big significance. European Union put smart specialization as its priority and adopted a principle to launch all funding linked to defined priorities. This means that all research and development processes will be directed by niches presented within smart specialization strategies. Bearing this in mind, process to select right priorities must be based on different, carefully selected data.

Information-communication technology with its tools is most suitable to analyse data. Authors presented in this paper use of software visualization tools that help to get to the right decisions.

The new method of creating smart specialization focus sectors should have a holistic approach and must include many stakeholders' groups into EDP activities. Afterwards, analysis using GIS tools is performed. This process should have the following steps:

- Smart specialization experts define which data are relevant for selection of smart specialization, regional or national, sectors;
- They present available sources of stated data;
- They define which layers of data should be created and overlapped;
- GIS experts create requested layers and overlapped layers;
- Smart specialization experts analyse all prepared layers and make conclusions;
- Conclusions are new inputs to a new EDP process;
- This circle should be repeated untill the final convergence of outputs of EDP process and of GIS analysis is reached.

Some other IT tools could be included into this process, too.

Such an approach will give better outputs and impacts and could be periodically run to bring continuous correction of resulted smart specialized areas.

V. Conclusion

In order to have continuous development of the European Union, it is very significant to have correct sectors/areas defined for smart specialization of each region. Any mistake in this procedure will cause slowing down of EU development process and will decrease EU capabilities to compete correctly and successfully with the rest of the world. Authors used QGIS software to visualize data on smart specialization sectors and data in countries' economies. Analysis made using this methodology shows lack of correlation between chosen/defined smart specialization sectors for certain countries and economic factors related to those countries.

In this article authors analysed sector of agriculture and food production and they proposed new method to cross-check smart specialization defined areas of agriculture with real economic data from regions' agriculture sectors. The authors suggest that this method should be used to cross-check smart specialization process outcomes for any sector of economy which was defined as focus sector. In order to avoid errors in decision making process, such a procedure should thoroughly be implemented in all regions and countries (where it is feasible).

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QUALITY ENGINEERING

Software Testing: Survey of the Industry Practices

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***Abstract* - The objective of this survey was to explore industry practices concerning software testing. We studied software organizations to assess how they test their products and what process models they follow. The data collection was implemented as an online implementation of the survey method. Additionally the collected data was compared to our prior survey study to understand how the industry practices have changed. According to our results, the organizations have shifted towards test automation and more sophisticated testing infrastructure, they apply more agile practices even in the mission-critical software, and they have reduced the use of formal process models.**

Keywords - software testing; survey; industry practices; quality assurance

I. INTRODUCTION

Testing can be one of the most expensive tasks for any software project. Besides causing immediate costs, problems of testing are also related to the costs of poor quality, malfunctioning programs and errors that cause large additional expenses to software producers during the maintenance [1], [2]. The costs related to testing are on the rise; the software industry has identified a need for reducing the growing cost of test environment management [3].

The objective of our study was to explore the software organizations' testing practices, tools and development process models to give an up-to-date picture of industry practices. In addition to answering these questions, this study is also a continuation study to our previous surveys (year 2009 [4] and year 2005 [5]) on the testing practices and test automation in the software industry. Comparison between earlier and current observations reveal changing practices.

The actual testing practices of the software industry were observed via an online survey, conducted in the beginning of 2017. We surveyed organizational units (OU) representing different sizes and business domains in software development. The survey questionnaire consisted of multi-choice, multi-item questions to collect quantitative data for statistical analysis and of open-ended questions for qualitative analysis. This mixed methods study [6] facilitated triangulation of the results [7]. Both the collected quantitative and qualitative data were used to assess the current practices, and compare our new results against our earlier survey results conducted seven years ago. According to the results, the applied software development models seemed to have shifted towards agile practices, causing changes in the testing infrastructure and test phases' emphasis. The number of automated tools in testing was rising, while the use of the formal process models and capability-maturity models were generally declining.

The work is structured as follows: In Section 2, related surveys and studies are introduced. Section 3 discusses the applied research method used in this work, and Section 4 presents the actual survey results with comparison to the results of our earlier survey. Discussion and conclusions are given in Sections 5 and 6, respectively.

II. RELATED WORK

In addition to our earlier industry-wide survey of test automation and testing practices [4], software testing and test process improvement have been studied by others, for example, Ng et al. [8] in Australia and Chen et al. [9] in China. The study by Ng et al. applied the survey method to establish knowledge on such topics as testing methodologies, tools, metrics, standards, and training. Their study indicated that the most common barrier to developing testing was the lack of expertise in adopting new testing methods and the costs associated with testing tools; also in their study, only 11 organizations reported that they met the testing budget estimates. In a similar vein, Torkar and Mankefors [10] surveyed different types of communities and organizations. They found that 60% of the developers claimed that verification and validation were the first to be downgraded in cases of serious resource shortages during a project.

As for the industry studies, a similar study approach has previously been used in other areas of software engineering. For example, Ferreira and Cohen [11] completed a technically similar study in South Africa, although their study focused on the application of agile development and stakeholder satisfaction. Similarly, Li et al. [12] conducted research on the Commercial Off-The-Self (COTS) based software development process in Norway, Chen et al. [9] studied the application of open source components in software development in China, and Belt et al. [13] surveyed major Scandinavian telecom companies to identify the challenges of testing. Overall, case studies covering entire industry sectors are not particularly uncommon [14], [15].

On longitudinal studies in the development of testing practices, Garousi and Varma [16] conducted a series of surveys in the province of Alberta in Canada. They observed that from 2004 to 2009, the industry transitioned with a distinct elevation of codified practices: all V-model [16] levels of testing work (unit, system, and acceptance) increased along with the level of applied test automation. In addition, the amount of systematic training for the test personnel increased in all of the measured categories. Garousi and Zhi continued the work in 2013 with a nation-wide follow-up survey on the actual software testing practices, where they observed that new tools and development practices have been adopted in the Canadian industry since the prior study [17].

A study of testing practices by Lee, Kang and Lee [18] surveyed the amount of applied testing tools and test practices in South Korea. Their study reveals that even within the last ten years, some software organizations (12% of answers) have not had any meaningful test process or applied any test methods in practice. Interestingly, Lee, Kang and Lee also observed that in their survey population, application of system testing practices was more common than unit testing. One offered explanation was that unit testing is low level activity conducted by the developers, so it does not require separate tools or a process to be followed.

Khosla [19] estimated that in the near future, 80% of the staff in IT departments may be replaced by "artificial intelligence (AI) type systems." This estimate highlights, for example, automatic collection of run-time data, AI analysis of collected data together with testing and deployment automation during maintenance. Gartner report [20] also emphasizes the importance of automation. According to the Gartner report, software development phases cover 8 % and the maintenance phase, consisting of, for example, defect fixing, testing and deployment of new versions, covers 92 % of the total life cycle costs.

III. Research Method

The survey method described by Fink and Kosecoff [21] was used as the research method in this study in both of the surveys, in 2009 and again in 2017. The objective for a survey is to collect information from people about their feelings and beliefs. Further, surveys are most appropriate when information should come directly from the people [21]. Kitchenham et al. [22] divide comparable survey studies into exploratory studies from which explanations and estimates can be drawn, and confirmatory studies from which strong conclusions can be drawn. We consider this study as an exploratory, observational, and cross-sectional study that explores software testing practices and software quality approaches applied in the software industry.

The 2017 online survey questionnaire included eleven chapters containing questions of organization profile, software testing, test process maturity, applied process models and the tasks related to software development. The constructs were divided into multi-item questions based on, for example, theory, definitions or best practices of the construct. Multi-item questions are questions that are constructed by several items that measure one underlying construct. Chapters in the questionnaire were planned so that combining respondent's answers yielded holistic information of the surveyed organizational unit.

To facilitate comparison between our earlier and current survey, seven of the questionnaire chapters were taken directly from our earlier survey [4] which also observed testing and quality assurance practices. The design of the original data collection questionnaire was done by seven researchers from two different research groups. Two additional people were involved in the testing of the questionnaire with test interviews. The questionnaire for the data collection in 2017 was compiled by three researchers, and tested with representatives of our partner organization. The survey questionnaires from both 2009 and 2017 are available in the online appendix at https://doi.org/10.5281/zenodo.803995.

The 2009 and the 2017 survey both use the five point Likert scale: 1 fully disagree – 3 neutral – 5 fully agree. The 2017 survey was launched as a web survey via Webropol [23]. The sampling method was probability sampling. The survey was advertised in social media platforms such as LinkedIn, Facebook, Twitter and Researchgate, and by direct contacts to our industrial partners and open calls for participation in several public online discussion channels.

The survey results were analyzed with the R statistical language and its statistics ("stats") library [24]. In the statistical analysis, survey responses were also treated as single-item and not full constructs to see if the distribution of data between 2009 and 2017 had changed with any statistical significance. Descriptive statistics, displayed in more detail in the online appendix, were generated with the psych R library [25]. When analyzing interval data with the Mann-Whitney U statistical test, continuity correction was enabled to compensate for non-continuous data [26].

To estimate the sample size for our survey we used publically available statistics provided by the Ministry of Economic Affairs and Employment of Finland. According to the latest report of the software business sector from 2014 [27] there were 3360 companies whose main line of business was software production. The survey questionnaire was opened 930 times and it collected 33 unique responses from respondents working in different organizations within the four-week period it was available in January 2017. This gives the survey a response rate of 3.5 percent, which is fairly normal for Internet surveys according to Fink [21]. In comparison, the 2009 survey had 31 respondents from different software development organizations. This also indicates that both of the surveys had similar-sized sample of the software industry which also, while acknowledging some limitations similar to Iivari [15], were sufficient samples of the industry, and could be analyzed with quantitative approaches.

The survey was anonymous. To identify clusters and to classify answers we collected general information of the organizational unit. This information helped us to classify qualitative answers of the open-ended questions to quantitatively observed clusters. The objective of the study was not to collect data from a certain country but to reveal possible changes in the industry practices.

IV. SURVEY RESULTS

The survey questionnaire included general information of the organizational unit, a number of multi-choice, multi-item questions and open-ended questions. The multi-item questions was estimated by using the Cronbach alpha in the earlier surveys: The Cronbach coefficient alpha expresses the degree to which items in a scale are homogeneous.

Questions concerned the development practices and the available quality assurance infrastructure. In this section we present the survey results collected in January 2017. The results were compared against the 2009 results. We use mode as the primary indicator for individual items in the questionnaire, as the survey questions used an interval Likert scale. Additionally, we performed statistical analysis for the items of the multi-choice questions. In the following we only present results from the statistical analysis that were significant enough. Our anonymized survey dataset, along with the full statistical analysis, is also published in the online appendix.

General information of the organizational unit revealed that the division between the 33 organizations that took part in the survey was very even; very small, small and medium-sized organizations represented each about 21 percent of the participants, while 36.4 percent were large or very large (more than 250 employee) organizations. Approximately eighty percent of the organizations were private companies, while rest of the participants were government agencies or nonprofit organizations. Organizations focusing mainly on national operations formed 21.2 % of the respondents while 39.3 % of organizations focused mostly on international business. Out of all organizations, 30.3 % of them were in-between national and international scale. Out of all organizations, 18.2 % also considered themselves solely or primarily as open source developers. Of the people who responded to our survey, a majority (66.7 %) considered themselves primarily as software developers, while 12.1% had a management position and 15.2% worked in quality assurance. As for the mission-criticality of the organizations, 51.5 % of the organizations reported that product fault could cause remarkable economic losses. Two of these organizations indicated that a fault in their product could cause a loss of a human life. The profiles of the respondent's OUs are shown in Table 1.

The use of testing tools was measured by the question, application level of different software testing tools, and changes were observed through comparison to the earlier results. In this survey, a tool was defined as "an application, framework, web service, extra library, feature of your development environment etc. whichever supports completing the mentioned task".

Table 2 presents the number of used tools is illustrated as percentages in 2017 and 2009. As observable, the three most popular tool categories include defect reporting tools, test automation tools and unit testing tools. Defect/code tracing tools are used by over half of all surveyed organizations. When comparing the new data with the 2009 data, the overall popularity of testing tools has increased in most categories, in particular, test automation, tracing tools and defect reporting. Since 2009, the popularity of test case management (for example, ticketing systems would also fall into this category) remains high, but is no longer the most common testing-specific tool.

TABLE I. THE PROFILE OF THE 2017 SURVEY RESPONDENTS (N = 33)

Category	% of respondents
Very Small organization (1-10 employees)	21.2 %
Small (11-50 emp.)	21.2 %
Medium (51-250 emp.)	21.2 %
Large or very large (250+ emp.)	36.4 %
Private company	78.8 %
Government or non-profit organization	21.2 %
Open source developer organization	18.2 %
Primarily national business/operations	30.3 %
Primarily service business	45.5 %
Primarily product business	39.4 %
Mission-critical organization (remarkable economic losses or loss of human life)	51.5 %

TABLE II. THE PERCENTAGE OF APPLIED TESTING TOOLS IN THE INDUSTRY

Tool	% of respondents	
	2017	2009
Bug/Defect reporting	72.7 %	22.6 %
Test automation	66.7 %	29.0 %
Unit testing	57.6 %	38.7 %
Bug/Code tracing	57.6 %	3.2 %
Performance testing	48.5 %	25.8 %
Test case management	45.5 %	48.4 %
Integration testing	45.5 %	16.1 %
Virtual test environment	42.4 %	12.9 %
Quality control	36.4 %	19.4 %
Automated metrics collector	36.4 %	3.2 %
System testing	27.3 %	9.7 %
Security testing	24.2 %	3.2 %
Test completeness	24.2 %	6.5 %
Test design	15.2 %	22.6 %
Protocol/Interface conformance tool	9.1 %	6.5 %

The second chapter of the questionnaire discussed the observed test and quality assurance process problems, identified originally in 2009 [4] supplemented with new questions related to maintenance issues. New maintenance and support questions were added because maintenance and support activities have continued growing and are responsible for a large amount of the total lifecycle costs [20]. The observations, especially when comparing the 2009 data with 2017, implied that the configurability of the testing tools has become an issue, and that the support for different software platforms might become an issue, when observing the trend of the changes. Additionally, feature development during late development phases shorten testing schedule and it has become an increasingly pressing issue. The detailed results containing the self-assessment figures for both 2017 and 2009 are presented in Table 3.

The third chapter of the survey was software processes and the amount of agile practices in the organizations. In the survey of 2009, the industry was observed to be interested in the introduction of agile and, in general, more informal practices. Based on our responses, the results of

TABLE III. SOFTWARE TEST PROCESS PROBLEMS, AS IDENTIFIED IN OUR 2017 SURVEY AND IN 2009 [9]. RESPONSES ARE ON A SCALE OF 1 TO 5 (1 FULLY DISAGREE - 3 NEUTRAL - 5 FULLY AGREE)

	2017 mode	2009 mode
Complicated testing tools cause test configuration errors.	4	1
Commercial testing tools do not offer enough support for our development platforms.	3	1
It is difficult to automate testing because of low reuse and high price.	4	5
Insufficient communication slows the bug-fixing and causes misunderstanding between testers and developers.	4	2
Feature development in the late phases of the product development shortens testing schedule.	4	4
Testing personnel do not have expertise in certain testing applications.	4	4
Existing testing environments restrict testing.	3	4

this chapter are very in-line with the earlier results giving emphasis on the agility of the industry-applied processes.

The industry drive towards agile practices can also be observed from another chapter in our survey where we asked about the use of formal process models such as SPICE (software process assessment, ISO/IEC 15504, currently part of the ISO/IEC 33000 series) [28] or software testing standard (ISO/IEC 29119) [29]. The question covered also the utilization of capability and maturity models, such as TMMi - test maturity model integrated [30] or CMMi – capability maturity model integrated [31]. Based on our survey results, the use of formal models have decreased within the last eight years. Some form of process model (formal or self-defined) was applied by 21.2 percent of organizations (62.5 percent in 2009), while none of the organizations in 2017 applied capability or maturity certificates in their organization (it was 43.8 percent in 2009). In 2017, V-model, acceptance criteria for tickets and "generic agile" were mentioned, all based on best practices collected from various sources and "self-defined". Detailed division of answers is presented in Table 4.

The final chapter in the survey included questions concerning the software testing and quality assurance practices. In general, the results do not indicate any major shifts in the applied testing and quality assurance practices between the two surveys. Organizational units are confident that they are building the product right, and at the same time, building the right product. Survey responses detailed in Table 5 highlights some differences between the surveys: Testing schedules may not be kept (2009 mode 4, partially agree, 2017 mode 2, partially disagree) and time is not necessarily allocated enough for testing (2009 mode 4, partially agree, 2017 mode 2, partially disagree). Respondents are less confident in their function testing practices (3.8 vs. 2.9 in average between 2009 and 2017. 2009 mode 4, partially agree, 2017 mode 3, neutral). Statistical significance in the difference of distributions between the years for the single question "our functional testing is excellent" can be established with the Mann–Whitney U test, U=613 at significance level p=0.005. Formal inspections are the testing practices on which the surveyed organizations have become more confident (2009 mode 2, partially disagree, 2017 mode 4, partially agree), while code review practices have become more varied between different organizations (2009 mode 4, partially agree, 2017 mode 1, fully disagree).

In addition to multi-choice questions the survey contained open-ended questions, where we asked the respondents to explain how their organization manages the increasing testing and maintenance effort. The following themes were highlighted from the responses:

- Moving from proprietary software to open source
- Increasing the coverage of automated tests
- Focusing on service scalability in design
- Re-implementing legacy applications
- Setting up dedicated testing and development environments
- Offshoring testing work
- Establishing pre-planned maintenance time for projects, during which last defects are fixed
- Forming dedicated maintenance teams
- Emphasizing the responsibility of current developers
- Employing a risk-based testing approach to cover the most critical components rather than trying to get perfect coverage.

TABLE IV. THE USE OF FORMAL PROCESS MODELS AND CAPABILITY OR MATURITY CERTIFICATES IN ORGANIZATIONS

Category	2017	2009
Process model - Yes, formal	9.1 %	25.0 %
Process model - Yes, informal	12.1 %	37.5 %
Process model - No	63.6 %	37.5 %
Capability certificate - Yes, formal	37.0 %	0.0 %
Capability certificate - Yes, informal	6.3 %	0.0 %
Capability certificate - No	56.3 %	81.8 %

TABLE V. THE SELF-ASSESSMENT OF THE QUALITY OF THE DIFFERENT TESTING AND QUALITY ASSURANCE PRACTICES (1 FULLY DISAGREE – 3 NEUTRAL – 5 FULLY AGREE)

	2017 mode	2009 mode
Our software correctly implements a specific function. We are building the product right.	4	5
Our software is built traceable to customer requirements. We are building the right product.	5	4
Our formal inspections are OK.	4	2
We go through checklists.	2	3
We keep code reviews.	1	4
Our unit testing (modules or procedures) is excellent.	4	2
Our integration testing (multiple components together) is excellent.	3	3
Our usability testing (adapt software to users' work styles) is excellent.	3	2
Our function testing (detect discrepancies between a program's functional specification and its actual behavior) is excellent.	3	4
Our system testing (system does not meet requirements specification) is excellent.	3	4
Our acceptance testing (users run the system in production) is excellent.	4	4
We keep our testing schedules.	2	4
Last testing phases are kept regardless of the project deadline.	4	4
We allocate enough testing time.	2	4

V. DISCUSSION AND IMPLICATIONS

The objective of this study was to explore the testing practices of software companies, compare the results with earlier survey result from the year 2009 and thereby outline changes in software industry. The collected data is publicly available in the online appendix should other researchers want to validate, replicate or build upon our findings.

Overall, the availability and application level of testing- and quality assurance-dedicated tools has increased across the industry, in almost all measured categories. Especially tools related to automated testing (e.g. test automation, automated metrics collection, performance testing, tracing tools) have increased significantly. The respondents of the survey refer to testing and automated testing almost synonymously. The available testing tools in 2017 are more sophisticated than in the 2009, imposing less restrictions but causing more configuration problems.

The use of different formal standards, certifications and process models has decreased, while the amount of agile practices has increased moderately. The mission-criticality of the software no longer limits the organization from using agile practices or other informal approaches. In 2017, the last product features are introduced later during the development process than in 2009. This leads to increased shortages of testing resources (time) and puts more emphasis on the acceptance phase testing. Test design and documentation work in general have declined while the confidence in functional testing practices has declined. Issues in testing and maintenance are more related to software development processes and practices, the quality and coverage of testing, and test schedule rather than the cost of quality assurance.

The survey results indicate increase in test automation, a shift towards agile practices, and that the formal software process models are less popular among industry practitioners. Results are in line with the observations of, for example, Khosla [19]: the rise of automation in testing, deployment and maintenance. Growing test automation also fits well to the observations of the Gartner report [20]. Explanatory factors to the growing test automation include, for example, agile methods with regression testing [32], continuous deployment and integration to shorten the timespan between product versions [33], DevOps to lower the threshold between development and use [34], and the general requirements for automation in IT-departments, server rooms and data centers to reduce the costs [19].

In comparison to other industry surveys in software testing, our results suggest similar trends as, for example, Canadian software industry report by Garousi and Zhi [17]. The most important testing tools in our study include defect tracking, unit testing and test automation, and Canadian organizations see functional and unit testing as the most common testing work. Likewise, Canadian organizations perform testing activities mostly during a dedicated testing phase in development (test-last approach). Our respondents did not suggest any other approach than test-last, and our results indicate that test phases may even be skipped in some circumstances.

Formal process models are more common in large and very large organizations. According to the study of Hardgrave and Armstrong [35], small and medium-sized organizations are able to apply the principles and best practices of the formal models in their work. Therefore, the reason for the decreasing use of the process models cannot be directly explained, and has to be assessed in more detail in the future works.

Concerning the validity of the study, even though the survey constructs and questions between the rounds were almost the same, there were differences in the data collection procedures: in 2009 the data was collected by interviewing representatives of software organizations whereas the 2017 dataset was collected online. The number of interviews in the 2009 dataset was 32 and the number of filled on-line questionnaires in the 2017 survey was 33. The response rate of 2017 was in line with the estimates given for on-line surveys [21]. The sample is small but comparable with the sample of 2009 and the observations are presented as explorative and not as strong conclusions. Overall, the metrics presented in this paper are accumulation data from the survey, so the researcher bias on the results should be minimal. The 2017 results were largely similar to the 2009 results, which adds to the rigor of the results, and helps highlight differences between the years.

VI. CONCLUSION

The results of the survey presented in this paper indicate that the software testing practices have undergone some changes in the industry within the last eight years. First, automation in testing has continued its growth. Within testing trends, automation has become more common on all levels of testing. Second, the application of formal software process models and capability maturity models seems to have decreased, while the testing tools have become increasingly common and more sophisticated.

This change is also reflected by the organizational considerations over the testing tools: the tools no longer restrict the organizational unit as much as they did in 2009 but in exchange, configuration problems and lack of platform support have become increasingly common. Also testing done during the design phase is decreasing. Since the last features are introduced later in the software development process, the emphasis on the late testing and, especially, acceptance testing has increased, while, at the same time, available time for testing work has decreased. Overall, the changes are not dramatic but the industry practices evolve as we can observe from the comparison of the surveys.

In our future work, the focus is on the expenses of testing and quality assurance. Based on our observations, the reduced use of formal processes, and the need to push new features into the product, mean that the products need better support for acceptance testing, regression testing and in general quality assurance for the features added after the initial launch. This study area is interesting, since the reduction of the costs of the maintenance cycle and automated regression testing would probably have a meaningful impact on the overall costs of quality assurance work.

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Code quality measurement: case study

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***Abstract* - As it stands, the maintenance phase in the software lifecycle is one of the biggest overall expenses. Analyzing the source code characteristics and identifying high-maintenance modules is therefore necessary. In this paper, we design the architecture for a maintenance metrics collection and analysis system. As a result, we present a tool for analyzing and visualizing the maintainability of a software project.**

Keywords - maintenance, code quality

I. INTRODUCTION

Maintenance and upkeep is a costly phase of software life cycle. It has been estimated that maintenance can reach up to 92% of total software cost [1]. Code quality can be analyzed using various existing metrics, which can give an estimate on the maintainability of software. There are several tools and frameworks for assessing the maintainability characteristics of a project. Many tools are included in integrated development environments (IDEs), such as Eclipse metrics [2], JHawk [3] or NDepend [4]. As such the existing tools are specific to platform and programming language, providing quality analysis during development. Considering maintenance also includes activities post-release of a software product, it would be beneficial to perform quality measurement also in the maintenance and upkeep phase of life cycle.

One solution to the post-release monitoring are online data gathering probes, which can be inserted into production code to gather runtime performance data. In order to establish and sustain a commitment for maintenance measurement this work introduces a design for data collection and storage. In this paper we present an architecture for systematically collecting code metrics for maintenance. Additionally, the visualization and analysis of the metrics are explored.

In this study we will focus on the analysis of web-applications. This delimitation is due to the collection of runtime metrics as well as static metrics. The focus on web-applications provides a reasonably standardized measurement interface for runtime performance through the browser's web API. In this paper we also propose the design and implementation of the system called Maintain. The probes for gathering metrics in the system are implemented in both JavaScript and Ruby programming languages.

Rest of the paper is structured as follows. In Section 2, related work in analyzing software maintainability is introduced. Sections 3 and 4 presents the architecture and our implementation for a metrics collection and analysis system, which is main contribution of this work. Evaluation of the system's performance and utility is presented in Section 5. Finally, discussion and conclusions are given in Section 4.

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II. RELATED RESEARCH

Software maintenance, as defined by ISO 14764 standard, is the "the totality of activities required to provide cost-effective support to a software system", consisting of activities both during development and post-release [5]. The analysis of software maintainability is by no means a novel concept. Motogna et al. [6] presented an approach for assessing the change in maintainability. In [6], metrics were developed based on the maintainability characteristics in the ISO 25010 software quality model [7]. The study presents how different object oriented metrics affect the quality characteristics.

A study by Kozlov et al. [8] distinguished that particular code metrics (data variables declared, McClure Decisional Complexity) have strong correlations with the maintainability of a project. In the work, the authors analysed the correlation between maintainability and the quality attributes of a Java-project.

In the study by Heitlager et al. [9] a practical model for maintainability is discussed. The study discusses the problems of measuring maintainability, particularly with expressing maintainability as a single metric (Maintainability index).

Studies where different evaluation methods are combined in order to get a more thorough view on the maintainability of a project have been conducted during the past decade. For example, Yamashita [10] combined benchmark-based measures, software visualization and expert assessment. In a similar vein, Anda [11] assessed the maintainability of a software system using structural measures and expert assessment. In general, these studies suggest that visualization systems providing developers and project managers with an analysis of the health of a software project can help distinguish problematic program components, and thus help in the maintenance efforts of software.

III. ARCHITECTURE

Maintain system architecture is presented at the figure 1. System consists of the following components:

- *Probe* is a program that gathers some valuable data from the software (static or dynamic). Each probe should have an associated analyzer;
- *Data Storage* – data storage that stores the raw data from the probes. It also has REST interface that receives the data from the probes;
- *Analyzer* is a program that gets the raw data from the associated probe and creates a report, based on this data;
- *Report Storage* – data storage that stores reports from analyzers;
- *Report Visualizer* is a component that creates a visual representation of the report.

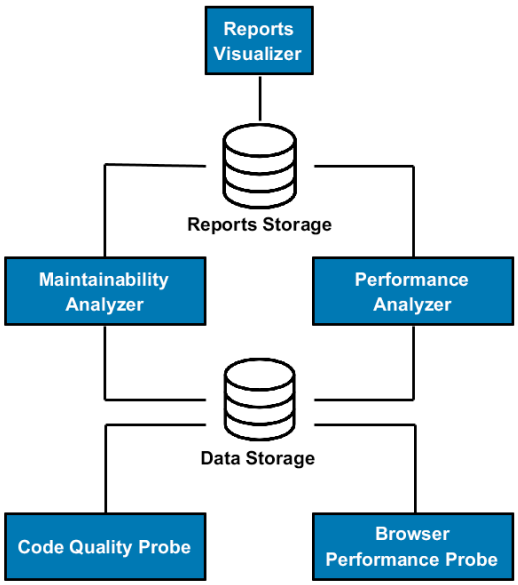

Figure 1. System architecture

Workflow of the system is centered around the Data Storage. Generally, it looks like this:

- Probes gather the information from the source code, it might be some static analysis results or dynamic performance data;
- Gathered and normalized data is sent to the Data Storage. Probe can have different data types, data structure is defined by analyzer;
- When new data is received by Data Storage, the associated analyzer is called. It requests the data from the Data Storage, produces report (object, that contains current status of the analyzed application aspect and a set of time series for the end user);

When end user requests the report, Reports Visualizer generates a visual representation of the time series, that were created by analyzers.

IV. Implementation

Maintain system was implemented using Ruby on Rails framework and hosted on Heroku cloud platform. Project details page is shown on Figure 3. This page provides the information about the current state of the project, that is described as a set of 8 scores, based on quality characteristics, described in ISO/IEC 25010 [7]. Those scores are visualized as a polar chart with 8 axis for each quality characteristic respectively. Score calculation is based on the report statuses – each report has an associated probe, and each probe has a set of associated quality characteristics. Quality characteristics are set by the project administrator.

System class structure is organized as pictured in figure 2. As system gathers the data using REST API, it is generally impossible to predefine all possible probes and probe types and set their quality characteristics in advance. That's why we decided to let user define the quality characteristics for probe when it is created or modified. Result score is based on statuses of last reports for each probe respectively.

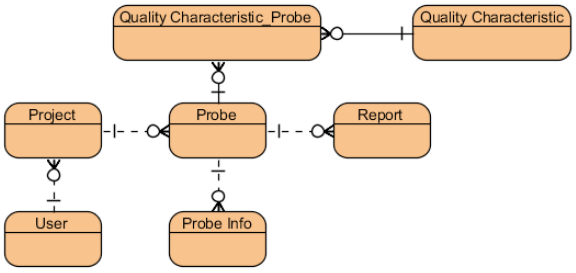

Figure 2. System entity-relationship diagram

A. Probes

As a case study, we have implemented four probes: HAML, JavaScript and Ruby code quality probes, and browser performance probe. JavaScript and Ruby code quality probes are based on maintainability index, which is calculated using the following formula:

```
maintainability = 171 –
                  (3.42*Math.log(effort))-
                  (0.23*Math.log(cyclomatic))-
                  (16.2*Math.log(loc))
```

HAML maintainability index uses recursive formula, based on linter report:

```
Maintainability = a*maintainability
```

where **a** is 0.9 for linter error and 0.99 for linter warning

Code quality probes produce the following data for Data Storage:

```
{
    maintainability: M,
    revision: R,
    datetime: D,
    modules: Ms
}
```

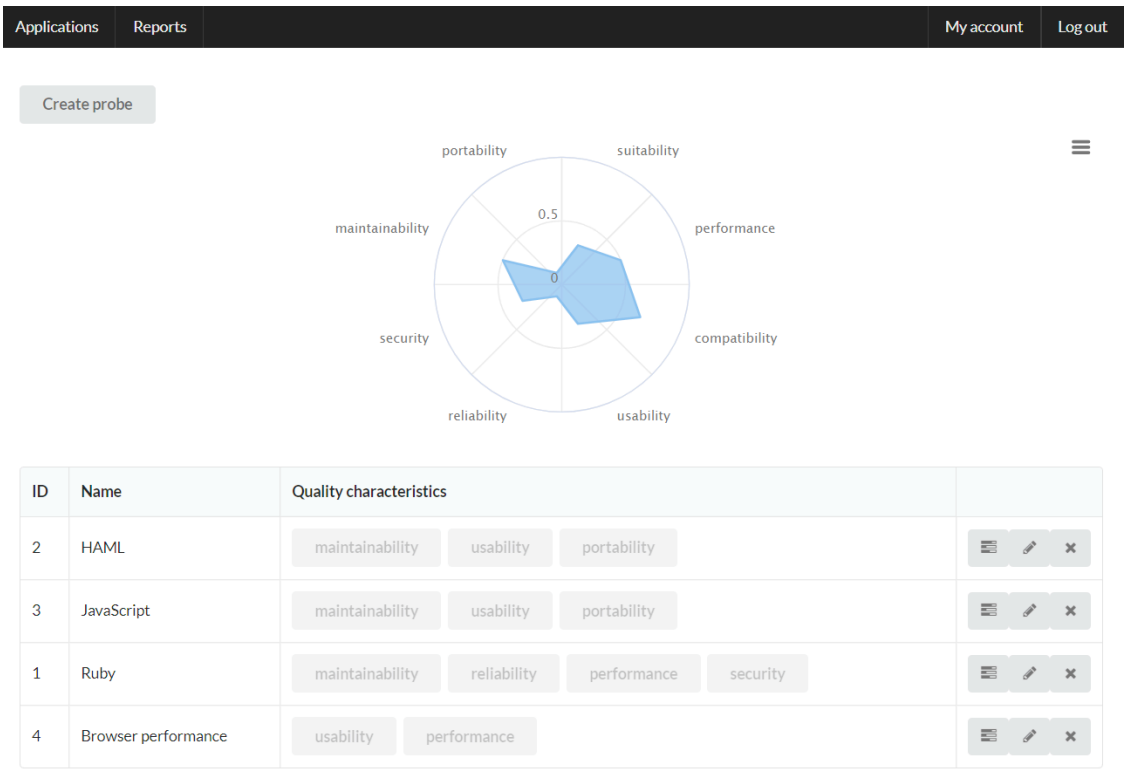

Figure 3. Project page example

where M is average maintainability index for the whole project, R is current Git revision, D is current date and time, and Ms is a list of maintainability index for project files and their names. Browser performance probe generates report in different format:

```
{
    page: P,
    timing: T,
    datetime: D
}
```

Where P is an URL of the current page (without query), T is the time between page load start time and DOM ready event time in milliseconds, and D is current date and time.

B. *Analyzers*

Currently we have implemented two different analyzers - maintainability analyzers for Ruby, JavaScript and HAML probes, and performance analyzer for browser performance probe. Workflow for maintainability analyzer works is described below:

- Data from Data Storage is grouped by days, maintainability index for each day calculated as a median of indices for day. If no data presented for day, analyzer sets the value for the previous day (fallback for weekends);
- List of maintainability indices are smoothed using exponential moving average method, those values are used as a time series for visualizer;
- Linear regression for last five days is used as a status of the project source code quality: if it is less than zero, then code quality is bad.

Workflow for browser performance analyzer is different:

- Performance data is grouped by five minutes, value for each section is calculated as a 95th percentile of all values for section;
- If values for all sections are less than 2 seconds, then browser performance is good.

V. MAINTAIN SYSTEM USAGE EXAMPLE

Maintain system was evaluated using a proprietary web application, that was implemented using Ruby on Rails as a backend, and CoffeeScript on top of React.JS as a frontend. This project is on maintenance phase, so we decided to analyze historical data and compare Maintenance system results with the feedback from the project manager, who managed the analyzed project. Application was used by 5 administrators and about 10000 users. Maintenance system was deployed in Heroku cloud, while probes were running on local PC, that had 1.8 GHz 2-core CPU and 4 Gb RAM. We gathered the code quality information for all the previous commits to make picture more consistent.

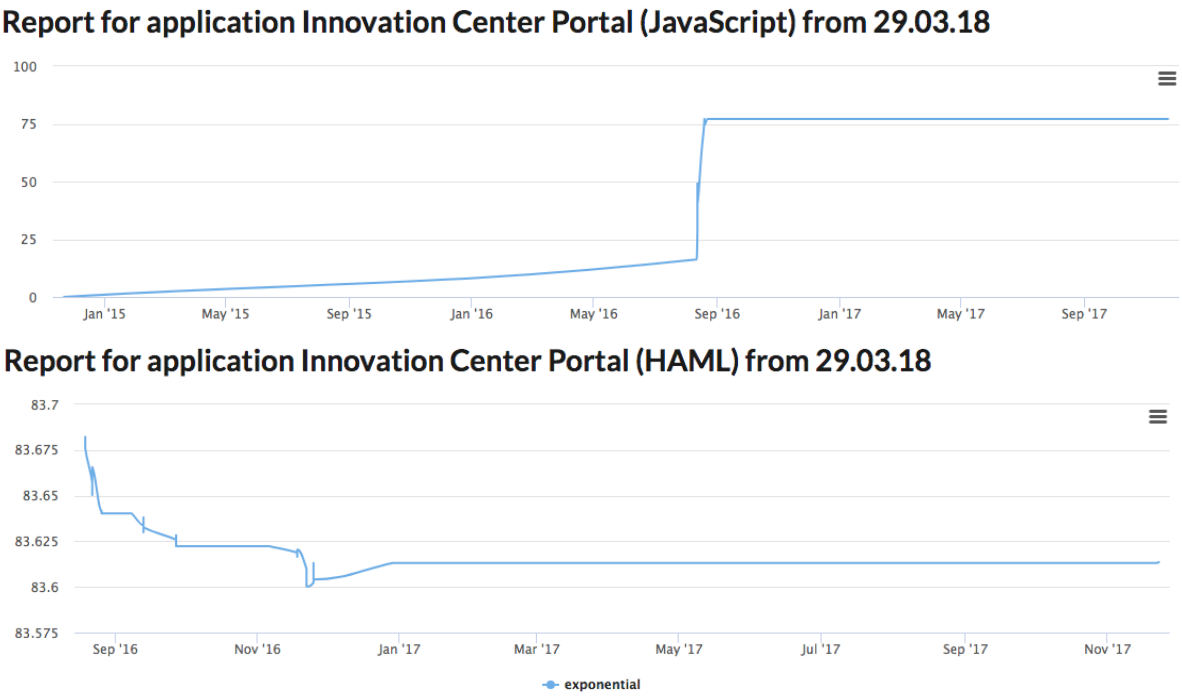

Figure 4. Project code quality measurements

Figure 3 illustrates the general 'health' of the analyzed application at the last Git revision at Master branch. Figure 4 shows the JavaScript (CoffeeScript) and HAML code quality. The project was started as a pure backend solution, while frontend development started at the beginning of September 2016. As shown in the graph, HAML code quality was decreasing from September 2016, until December 2016, then it was stable. This behavior can be explained by a deadline of the project, that was at the end of the year 2016. After the deadline, the project active development stopped. Project manager evaluated the results and stated, that such an 'early warning' system could notify the team and save some development resources.

VI. Discussion and Conlusion

The objective of this study was to facilitate the systematic collection and analysis of maintenance metrics, in order to reduce the effort required in the maintenance phase of software already during development. To realize the goal we designed and implemented an architecture for a system which can be used to collect both static and runtime metrics of a software project. We then implemented analysis tools to visualize these metrics, and display the most high-maintenance modules in a project repository.

The novelty of the presented work is the extendibility and modularity of the architecture. The architecture is not platform specific. New probes and corresponding analyzers can be added at any stage, using the REST API with any programming language or platform. The data storage and reporting system provide a common interface for the systematic collection of quality metrics, allowing the developers of a project to establish and sustain a commitment for quality measurement.

Providing a platform to establish the measurement commitment is important, because previous research shows that the quality assurance and testing practices of developers do not necessarily line up with measurement possibilities distinguished in academic research. For example, the recent study by Garousi and Felderer distinguishes that the industry and academia have different focus areas on software testing [12]. Likewise, Antinyan et al. show in [13] that existing code complexity measures are poorly used in industry. In this work, we used the maintainability index as an indicator for code quality, as it has been used in both academia and industry. In future, we should work on evaluating whether quality metrics presented in academic publications could be implemented into our system as probes providing reliable measurements.

Additionally, in future work we aim to develop more measurement probes in the system. We should evaluate the different metrics to distinguish which measurements provide the most useful information about software maintainability.

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Cross-release code churn impact on effort-aware software defect prediction

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Code churn has been successfully used to identify defect inducing changes in software development. Our recent analysis of the cross-release code churn showed that several design metrics exhibit moderate correlation with the number of defects in complex systems. The goal of this paper is to explore whether cross-release code churn can be used to identify critical design change and contribute to prediction of defects for software in evolution. In our case study, we used two types of data from consecutive releases of open-source projects, with and without cross-release code churn, to build standard prediction models. The prediction models were trained on earlier releases and tested on the following ones, evaluating the performance in terms of AUC, GM and effort aware measure P_{opt}. The comparison of their performance was used to answer our research question. The obtained results showed that the prediction model performs better when cross-release code churn is included. Practical implication of this research is to use cross-release code churn to aid in safe planning of next release in software development.

Keywords : Cross-release code churn, software defect prediction, software metrics

I. INTRODUCTION

Software defect prediction is focused on predicting defects during the software product life cycle at its earliest stage. There is a number of studies that investigate the impact of various metrics for software defect prediction purposes. A recent study by Nagappan and Ball analyzed the influence of relative code churn metrics which measure the amount of code change to predict file-level defect density. They concluded that the relative code churn metrics improve the prediction of defect density in large industrial software systems and can be used to discriminate between fault-prone and non-fault-prone software modules, i.e. classes [1]. In this paper, the focus of our research is to analyze the impact of both relative and absolute cross-release code churn on standard prediction models. We use the term cross-release code churn to define the difference of software metrics in a class between the current release of a software product and one or more previous releases.

Software products in evolution have a great number of different versions of program code. With each new version, there is a possibility to introduce new defects. Hence, it is important to define which software metrics are critical indicators for the appearance of defects. Recent studies have analyzed the impact of code churn between each version of project development [2][3][4]. Their conclusion was that code churn is very effective in effort just-in-time defect prediction, but it is neglected in existing studies [4]. That motivated us to analyze code churn between project releases, where all the changes are stabilized. Our recent study has found that several software metrics and its cross-release code churn achieves moderate level of correlation with the appearance of defects [5]. For each class we defined two types of cross-release code churn:

- between its version in the current project release and in the previous release, referred as Previous,
- between its version in the current project release and its oldest version, referred as Oldest.

In this study, we continue in this research direction and analyze whether datasets enriched with cross-release code churn can be used to improve the performance of defect prediction models. Experimental results using publicly available datasets show that the prediction performance of effort-aware models may be improved from a cost-effectiveness point, compared to the traditional, non-effort-aware models [2]. Guided by this, we implemented an effort-aware defect prediction model, similar to Mende and Koschke [6]. In such a prediction model, the prediction is based on a binary indicator, that is 1 if defects are present and 0 otherwise, and effort, that is expressed in terms of lines of code (LOC).

This study used defect prediction models that are based on standard classifiers, namely Random Forest, Logistic Regression, Naïve Bayes and J48. They were tested on 10 consecutive release of two open-source Eclipse projects and evaluated in terms of their classification power and effort-awareness. By comparing the results obtained with the original datasets and with the cross-release code churn enriched datasets, we managed to determine to which extent cross-release code churn improves defect prediction. We concluded that Logistic Regression classifier gained the best results. Generally, defect prediction is most affected by Previous and Oldest types of datasets. Hence, the contributions of this paper is the analysis of the predictive effectiveness of cross-release code churn through a comparison of six types of datasets enriched with cross-release code churn and original datasets.

The remainder of this paper is structured as follows: Firstly, we described the related work in Section 2. Next, we describe the specifics of our case study, the datasets, methodology and the evaluation technique in Section 3.

The results of this study are presented in Section 4 and lastly, we conclude this paper in Section 5.

II. Related work

Many studies have researched the impact of object-oriented (OO) design metrics on prediction of defects for software in evolution. Additionally, some studies have shown that OO metrics are better predictors than "traditional" code metrics [7]. Also, a number of papers describe the influence of relative code churn metrics, such as Nagappan and Ball, which measure the amount of code change to predict file-level defect density [1].

A study by Arisholm et al. [8], Menzies et al. [9], Mende and Koschke [6], and Kamei et al. [10] examines the performance of effort-aware defect prediction models. Mende and Koschke [6] use the number of lines of code as a measure of reviewing effort similarly to Arisholm et al. [11]. Whereas for file-level prediction the number of lines of code in a file is used as a measure of the effort required to review the file [8], [9], this paper uses the total number of lines modified by a change. For example, if a change adds and deletes many lines, it requires more time to validate than a change that adds or deletes fewer lines. This type of effort-aware prediction offers a more practical adoption oriented view of defect prediction results.

Although different techniques (e.g., logistic regression, Naive Bayes, neural networks) are used in the field of defect prediction, it is not obvious whether the factors that work well in one technique will also be useful in other methods [12]. Hence, we used four classifiers of different types as the defect prediction model in this paper: Random Forest, J48, Logistic Regression and Naive Bayes. The study started with J48 and Random Forest methods. They are widely used as defect learners and have been proven to perform quite well for defect prediction [13]. Later we introduced the Logistic Regression [7], [14], [15] and Naive Bayes methods to expand the research on standard statistical and probabilistic classifier, respectively, and thus, obtaining results that are more general. The output of the used models is a probability that a certain class is fault-prone [2] and the final classification decision is dependent on a cut-off value. If the output probability is above the cut-off value, a software module is classified as fault-prone.

Investigation of a greater number of software projects increases the diversity of investigated data and thus improves the external validity of the research results [12]. Therefore, this study investigated data from two open-source projects, Eclipse PDE and JDT.

III. Case study

A. Methodology

In our previous study we presented the methodology to process software defect prediction datasets from consecutive releases of open-source projects and calculate the cross-release code churn. The values were obtained with the use of a Python algorithm [5]. Cross-release code churn was computed as difference between the values of software metrics that describe a class. For each class, the difference can be computed between its version in the current release of a software project and its first (oldest) appearance in the evolution of the project or its version in the previous release of the project. In this paper, type of dataset that contains differences computed between current and oldest appearance of a class is referred to as Oldest, while Previous is referred to type of dataset that contains differences computed with previous release.

Since this study is interested in cross-release code churn, two additional cases were also considered. The classes that do not contain any change compared to the previous (or oldest) release, i.e. the classes with all the cross-release code churn equal to zero, were not considered in these cases. The first case considered releases with classes that have not been changed but had detected defects and the classes that are changed, regardless of the defect occurrence. The second case considered only the classes that have been changed, regardless of the defect occurrence. The summary of our notation for all types of datasets and its descriptions are given in Table1.

B. Datasets

Types of datasets used in our research consist of software classes that are described by their class path (class name) and 49 software metrics. Full list of metrics and the explanation of their abbreviations can be found in [16] and on-line. The type of dataset, referred to as Original, includes 10 consecutive releases of Eclipse JDT (Java Development Tools) and 10 consecutive releases of PDE (Plug-in Development Environment) open source projects. Based on Original type of dataset other types of datasets were obtained as we presented in Table 1. These types of datasets contain cross-release code churn. Additionally, two more cases were included in our

I. Types of datasets

Label	Description
Original	Dataset from open source project which have not been modified, do not contain cross release code churn.
Oldest	Dataset with cross-release code churn computed as difference between current release and its first (oldest) appearance for each class.
Oldest_case1	Oldest dataset that do not contain classes without defects.
Oldest_case12	Oldest dataset that do not contain classes without defects and classes with uncorrected defects.
Previous	Dataset with cross-release code churn computed as difference between current release and its previous release for each class.
Previous_case1	Previous dataset that do not contain classes without defects.
Previous_case12	Previous dataset that do not contain classes without defects and classes with uncorrected defects.

research regarding the Previous and Oldest types of datasets, described in Methodology.

C. Prediction models

Predictive models were built with J48, Random Forest, Naive Bayes and Logistic Regression. J48 is a class for generating a pruned or unpruned C4.5 decision tree. Random Forest is a class for constructing a forest of random trees. Naive Bayes is a class for a Naive Bayes classifier using estimator classes. Lastly, Logistic Regression is a class for building and using a multinomial logistic regression model with a ridge estimator. We used Logistic Regression model instead of a linear because our class value is binary (i.e. defect or not).

The implementation of all four classifiers, which are used to build the prediction model (Random Forest, Logistic Regression, Naïve Bayes and J48), is based on WEKA (Waikato Environment for Knowledge Analysis) library written in Java programming language. The prediction models are built using previous releases as training datasets and then utilized to predict the fault-prone classes in the current release [13]. To evaluate the performance of defect prediction model the following three metrics were used: P_{opt}, Area Under Curve (AUC) and Geometric Mean (GM).

D. Evaluation

There are four possible outcomes of binary classification, which are presented by confusion matrix in Table 2.

- TP (true positive) are correctly classified software modules with defects,
- TN (true negative) are correctly classified software modules without defects,
- FP (false positive) are incorrectly classified software modules without defects,
- FN (false negative) are incorrectly classified software modules with defects.

Using the four outcomes from confusion matrix, we may calculate various evaluation measures to quantify the performance of prediction models. In this study, the prediction performance of classifiers is evaluated in terms of commonly used measures for binary classification AUC and GM and in terms of effort-aware measure P_{opt}. AUC and GM are based on confusion matrix, while P_{opt} is based on effort that is required to resolve all the defects according to the principle that the simplest software modules are inspected first [2]. The range of values of all three evaluation measures is [0, 1], with higher values corresponding to better performance.

II. CONFUSION MATRIX

	True class	
Classified as	**Defect**	**Non defect**
Defect	TP	FP
Non defect	FN	TN

The *AUC* measure is calculated as the integral of Receiver Operating Characteristic (*ROC*) curve, where the *ROC* curve presents the trade-off between *TPR* and *FPR*. Different trade-off levels are obtained by changing the classification cut-off values. Cut-off values represent the probability above which we transform the probability given by a classifier into the positive class. True Positive Rate (TPR), i.e. sensitivity, is used to measure the percentage of actual positives which are correctly identified. False Positive Rate (FPR), i.e. fall-out rate, represents the percentages of the false positives which are incorrectly identified. Equations (1) and (2) are used to calculate TPR and FPR, respectively:

$$TPR = \frac{TP}{TP + FN} \tag{1}$$

$$FPR = \frac{FP}{FP + TN}. \tag{2}$$

The GM measure represents the geometric mean between classification accuracy of positive and negative class, i.e. TPR and TNR. True Negative Rate (TNR), i.e. specificity, presents a measure of the percentage of actual negatives which are correctly identified and it is calculated as (3):

$$TNR = \frac{TN}{TN + FP}. \tag{3}$$

The GM measure is used instead of a more general evaluation measure accuracy, because of its sensitivity to class-imbalance problem, which is common in software defect prediction [16]. It is computed as a square root from a TPR and TNR product; as shown in (4):

$$GM = \sqrt{TPR * TNR}. \tag{4}$$

The P_{opt} measure is based on the concept of the "code-churn-based" Alberg diagram used to show the performances of prediction model *m* [2], as shown on Fig. 1. In this diagram, the x-axis and y-axis are respectively the cumulative percentage of code churn of the changes (i.e. the percentage of effort) and the cumulative percentage of defect-inducing changes found in selected changes. To compute P_{opt}, two additional curves are included: the "optimal" model (full line on Fig. 1) and the "worst" model (dotted line on Fig. 1). In the optimal model and the worst model, changes are respectively sorted in decreasing and ascending order according to

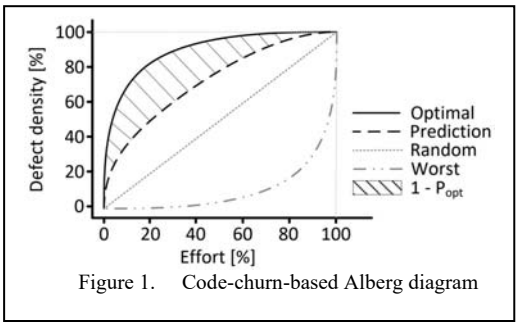


Figure 1. Code-churn-based Alberg diagram

their actual defect densities. According to [2] and [3], P_{opt} can be formally defined as shown in (5).

$$P_{opt}(m) = 1 - \frac{Area(optimal) - Area(m)}{Area(optimal) - Area(worst)} \quad (5)$$

When calculating the P_{opt} measure we used the defect density (DD) calculated as shown in (6).

$$DD(x) = \frac{Y(x)}{Effort(x)} \quad (6)$$

In (6) the *Y(x)* is 1 if the change is defect inducing and 0 otherwise and *Effort(x)* is the amount of effort required by the change (i.e. the number of modified lines) [2].

IV. RESULTS

The results obtained from using different types of datasets and various predictive models are described in this section. The results are graphically presented in Figures 2 to 10. The x-axis shows the number representing the project release, while the y-axis represents the obtained values for each of the evaluation measures, i.e. P_{opt}, AUC and GM. Under each graph there is also a table presenting the obtained values for easier interpretation of the results. Due to space limit, only the best results are shown graphically, thus the general conclusions are described afterwards. The analysis includes all types of datasets, presented in Table 1, and their comparison with the results obtained when using the Original type of dataset to examine which type of cross-release code churn enhanced type of dataset yields the best upgrade in predictive performance. We analyzed types of datasets related to the oldest version comparison and previous version comparison separately. The goal of this analysis was also to see to which extend do certain types of datasets influence the prediction of defects. Additionally, we compared each of the previously mentioned classifiers to conclude which classifier gives the greatest increase.

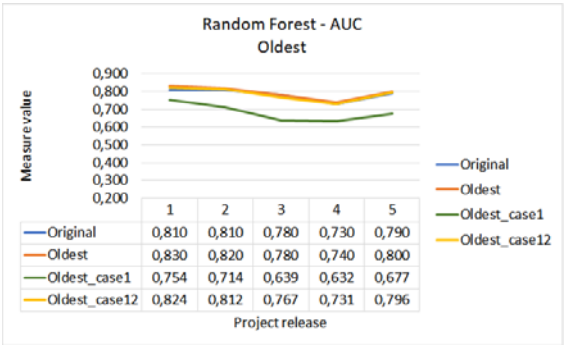
A. Java Development Tools project (JDT)

In Fig. 2 in terms of P_{opt} measure, we can see that the Previous_case12 type of dataset (yellow line) as well as Previous type of dataset (orange line) achieves better results in every release of the project compared to the Original type of dataset (blue line). Among all the previous types of datasets, the Previous_case12 and Previous types of datasets achieved the best results with average increase of 5%. The worst results were achieved by Previous_case1 (green line) type of dataset. The performance of Logistic Regression classifier had the highest improvement in the results, achieving 8% increase for the second release. The increase in the performance of Random Forest classifier is small in general.

In Fig. 3 we can see that the Oldest type of dataset (orange line) achieves better results throughout the project development compared to Original type of dataset

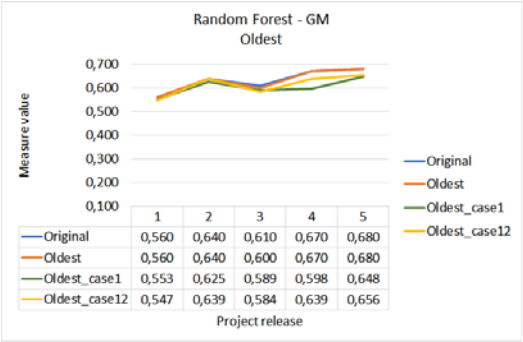
	1	2	3	4	5
Original	0,575	0,599	0,555	0,555	0,562
Previous	0,642	0,671	0,600	0,562	0,599
Previous_case1	0,627	0,638	0,502	0,565	0,631
Previous_case12	0,639	0,680	0,578	0,574	0,608

Figure 2. Logistic Regression - previous types of datasets result comparison for P_{opt} evaluation measure (JDT project)



	1	2	3	4	5
Original	0,810	0,810	0,780	0,730	0,790
Oldest	0,830	0,820	0,780	0,740	0,800
Oldest_case1	0,754	0,714	0,639	0,632	0,677
Oldest_case12	0,824	0,812	0,767	0,731	0,796

Figure 3. Random Forest - oldest types of datasets result comparison for AUC evaluation measure (JDT project)



	1	2	3	4	5
Original	0,560	0,640	0,610	0,670	0,680
Oldest	0,560	0,640	0,600	0,670	0,680
Oldest_case1	0,553	0,625	0,589	0,598	0,648
Oldest_case12	0,547	0,639	0,584	0,639	0,656

Figure 4. Random Forest - oldest types of datasets result comparison for GM evaluation measure (JDT project)

(blue line) in terms of AUC measure. The highest gained increase is in the earliest version, however only by 2%. The average increase of Oldest type of dataset results is 1%. The worst results were achieved by Oldest_case1 (green line) type of dataset. From Fig. 4 we can see that the Oldest (orange line) type of dataset achieves the best results from all the oldest types of datasets (including case1 and case 2), however the obtained results are not better compared to the Original type of dataset (blue line).

In terms of P_{opt}, the best results were achieved by Previous type of dataset in all classifiers except Logistic Regression where Previous_case12 achieved the best results. Oldest types of datasets gained similar results compared to Original and generally gained poor results. The worst results were achieved by Previous_case1 and

Oldest_case12 types of datasets for all classifiers. Oldest and Previous types of datasets achieved the best results in terms of AUC metric for all classifiers with exception in Logistic Regression where Oldest and Oldest_case12 achieved similar results. The worst results were achieved by Oldest_case1 and Previous_case1 for all classifiers. In terms of P_{opt} and AUC compared against Original type of dataset, all types of datasets gained poor results for J48. The difference in the performance is practically insignificant for this classifier while other classifiers achieved better results. Results based on GM measure vary more for each classifier. Prediction model based on J48 classifier achieved better results only with Oldest type of dataset, while Logistic Regression achieved better results with all types of datasets. Naive Bayes classifier gained better results for Oldest and Previous types of datasets. The worst results were achieved by Previous_case1 type of dataset for all classifiers, while Oldest_case12 is the worst type of dataset for Logistic Regression and Naïve Bayes. The worst results for J48 and Random Forest classifiers were achieved by the Oldest type of dataset.

B. Plug-in Development Environment project (PDE)

In Fig. 5 the Oldest_case1 type of dataset (green line) achieved better results in every version of project development, with the exception of first and last version. However, these exceptions are still quite close to the Original type of dataset (blue line) with an average increase of 3% compared to the Original type of dataset. The highest increase is gained in the fourth release, increasing the P_{opt} metric by 11%. When using the Naive Bayes classifier and analyzing the results obtained from previous types of datasets, we can see an increase in the Previous (orange line) and Previous_case12 types of datasets (yellow line) presented in Fig. 6. From the Previous line we can see that the increase compared to the Original type of dataset is achieved in first, second and fourth version. The average increase in both cases is low, i. e. 1% with Previous and less than 1% with Previous_case12 type of dataset.

From Fig. 7 we can see that the Previous type of dataset (orange line) achieved an increase in earlier versions, i.e. increase by 3% and 4%, however in later versions it is only quite close to Original type of dataset (blue line), but not better. The average increase is less than 1% compared to the Original type of dataset so we can conclude that the increase is not significant. In terms of P_{opt} metric for all classifiers, the best results are achieved for the Oldest_case1 and Previous_case12 types of datasets. In contrast, the worst obtained results are gained from the Oldest_case12 and Previous_case1 types of datasets dataset for all classifiers. When analyzing the AUC metric, almost all of the classifiers achieved poor results, i.e. a decrease in performance compared to the Original type of dataset. The exception is Naive Bayes classifier because it gained better results with Previous and Previous12 types of datasets, however these increases are only around 1%. When analyzing the results in terms of GM metric, we can conclude that the best results in all

Figure 5. Random Forest - oldest types of datasets result comparison for P_{opt} evaluation measure (PDE project)

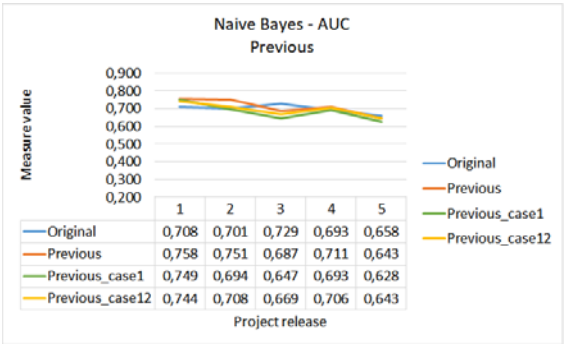


Figure 6. Naive Bayes - previous types of datasets result comparison for AUC evaluation measure (PDE project)

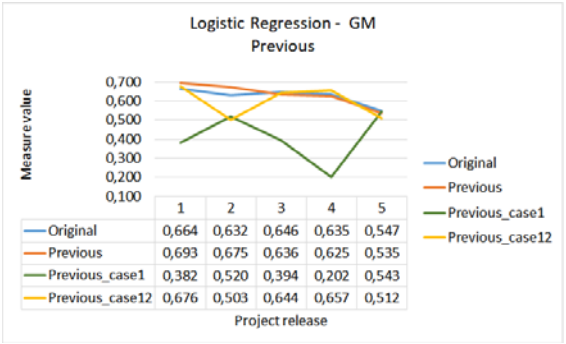


Figure 7. Logistic Regression - previous types of datasets result comparison for AUC evaluation measure (PDE project)

classifiers are obtained from the Oldest type of dataset, that is the highest gained increase in comparison with the Original type of dataset. Even though there are some exceptions where Oldest type of dataset achieved slightly lower results, they are still quite close to the values obtained from Original type of dataset. In terms of previous types of datasets, when using the Random Forest classifier Previous type of dataset in most of the releases achieves higher results compared to the Original type of dataset. Using other classifiers Previous type of dataset did not outperform the Original type of dataset, but was very close to it.

C. Prediction models comparison

The obtained results were used to find the type of dataset that yields the best performance for each classifier. Using this information, we analyzed which is

the most successful classifier for each evaluation metric and which classifier achieves the greatest increase compared to the Original type of dataset in general. In it important to note that the greatest improvements were obtained in JDT project.

In Fig. 8 we can see that the best results in terms of P_{opt} metric were achieved by the Random Forest classifier with the Previous type of dataset. Second best results were achieved by the J48 classifier with the Previous type of dataset. Next, follows the Logistic Regression with the Previous_case12 type of dataset. The average increase in J48 and Logistic Regression is very similar. Lastly, for the Naive Bayes classifier the best results were achieved by the Previous type of dataset. With these results we can conclude that in general the Previous type of dataset achieved the best results Observing results for each classifier compared to its Original type of dataset the highest average increase of 5% is calculated for Logistic Regression. Next, follows Naive Bayes with 4% and then Random Forest with an increase of only 2%. J48 classifier's best result is by 1% less then results from its Original datasets. In Fig. 9, the best results in terms of AUC evaluation measure were achieved by the Random Forest classifier with the Oldest type of dataset. Next, follows the Logistic Regression, followed by Naive Bayes, both with the Previous type of dataset. Lastly, the worst results were obtained by the J48 classifier with the Previous type of dataset. Each classifier gained the same average increase of 1% compared to its Original type of dataset, with the exception of Naive Bayes classifier with 3%.

The results obtained for the GM evaluation measure are presented in Fig. 10. Interestingly, Logistic Regression with the Previous_case12 type of dataset was the best classifier in first three releases. The second best result is achieved by the Random Forest classifier with the Oldest type of dataset. Next, follows the J48 classifier with the Oldest type of dataset. The worst results are obtained by the Naive Bayes with the Oldest type of dataset in all releases. Compared to the Original type of dataset, the greatest average increase is by 3% in Naïve Bayes classifier with Previous type of dataset. Second highest increase is by 1% in Random Forest classifier with Oldest type of dataset. In J48 and Logistic Regression classifiers all the results are in decrease compared to Original type of dataset, with an exception of 1% increase in Logistic Regression with Previous type of dataset. Generally, we can conclude that the best results for the GM measure for all classifiers are achieved by the Oldest type of dataset. Compared to its Original type of dataset Logistic Regression gained average increase of 7%, J48 and Naive Bayes of 1%, while Random Forest results were decreasing, with the exception of Oldest type of dataset that achieved the same average result as Original type of dataset.

D. Discussion

In JDT project, the highest increase of average values when compared to the Original type of dataset are

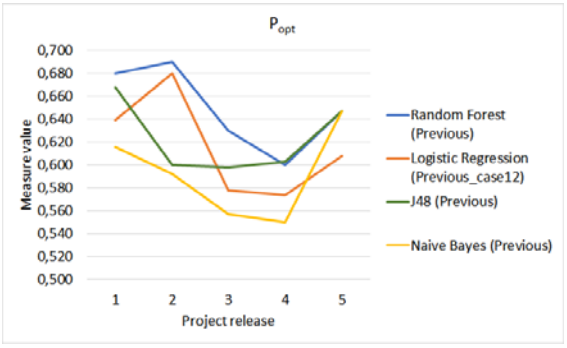


Figure 8. Comparison between the best type of dataset in each of the classifiers for the P_{opt} evaluation measure

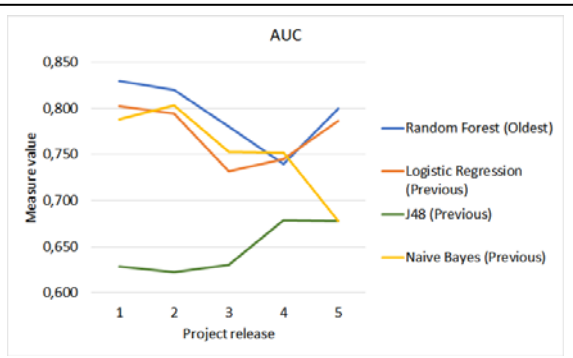


Figure 9. Comparison between the best type of dataset in each of the classifiers for the AUC evaluation measure

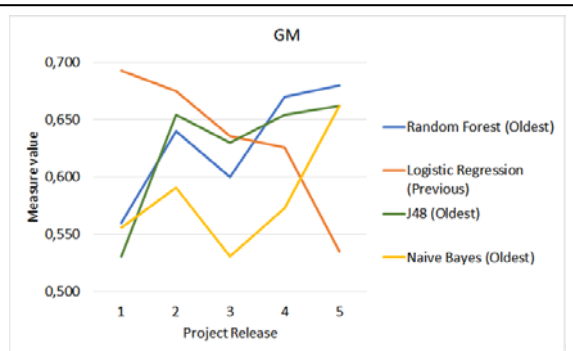


Figure 10. Comparison between the best type of dataset in each of the classifiers for the GM evaluation measure

achieved from the Random Forest classifier for each evaluation measure (Fig. 2, Fig. 3 and Fig. 4). In contrast, the worst results for the P_{opt}, AUC and GM metric are achieved respectively from the J48, Random Forest and J48 classifiers.

The highest average increase in PDE project when compared to the Original type of dataset in PDE project is achieved from the Random Forest, Naive Bayes and Logistic Regression classifiers, respectively for the P_{opt} (Fig. 5), AUC (Fig. 6) and GM (Fig. 7) evaluation measures. In contrast, the worst results for the mentioned metrics are achieved respectively from the Logistic Regression, Random Forest and J48 classifiers.

To generalize observations from the obtained results we can see that the greatest increase in each classifier was achieved when using the Oldest and Previous types of

datasets. It is important to note that these datasets include data from case 1 and case 2, i.e. the classes without defects and classes with uncorrected defects. In contrast the worst results, i.e. the smallest increase or even decrease, is achieved when using datasets with the exclusion of case 1 and case 2.

V. CONCLUSION

This study investigated whether cross-release code churn has an impact on defect prediction models. Several data types were analyzed, however some of them exhibit poor results. Prediction models built with Random Forest, J48, Logistic Regression and Naive Bayes classifiers exhibit various results. A general conclusion is that types of datasets referred to as Oldest and Previous yield the best performance in terms of P_{opt}, AUC and GM metric. Thus, we can conclude that cross-release code churn can be used to identify critical design change. However, this conclusion is not valid for all types of classifiers. We may expect the highest level of improvement for statistical classifier Logistic Regression and almost no improvement for ensemble classifier Random Forest.

By observing the average values in terms of P_{opt} measure of each type of dataset in a certain classifier the highest increase is gained by the Logistic Regression classifier, i.e. an increase by 5% with Previous_case12 type of dataset. Additionally, if we observe the results regarding each single release, the highest achieved increase was 8%. In terms of AUC metric the best results are gained with Logistic Regression (Previous type of dataset) and Random Forest (Oldest type of dataset) classifiers. Both achieved similar results, with average increase of 1% compared to the Original type of dataset. When observing single releases, the highest increase of 3% is gained from Random Forest classifier. It is interesting to notice that Logistic Regression manages even to outperform the Random Forest classifier in terms of GM when trained using the cross-release code churn enriched dataset. This observation is interesting because when trained on Original type of dataset, Random Forest usually outperforms Logistic Regression. The Logistic Regression achieves an average increase of 7% with Previous_case12 type of dataset compared to Original. When observing the single release, the highest increase is 8% compared to Original.

The general conclusion of this study suggests that cross-release code churn enhanced datasets increase the predictive performance. In terms of the analyzed metrics, i.e. Popt, AUC and GM, the average increase is up to 5%, 3% and 7% respectively. The highest gained increase in each classifier was accomplished when using the Oldest and Previous types of datasets. Additionally, we concluded that the exclusion of unchanged classes without defects or unchanged classes that contain uncorrected defects exhibits poor results. These types of datasets do not contribute to identifying critical design change.

ACKNOWLEDGMENT

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Community structure of a complex software-system in evolution

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***Abstract* - Due to the discoveries of complex networks in the real-world systems, recent researches in software engineering have also applied the same principles in analysis of software-systems. Moreover, network analysis enabled the determination of different statistical metrics proving small-world phenomena, power-law and scale-free properties also for the software-systems. But also, statistical network analysis of software-systems reveals interesting community structure, which has not been already enough explored for software-systems. Since many real-world networks exhibit natural division into communities, the same behavior has been explored for the software network. In our research, we have analyzed large and complex evolving open-source software-system. For determining community structure, a statistical metric called modularity was used. The presence of structural modules proves a deeper organizing structure of the software-system, which can be applied for the prediction of many software characteristics.**

Keywords - community structure, complex networks, software evolution

I. INTRODUCTION

Due to the discoveries of complex networks in the real-world systems, such as social and biological networks, www, communication and distribution networks, recent researches in software engineering have also applied the same principle in analysis of software-systems. Current software-systems are very large and they are evolving very fast. It has already been demonstrated that software-systems can be considered as complex networks [1,2,3,4,5], so considering object oriented (OO) software-systems it's possible to determine the corresponding complex network. In the last years many real-world systems have been investigated according to the network theory, revealing some similar properties regardless of the diversity of the analyzed systems. The same principles have already been applied in software engineering, discovering similar properties as in other complex networks. Our previous work [6] proves that a OO software-system in evolution has small-world property, it's a scale-free network, follows a power-law, and has high level of clustering. Exactly the same features as many other complex networks. There is another very important feature of many complex networks which claims that many real-world networks divide naturally into subgroups or communities [7].

The research problem of this work is a detection of community structure of an OO software-system in evolution, analyzing mesoscopic network properties. Though, it has already been investigated, there are still problems of detecting the community structure of a complex network. We present a case study of object-oriented system Java development tool (JDT) as an evolving open-source software-system.

Our work is based on consideration that software-system is a complex network, and that network analyses enables the determination of structural properties of software. This can help us following the process of software design, development, improvement and maintenance [7]. Moreover, network analyses enabled the determination of mesoscopic properties which indicate the presence of a structural modules and a deeper organizing structure of a software-system.

The paper is organized in five sections. In section II. we discuss the related work based on the community detection in software network. In section III we describe network communities, giving the results of our analysis in section IV. Finally, in section V. we conclude.

II. RELATED WORK

Many software-systems show properties typical of complex network, for example power degree distribution, scale-free properties, small-world property.

Bhattacharya et al. in their research [staro3] have examined large software-systems showing how a graph-based analyses is efficient to capture software evolution and predict defect, but they didn't consider community structure of a software-system.

Complex networks also have the possibility of partitioning them into smaller subnetworks, called communities. Well known mesoscopic structural modules have already shown their applicability [2], so detecting community structure is an important issue for complex networks [6], as well as for software networks.

Šubelj and Bajec [9], thus have explored a community structure of a complex software-system showing that software networks reveal important community structure. Further in [10], the same authors propose an algorithm for group detection of real-world networks.

Concas et al in [11] have analyzed OO software-system as a complex network computing community metrics and exploring the correlation between the community structure and software defectiveness.

Our work differs from the related ones since we have based our analysis on a large open-source software-system in evolution studying mesoscopic properties of an object-oriented software-system.

III. COMMUNITY STRUCTURE

Although, there is no even a strict definition of a community, we base our research on the description of a community as a group of nodes densely connected, and with only sparse connections between groups [9,12]. All nodes of one community have to be reached through other nodes of the same community [13]. For detecting a community structure of a software-system a statistical metric called modularity has been used.

Modularity is one measure of the structure of the network. It was designed to measure the strength of division of the network into modules, also called groups, clusters or communities. Networks with high modularity have dense connections between the nodes within modules but sparse connections between nodes in different modules. Modularity is also often used in optimization methods for detecting community structure in networks. Nodes from one community have higher likelihood of connection between each other than with nodes from other communities.

A. *Metrics analyzed*

Every version of our evolving software-system is one network. Our software-system has been analyzed using Gephi[1] [14,15] that already has an integrated statistical metric, called modularity. Thanks to this metric, each node gets assigned a module class, and then it is possible to process the data and reach the exact number of communities and the correct number of nodes in every network.

The detection of community structure is based on Louvain method of community detection [16]. This method is based on a heuristic approach for optimizing modularity. Compared with other algorithms for community detection, this method is faster [16], it takes less time to achieve modularity's, so it's suitable for large networks with a huge number of nodes.

Every graph can be defined as an ordered pair G(V,E), where V is a set of nodes and E is a set of edges between those nodes. The total number of nodes in a graph is indicated N. Although graphs can be directed or undirected, all our graphs are directed, which means that edges between nodes are arrows, and we know exactly the direction of links between any couple of connected nodes. The number of communities for every version is indicated with C.

IV. RESULTS

In this Section we analyze the results of our research work. Firstly, we present the general results of community detection of our networks, and then we consider each network for themselves.

[1] https://gephi.org/

In our research we have tested 10 versions of Java development tool (JDT) evolving open source software-system as a complex network. A source code files were transformed into their graph representation [17], transforming classes into nodes, and relations between classes into edges, thus obtaining Class Dependency Network (CDN) for every version of a software-system in evolution.

Table 1 shows the size of the software-system during the evolution, precisely the number of nodes (N) and number of edges (E) of every version, together with the number of communities (C) in each version. It's very obvious how the software-system grows with regard to the number of nodes and edges.

TABLE I: SIZE OF SOFTWARE-SYSTEM THROW THE EVOLUTION

Version	Number of nodes	Number of edges	Number of communities
1.0	803	2605	20
2.0	1429	5871	16
3.0	2463	11817	43
3.1	2787	13752	38
3.2	3305	16482	94
3.3	3460	17568	105
3.4	3614	18834	69
3.5	3736	19550	51
3.6	3780	19879	79
3.7	3808	19987	77

Using the results shown in Table 1 we create a Fig. 1 which clearly shows the number of communities over the software evolution. It's obvious that the number of communities increases with the size of network, but just during first six versions of a software-system in evolution. It's because as the software-system grows during the evolution the connectance decays very fast and causes saturation of the network [5], and we have just a small increase of a number of nodes and edges in the last versions. So, we can conclude that as the network saturates in the size (number of nodes and edges) the number of communities tends to stabilize.

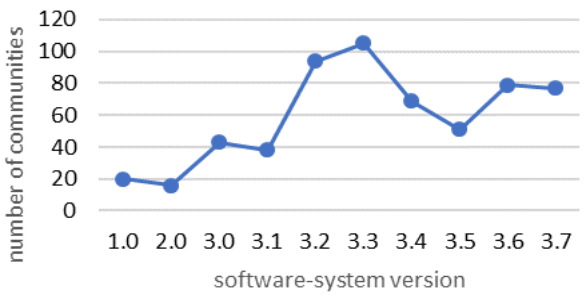

Figure 1. Number of communities during the evolution of a software-system

Analyzing the community structure of each version we notice that regardless of the total number of communities

in that network there is always one big community with a large number of nodes, which includes more than a half of the nodes, few other communities with a significant number of nodes, and all other communities have very small number nodes. We consider significant communities those with 100 and more nodes and those with a small number of nodes means less than five nodes per community. Due to the lack of space we only show he visualization of a community structure of two versions. Fig. 2 and Fig. 3. respectively, depict the community structure of the first and the last analyzed version of an open-source software-system JDK exactly the 1.0 and 3.7 version.

Applying different colors for each community gives us a clearer picture of the community structure. As statistical analysis indicates the colors confirm one biggest community and some smaller ones.

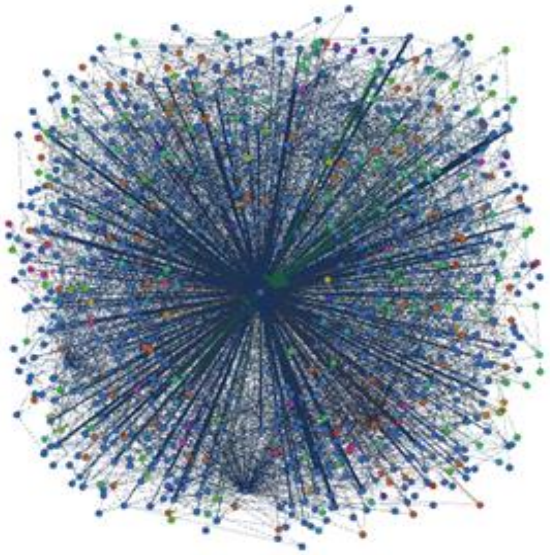

Figure 2. Network's colorized community structure of a version 1.0

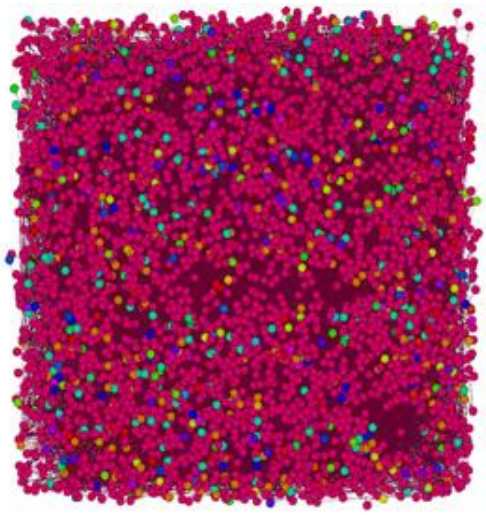

Figure 3. Network's colorized community structure of a version 3.7

The smallest communities are those with two nodes and they are the most often in every version of a software-system.

Further we show the number of communities for each version together with the number of nodes belonging to each community. In the Fig. 4 and Fig. 5 we show those results. It is noticeable that each version has only two or three large communities, taking into account the total number of nodes in the network.

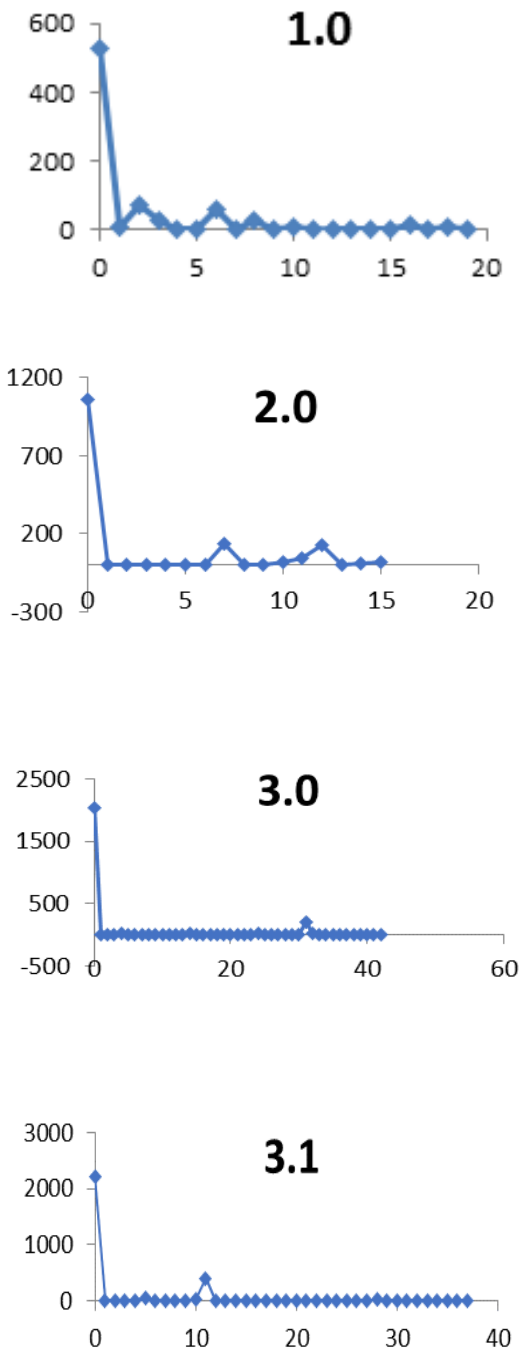

Figure 4. Sizes of communities during the evolution of version 1.0, 2.0, 3.0, 3.1

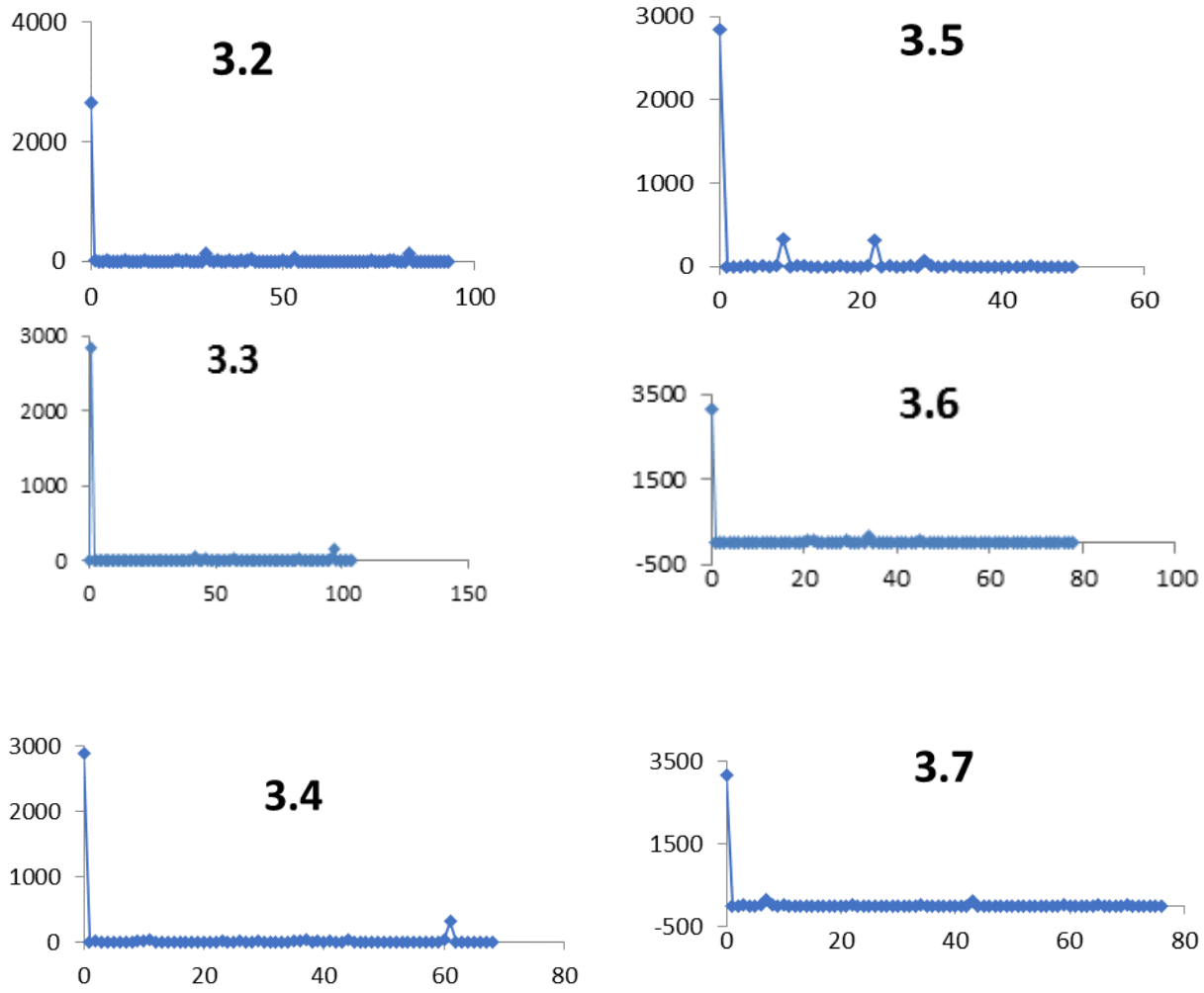

Figure 5. Sizes of communities during the evolution of versions 3.2, 3.3, 3.4, 3.5, 3.6 and 3.7

V. ACKNOWLEDGMENT

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A case study on reliable Erlang communication in open platforms based on Scribble

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ABSTRACT

In future generation networks and systems, innovation is enabled by introducing new open platforms where various developers may contribute with new and innovative services that will be provided to the end users as a service and at runtime. These open platforms have to secure high level of automation so that developers and users may contribute to or use the open platform via standard interfaces. Moreover, these new open platforms have to secure high quality standards that would be assured through autonomous mechanisms that are implemented within these open platforms. As one of the very important aspects for the majority of services and its users is the reliability that open platforms offer for its users. Here in this paper, we present a case study how to secure an open platform for reliable service delivery. The case study is based on the use of Scribble tool that implements session types as formalism for describing protocol interactions that secure reliable operation among Erlang applications.

Keywords

Reliability, Erlang, Scribble, Protocols

1. INTRODUCTION

In forthcoming era of computing, new service oriented platforms which are distributed platforms that offer chains of interacting services and form future innovative applications. Nowadays, interactive and communication oriented services are more and more integrated into new and innovative applications. However, the current software engineering technologies are still immature to enable its autonomous and reliable operation. The traditional development process of such applications is full of manual quality assurance methods and specialized tools that are used to implement required quality level and its reliable operation. On the other hand, these new platforms aim to form an open environment which would enable ad-hoc and autonomous creation of new and innovative services by interconnecting and reusing already developed services that are offered within the platform and developed by various contributors. It is important to stress that reliable operation of the services offered by these open platforms may influence numerous users. There are, various ongoing development efforts in providing solutions for reliable and secure mechanisms of such open platforms. Our efforts are devoted to this goal and part of our solution in that direction was already presented in [6].

One of numerous approaches to quality assurance while developing interactive and communication intensive applications is by using formal descriptions for specifying and validating protocol interaction. When developing complex and distributed communication-intensive systems the use for formal specifications is very limited because of complexity of system that is developed. However, formal specification is very useful in describing external protocols in interaction with other vendor equipment. It is used for validation of protocol requirements and validation of a system implementation.

In this paper we present an approach which use formal specification for verifying formal specification in an example of dog state machine as presented in [3]. The high level global communication protocol among two applications is described and formally verified with the help of Scribble. Scribble is a language for formal description of the communication processes, its structures and behaviors and enable mathematical verification of communication correctness at a high level of abstraction [2, 1]. Furthermore, this global protocol is projected into local protocols and implemented as two Erlang applications. Based on the global protocol we also developed a runtime monitor that communicates over the RabbitMQ message buffers and verifies interaction between two Erlang applications at runtime.

This high level approach is beneficial for the new and open distributed platforms since it enables formal specification of global protocol communication that is independent of programming and runtime platform. Thus, numerous developers that implement parties within that communication could get secure and reliable protocol description that they want to implement within its local implementations (e.g. local platform, programming language, etc.). There has been work

on implementing runtime monitors for the Python programming language, based on correct timing with respect to the corresponding specification [5]. Furthermore, with help of runtime monitors that are running as part of open platforms, at suspicious communication implementations developed by various developers, we may detect malicious and unreliable operation before it may harm the other party involved in the communication. The main contribution of this paper is to present an use case for Erlang applications and discuss expediencies and new future directions.

In the second section 2 we describe all the tools we used in the case study and section 3 describes case study. In sect. 4 we elaborate results of validation process and finally in 6 we conclude the paper.

2. TOOLS

In this work, we used several tools. Scribble was used to define the protocol, RabbitMQ was used as a messaging broker. All scripts were written in Erlang programming language.

2.1 Scribble

Scribble[1] is a language used when describing protocols between communicating systems. It is based on Multiparty Session Types and Pi-Calculus to ensure that the specified protocol is free from deadlocks and livelocks. When using it, there were few steps that we followed. First thing to do was to write a global protocol. Scribble will run to check if the specified protocol is valid, if it is free from livelock and deadlock. After that, with help of the Scribble tool we translated the global protocol to local protocols, one specified for every role in the protocol. Finally, we implemented every protocol role as an Erlang application that communicate over the RabbitMQ platform.

2.2 RabbitMQ

RabbitMQ is a broker for sending messages based on the AMPQ protocol. Its primary purpose is to provide a common platform used by various applications to exchange or receive and send messages. Messages are safe and secure while transporting. They are downloaded from the application that sends the data, and performs some operations like: message routing, message replication, response to events or errors that occur, etc. The messages that some program sends and receives are placed in a specific queue, from which can be easily read in the proper schedule. Queue is actually buffer, the container from which program can download and read the received message in a order of message reception. The basic idea of sending and receiving messages among applications through RabbitMQ as an exchange platform is to control their proper communication flow. Statefull applications thus may benefit from an additional security mechanism by using exchange platform such as RabbitMQ for verifying communication protocol correctness before it executes its messages.

3. CASE STUDY

The case study performed can be seen in Fig. 3. All steps are described in the following subsections.

3.1 Problem description

The main goal of this work was to try to find an automated way to check if agreed upon protocol is formally correct and if it is followed in the implementation of various parties present in runtime communication. We choose a simple two-sided communication reused from dog communication example as explained in [3]. Here we illustrate this example as communication between two processes in Fig. 1.

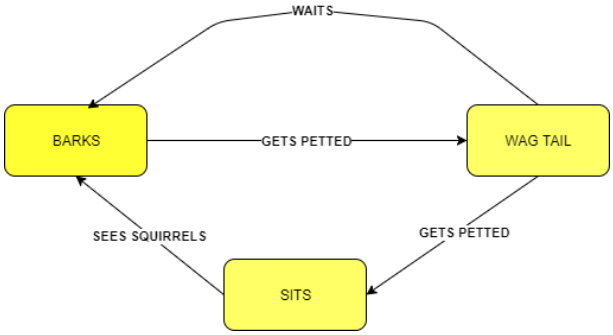

Figure 1: Message interaction

At one side, there is a process that acts like a dog. It has three possible states: sits, barks and wags tail. Every transition from one state to another is triggered by a specific message. At start, state of the process is ”barks”. At that point, only possible message is ”gets petted” and it shifts to state ”wag tail”. From there, it can either get message ”gets petted again” and change to ”sits, or it can get ”waits” and change back to ”barks”. At state ”sits”, the only possible transit is to state ”barks” when receiving ”sees squirrels”. The process that sends messages acts as a human that does the specific actions. This protocol is the global protocol agreed upon.

3.2 Parsing Scribble protocol

First step is to write in Scribble programming language and formally validate the global protocol using Scribble tool [4]. The global protocol can be seen on figure 2. In the tool we can get projections of global protocol into local protocols. In our example there were two local protocols. One is the dog process side and other is the human process side.

```
1
2  module thedog;
3  .
4  type <java> "java.lang.String" from "java.lang.String" as String;
5
6  global protocol stanja_psa(role Dog, role Message) {
7      rec LOOP{
8          barks(String) from Dog to Message;
9          getsPetted(String) from Message to Dog;
10         wagsTail(String) from Dog to Message;
11         choice at Message {
12             getsPetted(String) from Message to Dog;
13             sits(String) from Dog to Message;
14             seessquirrels(String) from Message to Dog;
15             barks(String) from Dog to Message;
16         } or {
17             waits(String) from Message to Dog;
18             barks(String) from Dog to Message;
19         }continue LOOP;
20     }
21 }
```

Figure 2: Scribble global protocol

For easier reading of the global protocol, script to parse it was made. The new text file contains only the necessary data to verify the communication between the sender and the receiver, which must take place according to the default

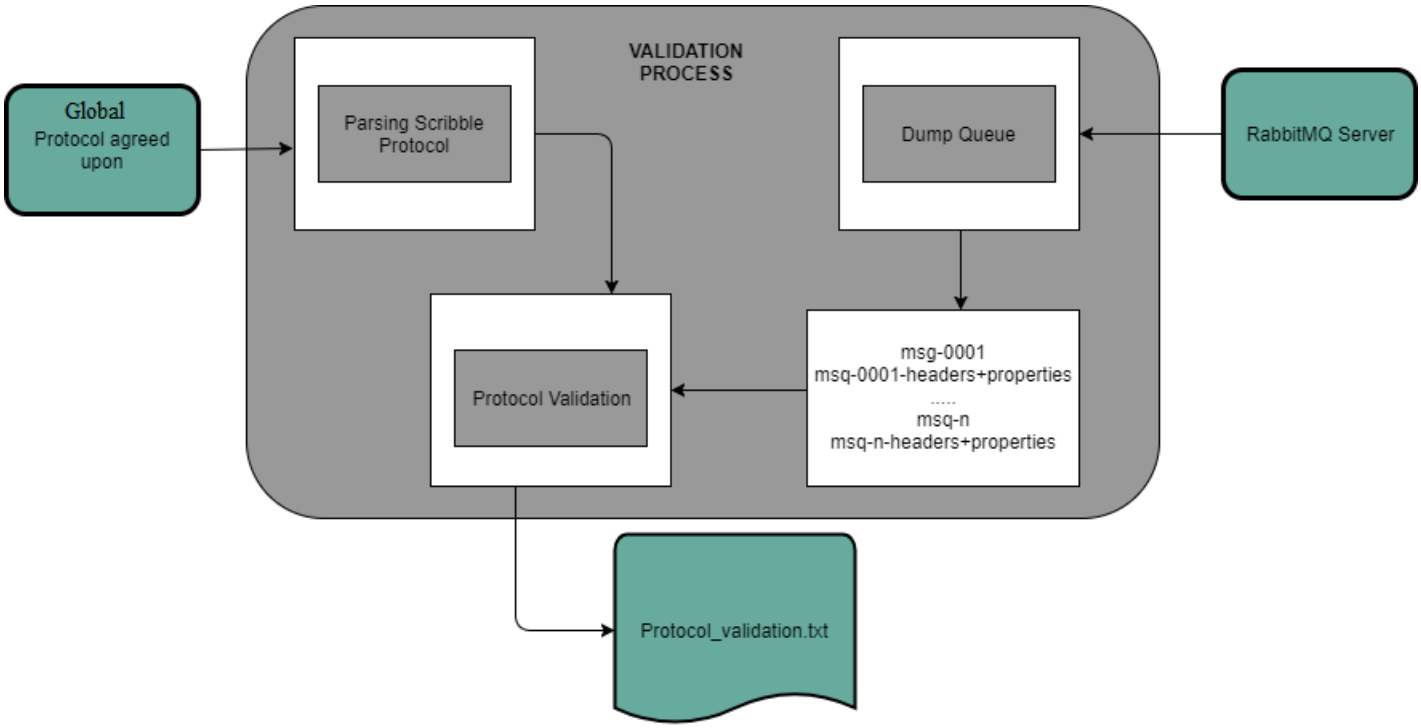

Figure 3: Protocol Validation process

global protocol. The file contains an action and information about who is within the recipients communication, who sends a specific message and who receives it.

3.3 Protocol validation

Protocol validation was done by comparing the message buffer content from RabbitMQ platform and global protocol specification. We used a RabbitMQ function that dumps all the messages passing through the RabbitMQ queues that is a part of the dump queue library. All messages from the RabbitMQ servers, that were created through communication between two or more systems, are simply downloaded. All messages are saved in a particular file, but it is not entire content of the message contained in a single file. It is divided into two files. In one file there are headers, and in the other is the message content. Two new files are created for every new message.

For the protocol validation, script written in Erlang was created. It uses file with the formaly verified global protocol and it scans through the messages and header files dumped by the RabbitMQ server. First thing it checks for is the process id in the header file given by queue dump command. The id is stored for comparison of each next message. After that the content of the message is compared to the message specified by the Scribble protocol. At the moment, all results are stored into the text file. Every message with process id is stored together with the information if it is according to the protocol or not, for example: true->0.187.0->gets petted as is presented in Fig.4.

4. RESULTS

In order to test the validation process, testing environment was established. Global protocol used for the testing was the one described in the Section 3.1. We used three computers. One of them acted as the dog process, and the other two were used to send message to it. RabbitMQ server and scripts for validation were run on the computer that was used as the dog process. The testing process ended as successful. Script correctly recognized that the communication was according to the protocol. In test cases where one of the actors did not behave according to the protocol, it was recognized and marked in the output text file. Both message and process id of the process in the wrong order were written.

```
true->0.239.0->gets_petted
true->0.239.0->waits
true->0.239.0->gets_petted
true->0.239.0->gets_petted
true->0.239.0->sees_squirels
```

```
true->0.53.0->gets_petted
true->0.53.0->gets_petted
false->0.53.0->waits
```

Figure 4: Testing process

5. FUTURE IMPROVEMENTS

More testing is necessary for this project. Larger number of processes together with more complex protocol could show defects in the current system. Also, there is room for project improvement. Dump queue library is not ideal. The problem is that it gives two different files, some adjustments to the library could make the system more efficient. A routing key is used to determine which process is sending a message. It is not applicable to any programming language, not all processes have access to its process ids. Some other so-

lution could be a better approach. More work is needed on this system. Some refinements in the scripts and a solution to automate the whole system.

6. CONCLUSION

In this paper, we present a case study which provides just an overview and starting point for implementing a reliable autonomous mechanism for open platforms in future networks. Here we presented a case that uses Scribble formalism for formal specification of communication among parties that communicate in open platforms. Our approach uses Scribble for formal specification and verification of protocol communication. We presented the use of Scribble on simple dog case. Furthermore, we use Scribble to project global protocol specification into its local projections. These local projections we used for protocol implementation in Erlang programming language. That simplified our development process while implementing protocol parties. Finally, we implemented a runtime monitor also as an Erlang application. The runtime monitor uses global protocol for validation of runtime messages that are transmitted over the RabbitMQ buffers in communication between two Erlang applications.

Our future work would focus on further implementation of autonomous control mechanisms for open platforms that would automate the process of detection of unreliable protocol implementations and automatically start the clean up process in an open platform. This work is one step further in our aim to develop reliable control mechanisms for future generation networks that we do within EVOSOFT project.

Acknowledgment

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APPLICATIONS

Web design - past, present and future

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***Abstract* - Nowadays there is a wide prevalence of various devices that can be connected online for different kind of activities, and among others, for browsing web pages. Web design is constantly changing and adjusting due to the appearance of different sizes and types of devices. Web design from the 1990s is greatly different from current web pages. The main goal of the design, is not the design itself, but to enable web content transfer on more readable and comprehensible way, no matter which device is used to present web content, desktop or hybrid computer, various mobile or wearable device. This paper shows development of web design from its beginning to nowadays modern design, and what we can expect in future.**

Keywords - web, design, progress, wearables, responsive, hybrid

I. INTRODUCTION

Today's average day of any person involves browsing web pages searching for various information and news, connecting to other users through many social networks and doing various business tasks. According to the user survey conducted in the United Kingdom in 2016, even 71% users have accessed the internet using smartphone, 62% using laptop, while only 40% using desktop, which implies how smartphones have taken up most of the market and internet access [1]. Therefore, it is questionable how good can users browse web pages through smartphones or some other mobile device, since smaller screen makes the user experience browsing web pages diminished. Hence, responsive web design is very significant, because devices with smaller screens demand adaptation of web page content to fit the screen. Certainly, in those cases it is more important to deliver good content, over visual impression, because content is the most important thing for users. New design methods allow to develop only one version of the web page for various devices compared to have to develop many versions and meanwhile loose much resources. Following paper chapters describes web development through four web generations, devices which allow connecting and using the internet, and connection between web design development, generations and devices.

II. DEVELOPMENT OF THE INTERNET AND WEB PAGES

Today's commercial internet foundations started 1990. At the end of 1990, Tim Berners-Lee created basic concepts of World Wide Web and many tools for efficient web usage. Those tools encompasses HyperText Transfer Protocol (HTTP), HyperText Markup Language (HTML), the first web browser and code editor, first web server and first web page which described new term „world wide web" and method of developing own web page [1]. From 1990, the internet was evolving really fast, and progress of its development can be described through four generations (Fig. 1) [3].

The first web generation web pages were static, and not frequently updated, and users could only read web content. The main motto was "read only web". All web pages were written with HTML and main communication protocol was HTTP [3]. The second generation starts 2004, and terms that make it are various social networks, blogs, the possibility of the user creating web page contents (motto "read-write web") and enhancement of user experience browsing web interface. During that period, famous social networks have appeared, like Facebook, Twitter, LinkedIn and other. Those social networks enabled global user connection. Also at that time, new technologies appeared, like JavaScript, Document Object Model (DOM), Ajax, Cascading Style Sheets (CSS), eXtensible HTML (XHTML), eXtensible Markup Language (XML), eXtensible Stylesheet Language (XSL) and Flash that enable the web services presentation and delivery, without web distribution problems. The third web generation starts 2010, and it is marked with the semantic web (adding semantics to the web), content personalization, intelligent search, and computer's ability for creating various content (motto "read-write-execute web"). Ontologies are used for meaning representation and reasoning (which is done by connections, rules, logics and ontology states). Besides ontologies, technologies that are also used within a third web generation are Resource Description Framework (RDF), Web Ontology Language (OWL) and other. The fourth generation is still developing, and it is assumed that it could start around 2020, when the whole operating system of clients' computers could be within the cloud,

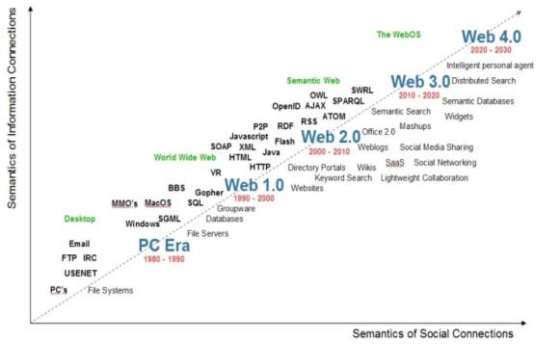

Figure 1. Web generations (Radar Networks & Nova Spivack, 2007)

and web participation inevitably.

III. DEVELOPMENT OF THE WEB DESIGN

The design is the universal language in the visual world, and web design refers to the user interface of the web page. The main purpose and goal of the design is putting content into focus, in order to users easily reach and use web content [5]. Because of various technological changes and trends, web design has changed a lot, from first web generation web page which showed contents using simple textual web page, through a second generation web page with lots of graphics, vivid colors in order to achieve memorable web pages, and finally towards todays simple and intuitive web design. Web page design should always be modern and have updated content.

Nowadays market encompasses different devices, respectively different sizes, shapes and purposes devices. Devices can be categorized into desktops, laptops, tablets, hybrid computers, smartphones, regular phones, and wearable devices (Fig. 2).

The design development can be categorized in two ways, according interface characteristics (desktop, tablet, smartphone, wearable devices) and according activators (keyboard/mouse, touch). During the first development phase, internet browsing was achieved with the desktop, and respective web pages design was influenced by many factors, of which the most influential were screen size and resolution, and also internet availability and speed. Screen size is defined as length of the screen diagonal expressed in inches (standard sizes are 17", 19", 21", 24", 30" and other). Screen resolution is the number of pixels (horizontal and vertical) of which consists image on the screen. Fig. 3 represents average screen resolutions (in pixels, px) through 1990s, at the beginning of 2000s, 2005s, 2010s, while nowadays usual resolutions are various and depend on screen size and manufacturer [6]. Fig 4. shows the standard resolutions for the different screen sizes (15", 17", 19", wider screen size 22", and wider screen size 30"). Full name of abbreviations contained on Fig. 4 are SVGA as Super Video Graphics Array, XGA as Extended Graphics Array, SXGA as Super Extended Graphics Array, UXGA as Ultra Extended Graphics Array, FHD as Full High Definition, and WQXGA as Widescreen Quad Extended Graphics Array. Fig. 5 represents average internet communication speed

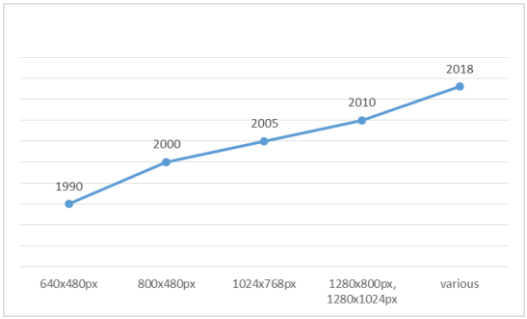

Figure 3. Average screen resolutions

from year of 1991 when speed was barely 1.2 kbits/s, to prediction that 2020 will be 230101 kbits/s [7]. Hence in the beginning of the development of the web design, it was necessary to be careful when using graphics, because of its size and quantity, and very long loading time.

Also, desktops weren't changed frequently, and in the few years those computers would become old and couldn't entirely follow all technological trends that need always the best. Then, web pages were developed only for desktops (desktop first philosophy), meaning that design concept with fixed width and centered content was used, because there were no other screen types and that suited the best. Since most screens were similar size, there was no need to complicate, so desktop first philosophy was stable and widely used. Fig. 6 represent initial and today's web design of Dell's home page, showing visibly changed web design, in used colors, layout, graphics, typography and similar.

Today, standard web application, apropos applications that are used through desktops, can use various web design elements (different kind of graphics, typography, animations and similar) in order to develop a desired web design. They can also use skeuomorphism without any limitations. Skeuomorphism is a type of web interface that mimics real objects in human surroundings to ease user browsing web pages, that is to keep it similar and simple, however on the other side it prevents creativity while showing different web elements. Still today, the flat design is mostly used, because of its effective appearance, and very successful representation through smaller screens. Flat design is a type of web interface that represents the content without unnecessary details, and that is focused on colors, typography and simplicity.

Figure 2. Nowadays devices (Designed by iconicbestiary /Freepik)

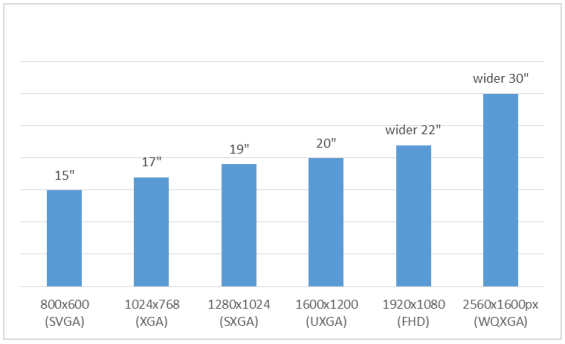

Figure 4. Standard resolutions for screen sizes

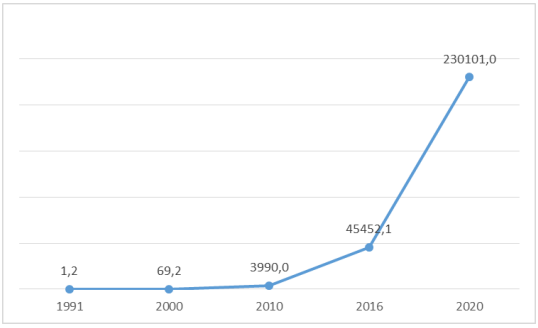

Figure 5. Average internet communication speed

The first appearance of browsing web pages using regular mobile devices was 1999, enabled by Wireless Access Protocol (WAP). WAP is a simple interface of older mobile devices that enabled limited web pages representation, and it was most commonly used for example, for reading timetables, daily forecasts, and similar [8]. The moment when browsing internet raised was 2007, when Steve Jobs presented the first iPhone, in which browsing web pages become more interesting using Safari browser. The main problem was web pages that weren't designed for small screens (smartphones usually have screen under 5"). The concepts of desktop oriented web design wasn't suitable for smaller screen because reading content was very inconvenient because of need to zoom and move page and their content, which in the end frustrated users. After that, mobile device prices began to fall, and so device compatible for browsing web pages was much cheaper than a desktop. 2010 the mobile network speed doubled, and therefore raised mobile device usage while creating suitable various web pages. Following that, tablet market also raised (screen size above 7"). Also, smartphones and tablets could be watched both horizontally and vertically.

Usual smartphone resolutions are 1080x1920px, 720x1280px, 480x800px and other, while usual tablet resolutions are 1024x1366px, 800x1280px, 768x1024px, 600x1024px and other [9]. Regarding technical specifications of mobile devices, users usually watch out for battery lifetime and prices, but not processor type which would enable best web page view. The problem of screen brightness is mostly expressed at mobile devices that cannot adapt to the surrounding brightness (mostly outdoors), so the content on the screen isn't enough visible and understandable.

Web design needs to adapt the appearance of user interface to the device that is used for web content representation, in order to achieve optimal content

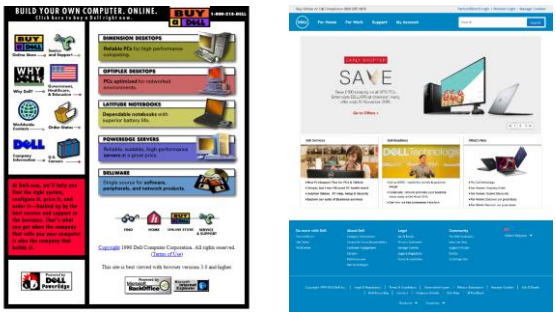

Figure 6. Dell's home page design 1996 and 2016

representation without unnecessary elements that would cause reduced free space for essential content (Fig. 7). Therefore, the concepts of responsive web design and flat design are introduced, and their combination has proved to be very successful. Responsive page elements can be adapted to any device, through usage of adaptation techniques. Responsive design goals are adaptation of web page layout, image size, and presenting only essential web page elements, developing larger and simpler to use navigational and graphical elements, and definition and usage of different device characteristics such as geolocation, screen orientation, contacts, messages and similar [10].

Regarding, mobile first philosophy arises, a philosophy that defines and develops design firstly for mobile devices, and then sequentially for other devices with larger screens. In that way, mobile devices don't need to download and use up their limited resources for downloading unnecessary contents, while for desktop that isn't really such a problem, because of its' better technical specifications.

Also, it is important to decide what is more important, to develop "friendly" web application for the mobile screen, that is, responsive web application, or to develop native mobile application that has to be downloaded from some online source, which makes the product more expensive [11]. Both applications have their advantages and disadvantages. Two main advantages of responsive web applications over native mobile applications, are money and time. Although majority of mobile applications currently run on Android OS (by the middle of 2017, 87.7% market share were Android smartphones [12]), other platforms (mainly iOS) exist. And new ones can still emerge at some point. Native applications have to be maintained separately and that costs time and money. Although hybrid applications can facilitate projects targeted on different mobile platforms, they are confined with frameworks' (i.e. Cordova) limitations. Current trend of native cross platform solutions development aim on achieving exact functionalities as dedicated native applications. Also, responsive web applications can be viewed on most modern web browsers, while native mobile applications need to be downloaded from application store or some other online source. Disadvantages of responsive web applications versus native applications, are requirement of permanent internet connection (if application data is centralized on a web server), lower performance (because of mobile's technical

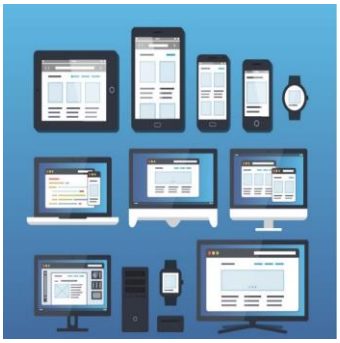

Figure 7. Responsive web design for different devices (Designed by iconicbestiary / Freepik)

limitations), push notifications (which are interesting for attracting user's attention) can't be implemented, and phone functions can't be accessed (like camera, geolocation and similar). Native mobile applications are a far better solution, but also more expensive, because of the development process for each operating system, in order to get better quality and more functionalities. Emerging technologies, like React Native should enable full cross platform native applications. The interest for such solutions is constantly growing. Fig. 8 shows Google search trends [13] for iOS, Android and React Native development.

The most popular type of design layout is "one single page", where the entire content is located on the one web page, and certain web page parts can be easily reached and displayed. This kind of layout is the most intuitive for mobile devices, because of mobile device's natural usage.

Responsive web design main techniques are the fluid grid, the flexible images, media queries and responsive typography [14]. Fluid grid enables creation web page layout using proportions, and not pixels. In order to compute element's proportions, designer uses element's width and parent's element size, in order to get the percentage value. Layout width defines the size of the general layout in percentage in the context of the web browser window. It is necessary to define minimal and maximal width, in order to ensure perfectly defined sizes (minimal size defined by pixels, and the maximal size defined by relative measuring unit em). Measuring unit em allows simple adaptation of element size to the rest of web page [15]. Em is relative according to the font size of the element (3em means 3 times larger from current font size), and also allows the definition of horizontal and vertical element size. Root em (rem) is equal to the root font size and provides greater simplicity when defining element size, because it is always relative to the root element no matter other nested elements [16]. CSS3 size units vw and vh depend on a viewport (browser window size) [17]. Unit vw is equal to 1% of the viewport width, while unit vh is equal to 1% of the viewport height. Viewport units are commonly used with typography. Image adaptation is done by cropping images, setting attributes of maximal width and using multiple images with HTML5, CSS3 and media queries.

Media queries enable developing style for a variety of individual items. So only one HTML document with the help of various media queries can represent different style

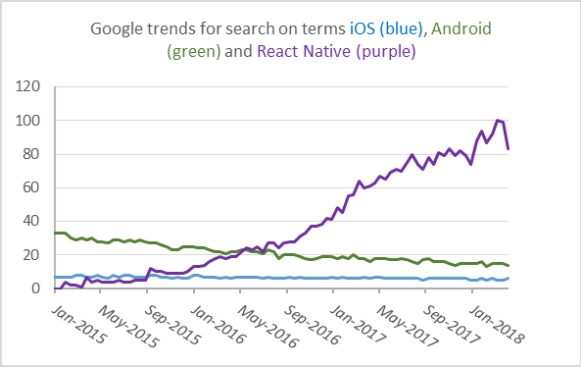

Figure 8. Google search trends on native applications [13]

sheets. Media queries can detect screen size, orientation, resolution and similar. In order to define a special style for screens that have resolution less then 480px, media query can be defined with the rule displayed in Listing 1. Within media query, it is possible to define styles for all web page elements that are important to be adapted above mentioned screen size. However by using media queries designers can' develop a complete web page for all devices, yet it is also necessary to use programming language JavaScript for achieving various additional variations and possibilities [18].

Responsive typography is usually done with two methods, using percentage and using a combination of minimal and maximal width.

Development of responsive web application on un-responsive way allows creation of complex web applications that are adapted to every single device [19]. Since it is impossible to develop one version of a web application that would work on all devices without additional adaptation process, and on the other side, it is extremely inconvenient and time consuming to develop different versions for every single device. Therefore, it is best to use the methodology of categorizing devices, and developing a design for every single category. Categorization usually depends on presenting the product to the target users. For example, usually following categories are defined: small touch screen (smartphone), big touch screen (tablet) and a big screen with keyboard and mouse (desktop, laptop) [19]. It is recommended to develop Model View Controller (MVC) application that enables separation of content and views for different categories, and in that way it is possible to define content only on one place, and develop different views for every device categories (Fig. 9). MVC application provides full control over application performance, which is performed independently on actual device.

Wearable technology is the newest trend which enables not only its primal dedicated purpose, but also limited browsing web pages [20]. Devices of wearable technology or wearables, help and guide person towards better health or managing their private and professional activities. It encompasses clothes or various wearable accessories, for example wristband bracelets for different purposes, glasses with embedded functionalities and other. The International Electrotechnical Committee Standardisation Management Board Strategic Group 10 on Wearables defines the following categories of smart wearable devices: near-body electronics, on-body electronics, in-body electronics, and electronic textiles [21]. Most commonly used wearable devices today are fitness bracelets that monitor user activity and accordingly warn, encourage and inform user. First devices are placed on the market 2011. This type of technology is still in its initial development phase, and its devices can communicate through a wireless connection or through some other device as for example, smartphone. Collected data can be processed using the local processor or certain server, and then be presented to the device carrier. Data

```
@media screen and (min-width: 480px)
{/*css style*/}
```

Listing 1. Example of a media query

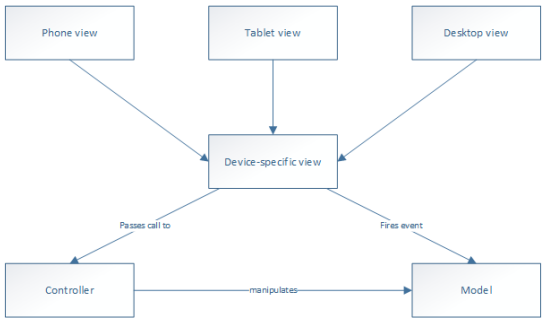

Figure 9. MVC application [19]

can be referred to the carrier himself or its surroundings. Devices of wearable technology can manage, communicate, store and act, respectively, can improve human life's and help people while doing certain personal or professional activities [21][22]. Given various devices different sizes, shapes and purposes, it is necessary, but not enough, to use responsive web design (Fig. 10). Wearables aren't able to show complete information as it can do a smartphone.

Content reach and load should be faster than usual, information access should be fast and direct, and web pages should be dynamic and reactive for every move in order to improve interactivity [23]. Accordingly, designers are challenged to develop web pages, so wearable users don't have to bring closer the device for better content readability. In order to achieve that, it is necessary to define bigger than usual font size for web content, and to focus content, using flat and intuitive design, because focused content is the most important concept for wearables [24]. It is important to emphasize that very small screen size prevents showing complete web content, however it is possible to show certain information that users are interested in. More detailed content is usually shown with another device, for example, smartphone, which can also be used for communication with wearable device.

Except design, essential features of developing wearables are also data safety and privacy, free flow of data and liability. Devices should be fast, small, safe, energetic, effective, smart, and be able to run on multiple platforms. The future of responsive web design for wearable technology relies on approach where the audio is the most important part (audio first approach), since it can store a large amount of data. Screen readers help with reading web content, and are already implemented at some pages. The screen reader is the web accessibility tool that helps blind users or users that have some vision problems, to read pages and achieve web page experience. Certainly, screen reading is possible only on pages that are appropriately designed. It strives that wearables operate using the same principle, and that using audio finds

Figure 10. Smart wearables design (Designed by Freepik)

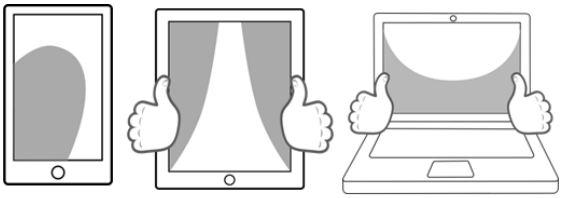

Figure 11. Thumb rule for smartphone, tablet or hybrid computer [26]

complex information [25].

Besides touch-sensitive smartphones and tablets, the market for touch-sensitive desktops or hybrid computers (compound of laptop and tablet), began to develop. Appearance of hybrid devices, respectively desktops that while using a standard keyboard and mouse, also have touch-sensitive screen, implies that it is always necessary to design an interface for different kind of activators (keyboard, mouse, touch). For example, usual top navigation is adjusted for larger screens keyboard oriented, meanwhile, they are very impractical for touch-sensitive screen, because of inconvenient selecting navigation links, and because of permanent holding hands in the air [26]. Therefore, essential items as navigation, should be put on the bottom of the screen because it is within reach of a user's hands. The main design rule for touch-sensitive interface is thumb rule, rule that monitors usage of smaller screen devices such as smartphones and tablets, where it is necessary to use thumbs to select the main options (Fig. 11). In 2013 researcher Steven Hoober observed peoples' interaction with their phone [27]. The study showed that while holding the phone with one hand, the thumb is the only finger comfortably available for tapping, and that thumbs drive 75% of all phone interactions. Because of the thumb rule, main navigation should be placed at the bottom of smaller screens, where user can easily reach with his hands, while for desktops main navigation is placed on the top of the screen, because it is much easier to use it with keyboard and mouse. Best design option for smartphone, is to develop design that allows holding the phone in one hand, and doing some other activity with other hand, for example writing. Because of different variations of holding the device, tablets are very inconvenient to use, but the thumb rule refers placing main controls at the sides and at the tops [26].

Nowadays it is important that every desktop interface is designed for every activators. Therefore, hybrid interface design should have controls at the sides and essential controls on its left, because most users hold their device with left hand, and with right hand select options. Every element of web page should be designed large enough, so even persons with bigger fingers could use it.

IV. CONCLUSION

Development of new technologies is inevitable, and web design has to be ready to follow and adapts to all changes. The main goal is to deliver correct and qualitative content to the users, independent about device's size and purpose. The flat and responsive design has shown to be the best combination for developing web pages for desktops, as well as for the smallest mobile devices. It should be taken with the reservation that

wearables in original shape can't browse web pages in the usual way, so that is what it should be adjusted, whether to show only the most important content or showing web pages using other connected devices.

It is interesting to emphasize that in the beginning, the main goal was to achieve the larger screen because of the better content presentation, while last ten years, size screen started to reduce to the size of postmark, in the case of wearable technology.

It can be concluded that it is very important to show certain content in the best way, and web design allows to achieve that using different kind of methods.

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Web-based University Staff's Publication Analysis System

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***Abstract* - This paper proposes an architecture of a web-based publication analysis system that makes the process of multi-source data gathering much easier, serves as a centralized data storage system and automates most of the time consuming procedures of statistical analysis. Every academic staff member is required to keep an up to date list of their research publications. Having access to all of the data, for all staff members, the system can easily aggregate and perform multiple statistical analyses on these data. The resulting analyses could be very important for the university management as they reveal the current research status of the institution and help managers forecast and plan strategies for its improvement.**

The system implements a 3-tier architecture where user interface, business logic and data are separated into three functionally-independent non-overlapping layers. That provides easier data replication and portability; higher reliability and flexibility; and allows fast and easy personalization or complete change of the user interface. The paper describes both the architecture and the system's features in details and presents some statistical analyses of the publication activity of the researchers at the University of Ruse.

Keywords – Information systems, web based applications, architecture

I. INTRODUCTION

Preparing annual reports and accreditation papers poses a great challenge for secretaries and administrative personnel of the faculty departments and the university as a whole. They have to spend a lot of time gathering, processing and analyzing data regarding the publication activity of the academic staff. Traditionally this process is done manually as follows: the administrative staff of a department requires that each lecturer provides a list of their publications and activities for a specific period of time; then the head of the department together with the secretary aggregate and analyze the data they received; and finally they prepare the relevant document/report. If this is a one-time procedure then the described manual process seems reasonable and acceptable. However, the frequency of reports preparation is quite high so it burdens not only the administrative but also the academic staff, diverting them from their main activities - teaching and research.

Modern information technologies and information systems in particular could significantly decrease the administrative workload by automating some of the tasks related to data gathering, processing and analysis [1, 4, 6]. In rich countries having a high living standard, e-government and e-services have long proven their effectiveness - both economic and organizational. Similarly, some data processing tasks in Academia could be automated by implementing an information system that store and accumulate (in time) research publications data. To comply with modern standards and requirements it should have a web interface allowing users to access data and functionalities anytime anywhere in the world.

A web-based publication analysis information system could make the work of both academic and administrative staff easier and significantly decrease their workload because, in nature, it is:

• ***Centralized data storage tool***. As "Everything is in one place" there is no need to retrieve data from multiple sparse sources and to aggregate them subsequently. It should be mentioned here that the term "centralized" is used on a logical level in respect to the user interface - a single user interface is used to access all of the data. But it does not influence the physical organization of the system and it could be implemented as distributed if needed.

• ***Automated data processing and analysis tool***. As the system has an access to all of the data it could automatically aggregate them and perform some statistical analyses on them. Results could be presented in both tabular and graphical form. The resulting analyses could be very important for the university management as they reveal the current research status of the institution and help managers forecast and plan strategies for its improvement.

II. RELATED WORK

There are other options that could be used for publication analysis of scientists [2, 5]. For example, Google Scholar[11], Scopus[8], Web of Science[10], DBLP[9], ResearchGate[7] etc. There are three main reasons why these platforms cannot be directly used by a university or a scientific institute:

1. They contain partial information
2. There may be incorrect/falsified information that can be manipulated
3. The scientific institute has no control over the data or the functionality of it.

Apart from Google Scholar, all other platforms contain data only for articles publicized at prestigious conferences or journals. All other articles that are not indexed by the latter bibliographic indexes will not be accounted for. On the other hand, Google Scholar indexes almost every article written in English and allows users to manually enter them. However, the information there can be easily manipulated. Due to bugs in the information retrieval and clustering algorithms, non-existent co-authors could be added to papers by using fake citations. This way one can "steal" other's articles and citations. This manipulation would only be observed in Google Scholar and other citation analyst platforms would show the truth. However, if Google Scholar is the main source of information for institutional reports or career development of the scientists, the possibility of manipulation in the records can introduce lots of unfair situations. Hence, the Bulgarian Ministry of Education and Science does not acknowledge data from Google Scholar.

Universities not only need analysis of articles and papers, but they also need reports and statistics of other types of publications – textbooks, books, monographs, patents etc. Such information is not stored or analyzed by the bibliographic indexes. Furthermore, universities require specific reports and analysis organized by time-periods and/or by faculty/department. The statistics from current scientific bibliographic indexes does not meet (it is not even enough) the requirements and needs of universities.

The combination of incorrect information and the lack of control over the data, the functionality and the types of analysis make the existing platforms unsuitable for publication analysis of the academic staff in universities. On the other hand, these platforms deliver additional useful information – number of citations, impact factor, sjr rank etc. Therefore, the newly developed system needs to be able to connect to their APIs and get additional information that will be used in the analysis and the automatic reports.

III. ARCHITECTURE

As most of the web applications, the system implements a 3-tier architecture where user interface, business logic, and data are separated into three functionally-independent non-overlapping layers (Figure 1). That provides easier data replication and portability; higher reliability and flexibility; and allows fast and easy personalization or complete change of the user interface [3].

The architecture consists of two types of modules: *universal* which are not related to any specific subject domain; and *specialized* that implements the business logic related to publication analysis and management. The "Access Control", "User Management", "Automatic Notification" and "Database Abstraction Layer" modules are universal and could be used, without any change, to implement their functionality in other projects / information systems as well.

The interfaces between individual components are described as detailed as possible on the diagram itself. The obvious dependencies are intentionally missed in order to keep the diagram clear. The <<call>> dependency is explicitly stated only when it is not clear that a module uses functionality from another one. In the case of direct interfaces, this dependency is obvious and thus deliberately skipped. For the same reason, dependencies between the provided "GUI data" interfaces and the relevant required interface of "GUI Management" are skipped as well.

Since all registered users work in the same institution, it is very likely (almost certain) that they have existing user accounts in other information systems or network infrastructure. For that reason the publication analysis system allows users to authenticate by their registrations in the university network as well. To implement this, the "Authentication by External User Accounts" module connects to the university LDAP server and checks if the specified user exists, and if it does, the system checks what their privileges are. Depending on the returned information it tells the "Access Control" module whether to allow or deny the user to log into the system.

The "Publication Management" and "Portfolio Management" modules play a central role in the architecture. The former implements functionalities for adding new publications as well as editing and deleting existing ones. Of course users are allowed to edit and delete just those publications that they own, i.e. publications they have explicitly added or they have been assigned to as co-authors. The "Portfolio Management" allow professors to create their own publicly-accessible CV (portfolio) that they can subsequently edit at any time. Although the CV is built based on a template, users can expand it with additional sections and include whatever information they want.

Since users work in the same institution and very often they work together in smaller teams it is likely that they have plenty of common (shared) publications. To avoid duplication and multiple entries of the same data, the system performs an automatic co-authorship recognition. Upon inserting a new publication the "Co-authorship Recognition" module analyzes the names of the authors and compares them with the names of the registered users. If there is a user whose first letter (initial) of his/her first name and his/her last name match with one of the co-authors, then the system suggests the user to recognize this publication as own publication. So it will be assigned to his/her list of publications without inserting it again. Alternatively if the names match but the user is not a co-author of the paper then he/she can reject the system's suggestion. All user responses are stored so that they are not constantly asked for the same publications.

Upon receiving a user request the "Statistics" module performs a real-time data analysis and prepares the relevant statistical report. Depending on it the system could present results in both tabular and graphical form. Some statistical reports however are computationally demanding and needs more time to be generated. In this case the system offers a report caching. The system administrator is required to set up the cache expiry time.

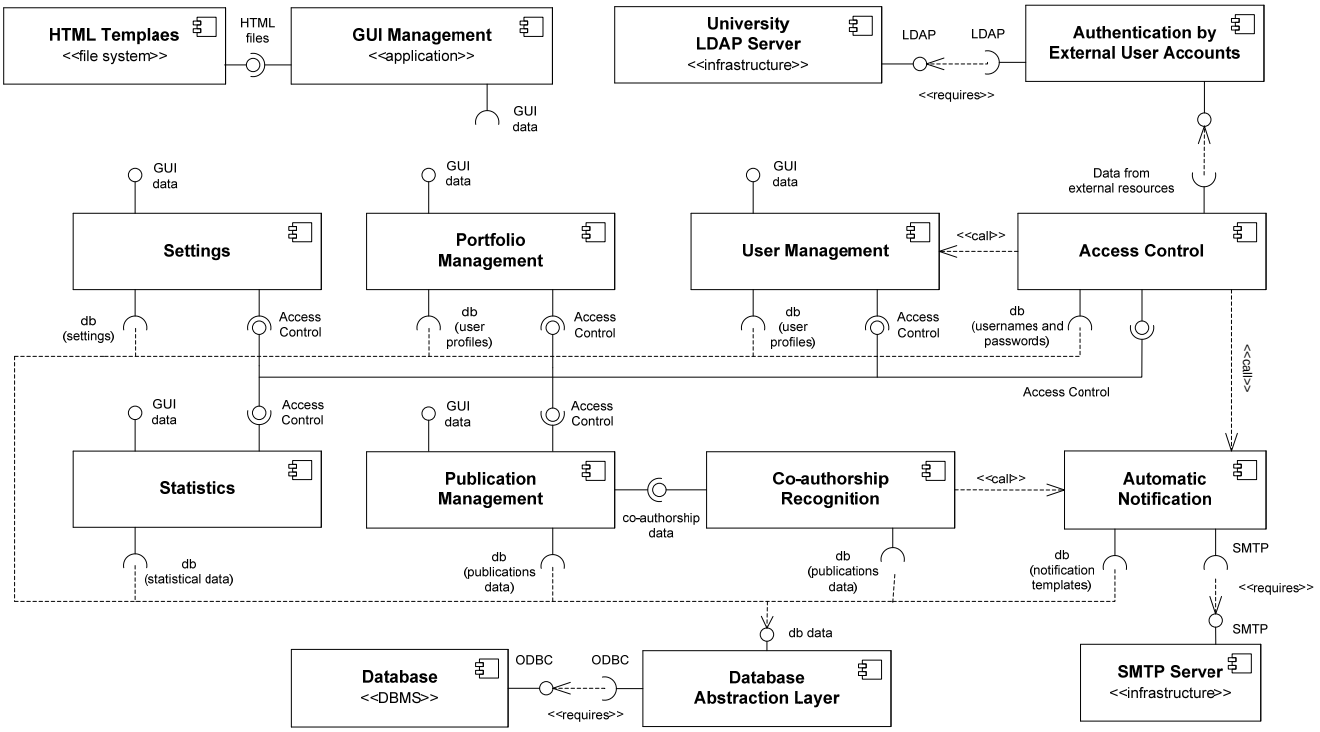

Figure 1. Architecture of the proposed web-based publication analysis system

In case an event occurs (for example, a user is recognized as a co-author, a registration is approved, a new password is generated, etc.), the "Automatic Notification" module automatically sends emails to the relevant users and tells the "GUI Management" module to show them notification messages on their home screen the next time they log in.

IV. FUNCTIONALITY OF THE SYSTEM

The proposed system allows three types of users to work:

•***Administrator*** - has full rights over information in the system concerning user registrations, publications, and structural units. He can manage faculties, departments, users and publications.

•***Guests*** - all users, that found the site of the system by chance or not, has the opportunity to browse and look for information about the publishing activity at the university, as well as to read the e-Portfolio of the lecturers and PhD students. There is also access to statistical information extracted from the data collected in the system.

•***Registered users*** - lecturers or PhD students from the university. Any registered user in the system will only have access to its full functionality after explicit approval by an administrator in order to achieve a higher level of data protection. Before approval, an administrator checks whether the entered data is real and only then activates the registration. Users with already enabled registrations have the right to see everything that guest can see in the system, and to further add, delete and edit data for their publications and e-portfolio.

The items in the menu for registered users have the following features:

- ***My registration*** - Add and edit user registration data. These are the basic personal data of the user to be filled in the registration form that are sufficient to be identified as a lecturer or PhD student at the university.
- ***E-Portfolio*** - a standard template is used to create an e-Portfolio available on the Internet. It consists of the following sections:
  - Personal information
  - Work experience
  - Education and training
  - Personal skills and competencies
  - Additional information

Registered user creates their own e-portfolio. Subsections and categories can be added, edited, and deleted in each main section, a photo can be added (it is not obligatory). At any time, the user can check what the public version of their e-portfolio looks like. The system gives the opportunity to generate an e-portfolio version suitable for printing or copying to a file.

- ***Password Change*** - Standard functionality for any application that uses a username and password for registered users. It is necessary to enter the old password and enter the new one twice. Separately, it is possible to generate a new password when the user cannot remember his/her password from the link Forgotten Password option. In this case the user receives an auto-generated e-mail message at the registration email address that contains instructions on how to generate the new login password.
- ***List of papers/publications*** - shows a list of all papers to which the active user is co-author or

author. There is a link to a list version suitable for printing and generating a file. There are also options for different filters for setting search criteria in the list. The list itself is ordered by type of publication and by the first author's family name. List is separated by 20 papers per page and there are buttons for navigation between pages.

- ***Add new paper*** - this menu option launches a dialog with the user to select a type of the paper (monograph, book, conference paper, ...) from a predefined list, and a corresponding entry form for the selected type of paper. In this entry form the user enters authors names list, title of the publication, where and when it is presented/published, link to the conference proceedings or scientific journal (if it is available online). Formal and logical control of the entered information and corresponding messages for data input errors are provided. Before adding the newly described paper the system checks for the presence of a paper with the same title, and if it was found, it is suggested to the user to add himself as a co-author rather than re-adding the same paper in the system. If the user confirms that it is different paper, regardless of the matching of the titles, it is added to the list with publications.
- ***Recognition*** - Since it is possible for several colleagues from the university to be co-authored in a publication and to prevent the situation when everyone from the co-authors added the same paper and there are repeating titles in the database, the following functionality is provided: Each registered user, with activated registration, receives a list of publications, the authors of which meet initials of their own name and full surname on entering the system with a username and password. If he recognizes himself as a co-author instead of re-entering the paper again, he simply associates it with himself, and it becomes his own. This is organized through appropriate dialogue with the user. He also has the opportunity to say that he is not a co-author, despite the name match, and this publication will not be offered to him anymore. This avoids duplication of information in the system and optimally accurately reflects the actual publication activity at the university.

On the basis of the collected data, various queries and reports can be drawn up, which would be useful for analyzing the publication activity of the lecturers and PhD students in the university as a whole and by the individual faculties or departments.

- ***By lecturer*** - from a list of all registered teachers sorted alphabetically, the list of publications or the e-portfolio of any lecturer can be selected. Since the list of lecturers is too long, there is a search filter by name and / or surname.
- ***By PhD students*** - the same as the above option, but for registered PhD students.
- ***By Department*** - List of all departments grouped by faculty with a search filter by department name. It is possible to select to see a list of all lecturers, a list of all PhD students or a list of all publications for this department.
- ***By faculty*** - a list of faculties at the university and the user can select to see a list of all departments in the selected faculty or a list of publications by the chosen faculty.
- ***By University*** - List all publications in the database of the system, grouped by type. There are search filters by keyword, by type, by time period, or by user groups.
- ***Last published*** - the last twenty publications of all in the system that were published most recently.
- ***Last Added*** - the twenty most recently added publications in the system.

This type of systems does not represent any specific novelty in terms of design, development, implementation, and functionality, but they are extremely useful with the collected data in them and with the capabilities they provide for analyzing. Because of this a module for compiling and displaying statistical information is implemented in the system, which analyzes the data in real time and output the results both tabular and graphically.

561 lecturers and 209 PhD students are registered, and they have entered data for 20343 publications. Figure 2 shows the distribution of the number of publications by type for the last 15 years. It is seen that the highest number is the number of conference papers, followed by the number of articles. Relatively small is the number of monographs, studios, books and textbooks.

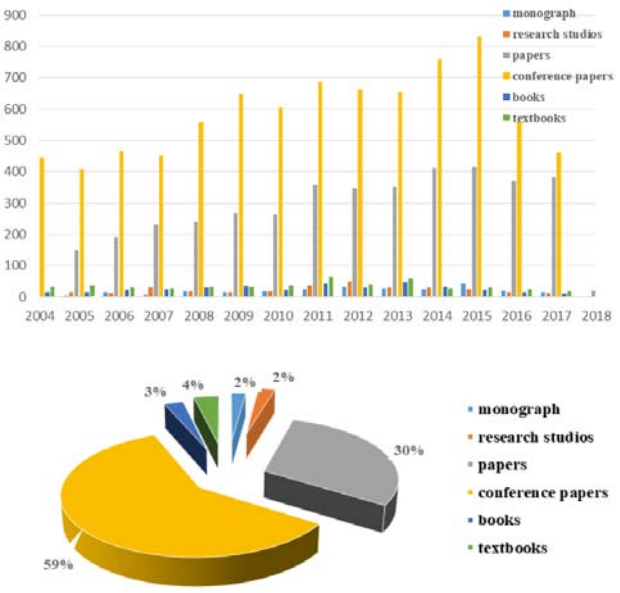

Figure 2. Distribution of the number of publications by type for the last 15 years

Figure 3 shows the number of the conference papers per year for the last 15 years. The highest number of the

conference papers is published in 2015 and the lowest number in 2005. 42% of the conference papers are presented and published in our local conference in Ruse and 74% of all conference papers are written in Bulgarian, and the others 26% are in other languages (Figure 4).

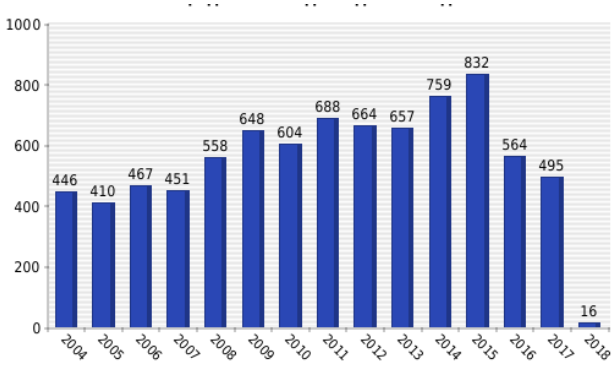

Figure 3. Distribution of the number of conference papers for the last 15 years

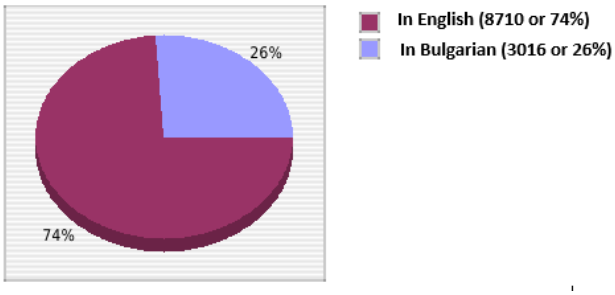

Figure 4. Distribution of the number of conference papers by language

V. CONCLUSIONS

The proposed web-based publication analysis system makes the work of both administrative and academic staff easier. Stored data are available 24/7. The system automatically performs data aggregation and analysis. If the administrative secretaries need some report about the publication activity of the academic staff they can take it out directly from the system, rather than asking lecturers/tutors to provide data that should be further processed and analyzed.

Professors have an up to date list of their publications available anytime anywhere. If they need to apply it to some document they can just copy it ordered and formatted from the publication analysis system. The latter also allows professors to create their own publicly-accessible e-CV (e-Portfolio) and provides a personalized URL that could be attached to documents or inserted as an email signature.

Apart from academic and administrative staff, the system is quite useful for the university management as well, as it reveals the current research status of the institution and help managers to forecast and plan strategies for its improvement.

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ERP Systems in Higher Education Institutions: Review of the information systems and ERP modules

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***Abstract* - This study reviews the enterprise resource planning (ERP) systems in higher education institutions (HEIs), as a study like this is very scarce in literature. Because ERPs are consisted of modules, understanding modules designed for HEIs has remained unclear. The current scenery of research is very scattered with analysis conducted mainly in failures or success stories, or specifically factors for success during a module implementation. However, to this date there are no studies that provide a comprehensive picture of ERP modules for HEIs. This research contributes by reducing this gap by providing characteristics of the identified modules and making a clear distinction between the ERP modules in HEI and business. The results of this study show that it is arguable that standard tools for business organizations can be similarly applied in HEI. Rather, ERP systems in HEI are very different in terms of functionality and modules compared to corporate ERPs. The main contribution of this study is its originality and is the first study that provides an overview of HEI ERP with the core and extended modules, the functionalities and differences with the business ERPs.**

Keywords – Higher Education Information Systems; Enterprise Resource Planning Systems; ERP Modules for HEI.

I. INTRODUCTION

Today the influence of technology is perceived as a changer of the landscape in which higher education institutions operate. The use of information systems and the application of available technologies are growing progressively. Existing information management and strategic management theories, methods and literature are unable to describe, explain, and show the impact of information systems in higher education institutions.

The aim of this study is to reduce the research gap regarding the approaches of enterprise resource planning (ERP) systems and information systems (IS) implementation in higher education institutions (HEIs). ERP systems that are built on organizational assumptions do not correspond with the characteristics of higher education organizations. Since ERPs are consisted of modules, the issue of having a comprehensible picture of the distinction between those that are for businesses and those for HEIs has remained unclear. The current scenery of research is very scattered with analysis conducted mainly in failures or success stories, or specifically factors for success during a module implementation. A comprehensive picture of the IS and ERP modules for HEIs still remains unclear. This research contributes mainly to reduce this gap.

The study is organized as follows: First, a review of IS for HEI is provided. Categorization of the different systems is provided, and the rationale and importance of system integration to provide a fully functional ERP is given. ERP benefits for HEIs are derived. Second, HEI ERPs are investigated. Clear distinctions between the core ERP modules in HEI context are given. Moreover, learning management module library management module and other modules are analyzed as extended modules. Finally, summary and implications of the study are provided.

II. REVIEW OF HIGHER EDUCATION INFORMATION SYSTEMS

Higher education (HE) is in the core of every economic unit. It is the engine that generates new workers, new business ideas, and new policy developers. HE is the driver of today's economic, social and cultural change. In these institutions knowledge is accumulated and conveyed. According to Varghese, universities "through their research and teaching they help to produce expertise, manage development, engineer social transformation, and preserve social values and cultural ethos" [1].

Higher education has experienced a crucial change, and we witness the rapid development in this area. Looking at these changes from the European perspective, we can see that several joint European Union initiatives are taken [2]. First, the Bologna Declaration (19.06.1999) with the joint declaration from the European Ministers of Education, is the major point for development and modernization of HE in Europe. According to this declaration, the main focus is the acceleration of student, graduates and HE staff mobility, as well as access to high-quality HE [2]. In line with this, defining what constitutes high-quality HE has remained unclear. This study addresses this imbalance by making the premise

that technology plays a big role in offering high-quality education. "*Technology is in the process of taking over the traditional values of without exception*" [3] – and is well seen in the way universities around the world operate nowadays. There are patterns that show that the traditional university will not succeed if it doesn't adopt the changes. HEI's are in the process of designing appropriate IS to ensure sustainable development and meet the constantly changing need for market-oriented learning and new knowledge. The landscape of a contemporary university consists of students that prefer to get their degree completely online or to some extent, students that want to have access to the information in anytime and anywhere in and outside the campus, and moreover, students that want to get the specific skills to penetrate the labor market as soon as they graduate. Universities are remodeling themselves not only to provide the abovementioned, but also to generate products or research that will address the issues and challenges of the modern society.

Different authors classify information systems in higher education in different ways. However, grouping the distinctive systems according to their functionality best fits the clarification for Higher Education Information Systems (HEIS). The major functions that are supported by information systems in higher education can be categorized in four major areas: (1) Education Activities, (2) Research Activities, (3) Business Activities, and (4) Management Support. This separation of information systems in university setting is supported by a research from Zornada and Velkavrh [4].

TABLE I CATEGORIZATION OF HIGHER EDUCATION INFORMATION SYSTEMS

MANAGEMENT SUPPORT IN HIGHER EDUCATION INSTITUTIONS Business reports, controlling, decision support systems, quality assurance		
SUPPORT OF EDUCATION ACTIVITIES	SUPPORT OF RESEARCH ACTIVITIES	SUPPORT OF BUSINESS ACTIVITIES
• student information system, • portals/CMS, • e-learning systems, • library systems, etc.	• research information systems, • library systems, • support for project work, • research software, etc.	• human resource management systems, • financial and accounting IS, • administrative IS, etc.

Source: Adapted from Zornada and Velkavrh (2005)

In Table I above, examples of information systems for each category are shown. Information systems that support education activities are mainly systems that serve the core functionality of universities as teaching, keeping student records, library, etc. These systems are very important for universities as they are the systems with whom students and instructors interact with. The second category of information systems supports another important function of universities, which is research. These systems include research information systems, library information systems, etc. The third category supports mainly the departments and these systems are the closest to corporate information systems. Examples of information systems that support business activities are financial and accounting information systems, human resource management systems, etc. The fourth category of information systems support the managerial level and serve for business reporting, decision making, business intelligence, control, and support the major functions of the managers.

As seen from the Table I, in a perfect setting, the input for management activities comes from the systems in the other three areas. To be able to use the data from all these systems there is a need for integration of functional silos. However, integrating information systems from different functional areas or implementing Information and Communication Technologies can be a complex task. These issues can range from technological to organizational and human related issues [5], [6]. One of the best ways to do this integration is through implementation of ERP systems.

Many universities have implemented or are planning to implement enterprise systems because they include many of the functionalities required by Higher Education Institutions [7]. According to a study conducted by ECAR [8], the top three reasons for implementing ERP's are: replacing aging legacy systems, improve services, and transform how the institution operates. The universities that have implemented these systems have reported positive end results, which are illustrated in Table II below.

TABLE II ERP BENEFITS IN HEI

ERP Benefits in Higher Education Institutions	
Business Benefits	**Technical Benefits**
Campus wide integration on a common system	Create a more seamless integration between technology and education delivery by providing a single platform based on new technologies
Reduce or eliminate manual processes	Improve internal communications
Establish a self-service environment for employees	Improve self-service environment for students and faculty
Enable higher availability of administrative systems	Enhance strategic decision making and planning capabilities
Provide accessible, user-friendly administrative and student support services	Support sophisticated data analyses for use in decision-making

Source: Adapted from SEO(2013) [6]

However, this implementation usually is costly and is accompanied with difficulties and time consumption. According to the same study [8], universities that have implemented ERP's state that the difficulty is around 3.52 for financial modules, 3.53 for HR, and 3.80 for student on a scale 1-5 where 5 is "very difficult" and 3 is "about the same". The same report brings into light that managing the process and organizational change in ERP implementation were rated as more difficult than the technology.

Enterprise systems have been a hot topic during the last two decades. By 2011 most of the universities have already implemented an ERP [9]. In line with this, the

difference between ERP solutions from early 2000's is that during the early stages, ERP's in HEI had only the core functionality as finance, student services, and human resources, and decade later, ERP's are much more complex, and have almost every functionality needed from a higher education institution, including CMS, LMS, library, business intelligence, etc. Universities adopt these systems to gain the integration advantages [10] as well as increasing operational efficiency and decreasing costs [6], [7], [11]. Despite the fact that there have been reported failures in achieving the expected outcomes and results of ERP implementation [6], [12], and that these systems create tension and affect the business processes of the universities [6], [13], universities continue to adopt these systems. This is due to the possibility ERP's provide in terms of facilitating the integration of the administrative functions that in the past have been supported by separate legacy systems [4], using modern technology [6], accessing data in real time [14], and thus resulting with increase in income and decrease in expenses [15].

III. HIGHER EDUCATION ERP SYSTEMS

This section starts with analysis of the core ERP modules in HEI context, and then moves into analysis of the most common extended modules for institutions of higher education.

The core modules of ERP systems are as follows: Financial Management, Operations Management, and Human Resource Management. For meticulous reasons, core modules in ERPs for higher education are considered financial management, human resource management and student module [4], [8], [16].

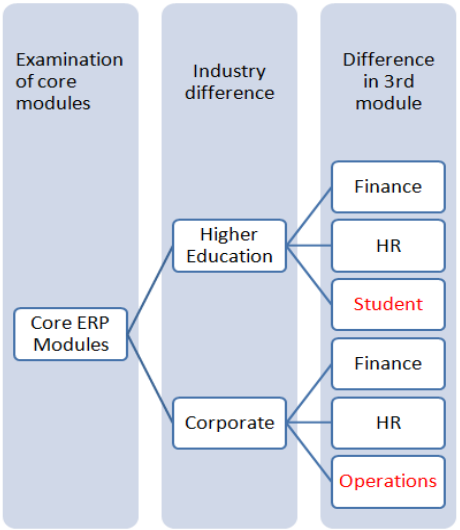

Figure 1 Core modules in Corporate and Higher Education ERPs
Source: Author's own work

The fundamental notion of the ERP systems rests in integrating and connecting the major functions of a conventional organization. ERP systems for higher education mature in the direction of carrying key administrative and academic services with the support of three core modules as depicted in Figure 1, i.e.: 1) Student module or student administration – that has enrolment procedures and student enrolment, financial support for students and student data as core functionalities; 2) Human resource module that monitors employees as a major functionality; and 3) Finance module with accounting, payments, investments, and budget as major functionalities. [4], [16], [17]. Table III depicts some major functionalities that each of the three core modules should have.

TABLE III CORE MODULES AND FUNCTIONALITIES IN ERP FOR HEIS

ERP Modules in HEI		
Finance Functionalities	**HR Functionalities**	**Student Functionalities**
Payroll	HR Management	Academic Setup
Budgeting	Faculty Management	Student Enrolment
Accounts management	Holiday Management	Student administration
Invoicing	Leave Management	Attendance Management
General Ledger	Promotion Management	Fee Management
Reporting	Staff profile	Finance Assistance
	Job requirements analysis	Student Profile
		Curriculum Management
		Alumni Management

Source: Authors own work.

ERPs are one of the most successful systems for resource management in any organization [18]. The benefits from these systems are well documented in literature [14], [19]–[25]. In the last two decades universities have also started to adopt these systems to gain the integration advantages [10] as well as increasing operational efficiency and decreasing costs [6], [7], [11]. Despite the fact that have been reported failures in achieving the expected outcomes and results of ERP implementation [6], [12], and that these systems create tension and affect the business processes of the universities [6], [13], universities continue to adopt these systems since it facilitates the integration of the administrative functions that in the past have been supported by separate legacy systems [4], use modern technology [6], access data in real time [14], increase income and decrease expenses [15].

As ERP is designed with modules, it becomes more challenging for HEIs to implement packaged solutions, since they request altering of the business processes and customization to fit into these systems [26]. Thus, there is a need for understanding each of the modules that an ERP is consisted of. These will be elaborated in the sub-sections below.

IV. CORE ERP MODULES IN THE CONTEXT OF HIGHER EDUCATION

As depicted in Figure 1, core modules in higher education ERPs are finance, human resources and student module. Figure 2 extends these modules with applications that are part of each of the three core modules to give an overview of what each is consisted of.

Figure 2 Core ERP modules in HEI
Source: Authors work

A. *Financial Management Module*

Financial Management (FM) module in ERPs usually incorporates all the financials of an organization. Functions of this module include but are not limited to: accounting, budgeting, payroll, financial analytics, asset lifecycle management, as well as management of other financial data. In today's fast changing landscape, institutions of higher education depend evermore on swift, precise, and effective financial management systems to nourish their economic well-being.

FM module is very similar to corporate FM - ERPs. Nonetheless, there are some noteworthy differences. First, higher education institutions are usually subject to accounting for non-for-profit organizations [27]. Second, higher education institutions have some specifics in finance such as: grant management, research budgeting, student finances, student financial aid, etc. In university setting, the financial module allows proactive planning, real time visibility of the budget, consolidated financial reporting, rationalized cash flow activities, and optimized financial transactions [18]. There is more visibility of financial processes since centralized financial reporting and management is accomplished.

These systems, if deployed properly in institutions of higher education will allow users (especially the top-management) to select and pull high level information, as well as drill down to concrete transaction. However, this can be only achieved through integration with other systems, especially HE and SIS.

B. *Human Resources Management Module*

Human Resources Management (HR) module in ERPs usually deals with functions as: recruiting, payroll, time and attendance, performance appraisal, benefits administration, learning management, performance record, employee self-service, scheduling, absence management, analytics, etc. From the higher education institutions perspective, most of the features and functionalities provided by business ERPs are needed. However, there is still a need for additional functionalities in higher education institutions, like: 1) denote the academic titles; 2) address the different type of engagements such as: teaching, research, mentorship, projects, administrative work; and 3) embed rules on academic promotion and remuneration policy.

HR Systems are important for universities for several reasons. They enable universities to keep up to date administrative and academic staff data which are used for various needs as: defining roles, identity access management, determining salaries and payments, determining staff engagements, keeping teaching history, etc. This system is tightly integrated with the financial and accounting module depicted above [28]. According to a survey conducted by Sierra-Cedar in institutions of higher education, as the growing number of institutions who are considering HR systems only as administrative support tool and as strategic instrument so that they can leverage the system to support engagement and optimization of the workforce, it becomes obvious the need for enterprise HR system integrated tightly with finance and accounting, as well as with the student information system [29].

C. *Student Information System*

Student Information System (SIS), as a core module in HEI ERPs, is the most diverse module in ERPs since operations of an organization depend from the nature of its operations. SIS includes many sub-modules and functionalities including, student lifecycle management (student recruiting, admissions, student, graduation, and alumni), curricula management, academic planning, course scheduling, bursar, etc. It can be argued that in the business of higher education, this module lies in the heart of the institutions ecosystem of administrative and enterprise systems.

Since SIS have an impact in the perceptions that students gain for the institution and impact their satisfaction, institutions of HE face challenges in retaining optimal SIS operations. According to CDS 2013 data, more than 95% of U.S. institutions have an SIS. With a mean of 12 years old and with 86% of institutions maintaining at least some SIS customization, these systems rank among the oldest and most customized of institutional enterprise systems [30].

While the student information system is one of the core administrative systems in HEIs, it is almost impossible to scrutinize its long-term strategy in an autonomous manner, due to its linkage and tight integration with other systems, predominantly the finance system and human resource system. This is a major reason why HEIs turn to enterprise applications, ERPs, to join these isolated services and systems into an integrated ecosystem.

V. Extended ERP Modules for Higher Education Institutions

A. Learning Management Systems

Learning Management Systems (LMS) are complex data systems primarily determined for the support of the pure set of learning activities. These activities include not only study activities, but also managing and governing activities of study courses. According to a report from Trimeritus, as of 2016, there are more than 230 commercial and 60 open source Learning Management Systems [31]. Most popular Learning Management Systems include systems such as: Blackboard, Moodle and Sakai. However, some ERP packages (for example SAP) have a module for learning management.

Consistent with a research conducted by Elaine Allen and Jeff Seaman based on responses from over 2,800 Chief Academic Officers (CAOs) and academic leaders, 69.1% of the respondents agreed that online learning is of strategic importance for the university [32]. Figure 3 depicts that the growth in distance/online learning will outpace the traditional learning in any way by 2021.

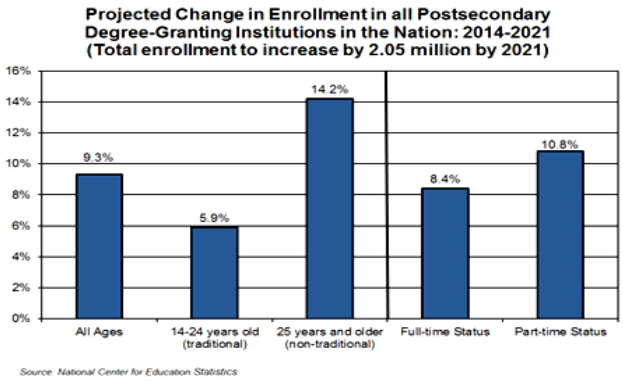

Figure 3 Increase in Online Enrollment in USA

B. Library management systems

Library management systems also called Library Automation Systems, are information systems that support basic housekeeping functions of a library [33]. These library functions include: cataloging, Online Public Access Catalog (OPAC), circulation, acquisition, serial control, and interlibrary loan (ILL) [33]. In the context of ERP modules, library management modules provide the abovementioned functionalities as well as integration with student and staff data. This additional functionality is required since the main customers of the university libraries are students and academic staff. Since this data already exists in the database, it can be readily used by the library management system.

A typical library system in a university setting has data about the books available on library, and data about rental history of its books. The system, through its web interface that is available to faculty and staff members, gives the users the ability to search and reserve books, as well as access to online databases such as EBSCO Host. The data collected from this system is used for predicting how many copies of each book the library should buy, which are the most wanted books, which books are not needed. This data is used from the library for predictive analysis of future purchases.

However, a study by Wilson states that this type of a system has to be integrated with ERP systems, since disintegrated model does not work due to the fact that too many silos need to be maintained. The integrated library system (ILS) includes, but is not limited to: core library data (including purchase and cost data), bibliographic records, and circulation information [34]. Similarly, holdings management for electronic resources has moved to knowledge base products, which in turn provides a powerful tool for the librarians to keep track of which resources they own. Library system is serving universities in more way than one. Not only they serve students, but are the hub where research meets the opportunities, thus integrated library that offers access to other national and international libraries is becoming core IS for HEIs.

C. Other modules

University ERPs also have other modules that change from vendor to vendor and from university to university. Examples of these modules include: Research Management Module, Customer Relationship Management (CRM), Grants Management, Career Services, Facility Management Systems, Content Management Systems, Executive Support Systems with embedded Business Intelligence capabilities, etc. These optional modules/features provide extended functionalities to institutions of higher education depending on their needs. Figure 4 provides an overview of the most common extended modules for HEI ERPs. They can also be implemented as separate systems within the organizations.

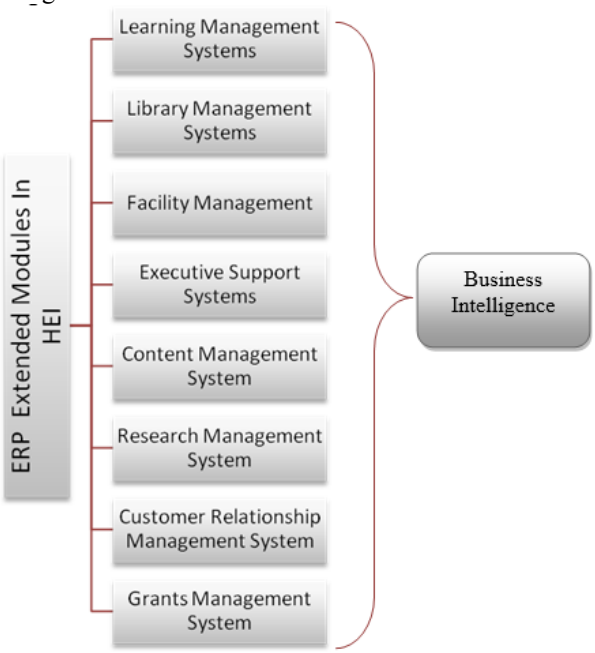

Figure 4: Extended ERP Modules for HEI
Source: Author's own work

Research Management: Authors argue that the main two components of universities are *teaching* and *research* [35], and the per say research process has not been given the desired attention as teaching, but this has changed

during the last 10 years. Information regarding research in the university is found transversely between different systems in university setting, starting from HR, to publication databases, repositories and web pages of the universities. A research information system, or research management system (RMS), integrates these systems and makes possible capturing and exchanging of the research output, automatic updates of the researcher profiles and web sites, updates of departmental and institutional records, as well as enables benchmarking with other institutions [36]. Moreover, since HEI are contributing directly to social, cultural and intellectual life of the society by improving the human capital [37], many governments have started to address the question of research as more strategic issue due to the economic significance of the academic capital and dissemination of the same. Much of the funds for HEI are addressed to research and development, which creates pressure on the institutions to reorganize in order to meet the challenges. According to OECD study *"Participant HEIs have identified the need to strengthen research capacity and capability as critical to their institutional mission and to their survival as an institution"* [37], which as guidance provided by JICS states, lead to better management of the research within institutions. An example is the U-Gov Research developed by the Italian government and adopted by more than 20 universities that has allowed these universities to develop a single database of scientific research results, which serve as a basis for monitoring and assessing publications and checking achievement of objectives [35]. RMS offers this integration and provides acceleration of the recognized speed of information delivery, benchmarking as well as institutional compliance with government regulations.

Customer Relationship Management: CRM system in higher education institutions have recently taken the position of becoming to a certain extend crucial for the operation of the institution. One of the major reasons why would HEI adopt this system is the pressure that HEIs face to attract and retain students through traditional business perspectives. However, keeping in mind that around 50% of all CRM implementations fail in the private sector, the percentage in higher education doesn't look much better, adding here that it takes six to twelve times longer to implement than in the private sector [38]. According to the same log post, CRM are systems that universities adopt to manage communications, relationships, and reporting processes for external audiences, which in university setting allures to prospective students, current students, or alumni and donors. An AACRAO study that surveyed more than 600 US HEI, reveals that around 64% of institutions have reported some use of the CRM and 42% of those that of not have CRM, are planning to adopt one [39]. Out of those that use CRM, they utilize this system for supporting admissions and recruiting mainly, rather than to provide support for student lifecycle. This is one of the reasons that around 75% of the institutions are not maximizing the use of their CRM, followed by the fact that only 33% of the institutions share the CRM data with the institutions SIS, and the majority (more than 60%) do not currently have all of the data needed (and available) from their CRM imported into their SIS. [39]. Nonetheless, research in this area suggests that the benefits of implementing CRM in a college setting include a student-centric focus, improved customer data and process management, increased student loyalty, retention and satisfaction with the college's programs and services [40], [41]. In the context of HEI, students should not be viewed as "customers", rather as "products", thus this name has only kept the functionality of the module for businesses, but in reality, it has to do with offering students the best services, so they achieve success and increase the competitive advantage of the institution in terms of student hire in the labor market.

Grants Management: Many universities, especially in USA use grants management system for submitting grant applications and reimbursement requests [42]. Some of the features of this system include: proposal and budget development, summary of institutional proposals, questionnaire assembly and response management, government grants integration, negotiation management, award management, report tracking, and management of conflict of interest [43]. Grants mainly are served and implemented in public institutions, but nonetheless are considered among the core information systems for higher education functioning.

Career Services Management: These systems are designed to manage all aspects of career services, including job postings, on-campus recruiting, post-graduation metrics, and more. Some of the features these systems have are: recruiting management, career fair management, student CRM, as well as recruitment reporting tools [44]. Institutions of higher education should coach students for entry into the work force and their future careers [45]. Since this is a more daunting task than simply preparing student with the necessary skills, career services play an important role in giving an immediate assistance for the students to start with their careers. Thus, career management systems are increasingly taking place in HEIS.

Facility Management: These systems manage and utilize the space and infrastructure to meet the needs of the students, employees and the institution, reduce office movements, carry out maintenance, streamline processes, greater energy efficiency and check what is required with the budget allocation so that it aligns with the core business needs. According to post from Costanzo, Director of Facilities Management Team, Imaginit Technologies, campus facilities are central to the quality of the experience students get in the university, and that to *"build, operate, and maintain facility space is a growing proportion of higher education institutions' annual budgets"* [46]. These costs are estimated to have growth by 20 percent in the public institutions, and around 48 percent at private ones. There are systems developed to help the institutions to reduce costs, collect and organize data, streamline processes [47]. They play an important role in university setting since they keep accurate facility inventory, prepare building condition

reports, and are embedded in scheduling systems for better functioning of the academic planning process.

VI. Summary and Implications

The sector of Institutions of Higher Education (HEIs) is one of the most important sectors that looks to keep in pace with technology developments. Many universities have turned to ERP systems to ease the management of data and processes and procedures and to benefit in terms of cost reductions and efficiency amplification to boost institutional performance. It is very enticing to see institutions of HE as unique. On one side we have the universities as distinctive with an "autonomous place in society and the right to choose its members, settle its aims, and operate in its own way" [48], and on the other side "universities as organizations face many problems common to most modern organizations" [13], including here, but not limited to, coordination of resources, controlling costs, managing resources, information sharing etc. Therefore, it is arguable that standard tools for business organizations can be similarly applied in HEI. The gap between commercial ERP systems and information systems in HEI is quite evident even in the number of all enterprises, with HEIs rounding to 1%, thus this market is mainly created for businesses, Moreover, as depicted earlier processes in HEIs vary considerably from those in enterprises since they are very complex (many processes) and complicated (many interactions). ERP systems are developed for enterprises on the market, with lot of parameterization. Consequently, it is of no surprise that ERP systems were not designed for HEIs, instead for corporate sector, and very modest endeavor has been made to make them fit into the business processes of the universities. This argument is also supported by many studies [14], [17], [49]–[51].

This study brought in light the importance of information systems and especially ERP systems in HEI and differentiates the same in terms of functionality and modules. There is a lack of studies on information systems and ERP systems in higher education, an argument supported by many authors indeed [13]–[15]. Thus, this study reduces this gap in literature by providing an overview of HEI ERP with the core and extended modules, the functionalities and differences with the business ERPs.

Last, but not least, the analysis conducted in this study, starting from in depth examination of the modules of ERP systems for HEI, which has not been carried out by now – contributes to the literature in many ways bringing fresh breeze of new critical thinking. However, the central significance is, as represented above, the gap reduction in literature for ERP systems in HEIs.

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Digitalization of Regulation Unit Selection Process in Power Transformer Design

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***ABSTRACT* – Large power transformers generally include a customer request for a technically appropriate regulation unit. The selection process of the regulation unit consists of defining the required input data, performing mathematical calculations necessary to find the technical limit values that the regulation unit has to satisfy, and finally optimizing and selecting the appropriate regulation unit.**

The regulation unit is defined by the tap changer type, number of phases, maximum rated through current, insulation level, tap selector size, number of positions and type of regulation. Each of these items is mutually dependent and may have an impact on the restrictions of other items (according to the manufacturer's technical data). Taking this into consideration, the number of possible permutations for selecting the appropriate regulation unit consists of thousands of different combinations, depending on the type of regulation and other technical limitations.

The process of finding the optimal regulation unit „manually" can take up to several hours. Implementing the developed algorithm and introducing Tap Changer Selection application, the required time is reduced to several minutes, which represents significant time savings and reduced possibility of errors during power transformer design process.

Keywords – Power transformer regulation, tap changer selection, tap changer database, tap changer calculations

I. INTRODUCTION

Large power systems such as electrical grids of entire cities, countries or continents are systems which must be continuously regulated in order to keep the voltage supply constant, thereby ensuring all the electrical devices and equipment to work in the expected voltage range. In such large systems, disturbances in the load and/or supply is inevitable – i.e. under greater load, the current increases, and consequently the voltage drops along the transmission lines which connect the power supply to the power consumption. Handling such disturbances and maintaining a constant voltage supply is (among others) the responsibility of the power transformer as one of the most expensive parts of the power grid. For this purpose, the regulating power transformer is equipped with a regulating winding which is connected to the regulation unit – usually **O**n **L**oad **T**ap **C**hanger (OLTC). The voltage regulation basic principle is adding or subtracting turns from either the primary or the secondary winding. The task of an OLTC is the current break function when transformer is energized and in service. As opposed to the OLTC, the DETC (**D**e **E**nergized **T**ap **C**hanger) must not be operated while the transformer is energized. This means that for the DETC to operate, the transformer must be disconnected from the network for a short period of time. This is why an OLTC regulation unit is more and more becoming a standard customer request for power transformer regulation.

Generally, many different regulation units are technically appropriate and may be used for a particular transformer design. In order to minimize the overall costs while still managing to provide the required regulation capabilities, one of the transformer manufacturers' challenges is to optimize the regulation unit selection process. Since the regulation unit (i.e. tap changer) can make around 10 – 20% of the total material cost of the transformer, the overall effect of optimizing the regulation unit becomes significant.

II. RELATED WORK AND MOTIVATION

Related work on this area consists of different power transformer design tools which (at most) consist of a regulation unit database, expecting the user to choose the appropriate regulation unit from the list (manually). A tool example presenting automated regulation unit selection functionality in the power transformer industry is *ABB Compas* tool [5]. Since this tool is limited only to *ABB* types of tap changers, the main motivation for this work was to provide a faster and more efficient way of selecting the optimal regulation unit also for manufacturers other than *ABB*, e.g. *MR* (Germany) and *C.A.P.T.* (Italy) for OLTC and DETC regulation units since this is a common customer request. The main advantage of this application becomes evident in the offer stage where quick and correct selection of the optimal regulation unit is important for the final transformer design cost estimation.

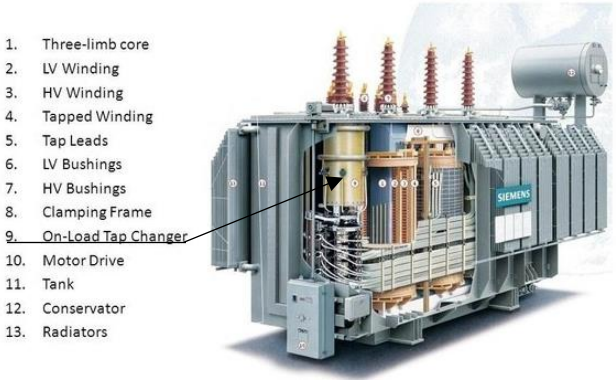

Figure 1: Power transformer with a regulation unit

III. MANUAL SELECTION AND CALCULATIONS

Each type of regulation unit is available in a number of variants, with different values of maximum rated through-current, number of phases, highest insulation level, tap selector size and basic connection diagrams. Therefore, the type designation (examples in Fig. 6) of a regulation unit depends on these features.

When selecting the appropriate type of OLTC or DETC manually, a number of parameters and technical limits have to be considered.

First of all, the **rated through current** of the regulation unit must not be less than the transformer highest current value of the regulating winding. For regulation at the neutral end with constant induction (constant flux voltage variation, CFVV), the rated through current in case of a **three-phase full transformer** is:

$$I_{max} = \frac{S_n \times 1000}{\sqrt{3} \times U_{1min}} \quad (1)$$

where:

I_{max} is the maximum rated through current [A];

S_n is the transformer rated power [MVA];

U_{1min} is the rated line voltage in the minimum tap position in [kV].

For a **three-phase autotransformer** with regulation in neutral end, variable induction (variable flux voltage variation, VFVV), $S_n = const.$, the rated through current depends on both regulated and non-regulated voltage levels:

$$I_{max} = \frac{S_n \times 1000}{\sqrt{3}} \times \left(\frac{1}{U_{2min}} - \frac{1}{U_1}\right) \quad (2)$$

where:

U_1 is the rated line voltage of the non-regulated side in [kV];

U_{2min} is the rated line voltage in the minimum tap position in [kV].

In case of **one-phase transformer**, the rated through current is multiplied by a factor of $\sqrt{3}$ since the rated power is per phase and the rated voltages are phase voltages.

Maximum rated through current is the current which the regulation unit is transferring from one tap to the other at relevant step voltage.

Step voltage U_{step} [V] is the phase voltage between the taps which depends on the required regulated voltage range and the required number of positions. This value is constant in case of CFVV (constant flux voltage variation), unlike in the case of VFVV (variable flux voltage variation) where different regulating positions have different volt/turn ratio and therefore different step voltage values:

$$U_{step} = \begin{cases} \frac{U_{1max} - U_{1min}}{\sqrt{3}(n-1)} \times 1000 & ; \text{CFVV regulation} \\ \max(U_k - U_{k-1}) & ; \text{VFVV regulation} \end{cases} \quad (3)$$

where:

U_{1max} and U_{1min} are the required maximum and minimum regulated line voltage in [kV] (equivalent three-phase bank line voltage in case of a single-phase transformer);

n is the required number of regulating positions (including the rated position);

$U_k - U_{k-1}$ is the (phase) voltage [V] difference in the regulating position *k* and *k-1* (for positions *k = 2* to *n*).

The required regulation unit **external insulation level** depends on the insulation level to ground of the side where the regulation unit is connected. The withstand voltages of the external insulation are standardized by international standards and correspond to the highest voltage for equipment [4]. In case of regulation in neutral end (common for full transformer or VFVV autotransformer), the insulation level is usually the same as the insulation level of the transformer neutral (unless otherwise specified). In case of regulation in line (common for CFVV autotransformers), the insulation level is the same as the lower voltage side to which the regulation unit is connected. The insulation level has to be checked against the applicable technical guide.

The **internal insulation level** affects the regulation unit tap selector size, whose price can vary significantly, meaning that the proper selection is of the essence in choosing the optimal regulation unit. Highest operating voltage across the regulating winding is the value that has to be compared with the highest permissible phase service voltage across the regulating winding described in the technical guide, which defines several internal insulation distances to be checked, most important of which are distances 'a' and 'b'. For insulating distance 'a' between start and end of the regulating winding and insulating distance 'b' between the fine tap selector contacts of different phases, a statistics-based estimation is used. The logic behind the estimation is assuming linear distribution, and additionally applying a „non-linearity“ factor depending on the regulation concept (reg.in main / coarse-fine / reversing / linear) and transformer type (full / auto). The mentioned factor is determined using statistical analysis derived from experimental data. The differences in factors arise from the specifics of the distribution of electrical field in various power transformer types:

- If regulation concept is <u>regulation in main</u>, then the voltages are estimated as:

$$ACa = AC \times \frac{RR_{+,\%} + RR_{-,\%}}{100} \quad (4)$$

$$LIa = 2 \times LI \times \frac{RR_{+,\%} + RR_{-,\%}}{100} \quad (5)$$

- If regulation concept is <u>linear regulation</u>, then the voltages are estimated depending on the transformer type:

$$ACa = AC \times \frac{RR_{+,\%} + RR_{-,\%}}{100} \quad (6)$$

$$LIa = \begin{cases} 2.35 \times LI \times \frac{RR_{+,\%} + RR_{-,\%}}{100} & ; \text{full transformer} \\ 3.5 \times LI \times \frac{RR_{+,\%} + RR_{-,\%}}{100} & ; \text{autotransformer} \end{cases} \quad (7)$$

- If regulation concept is coarse-fine or reversing, then the same logic applies as in the case of linear regulation, with the additional factor of 0.5 due to the existing selector switch (indicated by capital letter 'G' in tap changer type designation, e.g. in Fig. 6) which doubles the regulation range for the same number of steps in regulation winding:

$$ACa = 0.5 \times AC \times \frac{RR_{+,\%} + RR_{-,\%}}{100} \quad (8)$$

$$LIa = \begin{cases} 2.35 \times 0.5 \times LI \frac{RR_{+,\%}+RR_{-,\%}}{100} & ; \text{full transformer} \\ 3.5 \times 0.5 \times LI \frac{RR_{+,\%}+RR_{-,\%}}{100} & ; \text{autotransformer} \end{cases} \quad (9)$$

where:

$RR_{+,\%}$ and $RR_{-,\%}$ are the regulation ranges in + and – side in [%];

LI and AC are the standardized **L**ightning **I**mpulse and **AC** power frequency voltage values in [kV] for the regulated voltage level.

For example, in case of regulation range 400kV +/- 8 x 1.25%, the standardized voltage levels are LI = 1550 kV, AC = 630 kV, and $RR_{+,\%} = RR_{-,\%} = 10\%$. Other voltage types (**S**witching **I**mpulse SI and service voltage Upog) and voltage distances (c_1 and c_2) can be calculated in a similar manner using values from [4]. Example values can be found in Table 1. With some winding arrangements (neutral-end in autotransformers and line-end regulation in delta connected windings), very high voltages may occur. These voltages are significantly influenced by the choice of the regulation concept (linear, coarse fine or reversing regulation). In such cases, additional tools are used to determine the electrical field distribution in the power transformer (FEM analysis). Since the tap selector size price varies significantly, this can also be subject to optimization.

The **switching capacity** P_{StN} [kVA] determines the capability of the regulation unit to switch between regulation steps. Since the worst case has to be considered, the required switching capacity in the regulation unit is the product of the relevant step voltage and maximum rated through current (both described above):

$$P_{StN} = \frac{I_{max} \times U_{step}}{1000} \quad (10)$$

The selected regulation unit must be within the switching capacity diagram (example in Fig. 2). Limit values are given in the manufacturer's technical guide and may rectrict certain types of tap changers in some cases.

The **number of tap positions and the number of contacts** have to be considered as well - different types have different maximum regulation range, depending on the regulation concept. A higher number of positions may also increase the voltage stress of the regulating winding, so this has to be taken into consideration (as described in the internal voltage calculations above).

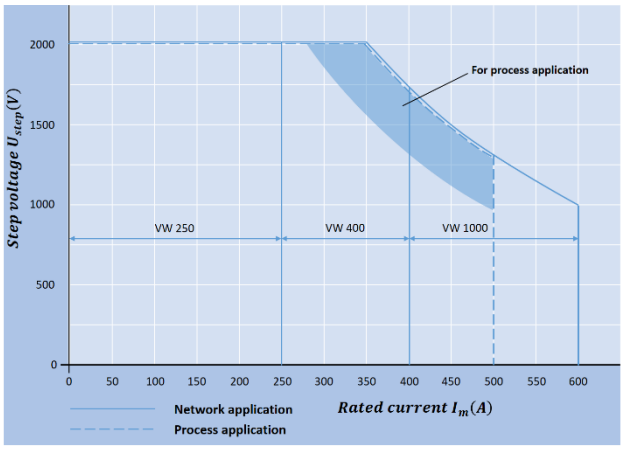

Figure 2: Switching capacity diagram example

The **predicted contact life** of fixed and moving contacts is a function of the rated through current and has to be compared with the diagram for a specific regulation unit which can generally be found in the regulation unit manufacturer's technical guide.

The recovery voltage occurs on the open change-over selector contacts during switching sequence. It depends on the geometric winding arrangement and the capacitances C1 and C2 (see Fig. 3). Recovery voltage can cause switching sparks or low-energy arcs, thereby producing unwanted gas which has a negative effect on the characteristics of the insulation media (usually insulating oil). The recovery voltage and breaking current values have to be checked in + and – selector switch positions [3]:

$$\left|\overrightarrow{U_{W+}}\right| = \sqrt{\left(\frac{U_1}{2} + \frac{U_f}{2}\right)^2 + \left(\frac{U_1}{2\sqrt{3}} \times \frac{C_2}{C_1 + C_2}\right)^2} \quad (11)$$

$$\left|\overrightarrow{U_{W-}}\right| = \sqrt{\left(\frac{U_1}{2} - \frac{U_f}{2}\right)^2 + \left(\frac{U_1}{2\sqrt{3}} \times \frac{C_2}{C_1 + C_2}\right)^2} \quad (12)$$

The breaking current I_{s+} and I_{s-} :

$$\overrightarrow{I_{s+}} = \frac{\overrightarrow{U_1}}{2\sqrt{3}} \times \omega C_2 + j \frac{\overrightarrow{U_1} + \overrightarrow{U_f}}{2} \times \omega(C_1 + C_2) \quad (13)$$

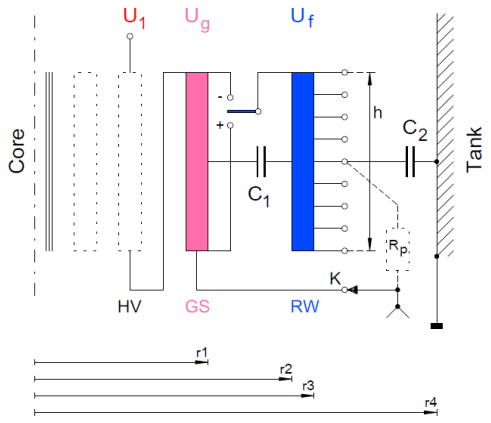

Figure 3: Recovery voltage – capacitances per phase

$$\overrightarrow{I_{S-}} = \frac{\overrightarrow{U_1}}{2\sqrt{3}} \times \omega C_2 + j\frac{\overrightarrow{U_1} - \overrightarrow{U_f}}{2} \times \omega(C_1 + C_2) \quad (14)$$

where:

U_{W+} and U_{W-} are the recovery voltages in [kV];

I_{S+} and I_{S-} are breaking currents in [mA];

C_1 and C_2 are the capacitance values in [pF] of the regulating winding (see Fig. 3) which can be approximated assuming cylindrical winding system [2].

U_1 is the rated regulated voltage in [kV];

U_f is the preselector voltage in [kV] (see Fig. 3);

$\omega = 2\pi f$, where f is the power frequency in [Hz].

The recovery voltage permisible value is the function of the calculated breaking current value. The mentioned $U_W(I_S)$ function for each tap selector type and size can be found in the technical data of the regulation unit. If the calculated values of recovery voltages are exceeded, it is necessary to install tie-in resistors or select a different tap selector. The installation of the tie-in resistors affects the regulation unit price as well as overall transformer dimensions, so a solution with bigger tap selector size and therefore higher permisible values of recovery voltage should be considered in such cases. Furthermore, the tie-in resistor dimensions are defined by the regulation unit manufacturer specifically for each design, which can cause an additional unwanted time delay in the transformer final design process. For phase shifting transformers, using regulation unit with two-way change-over selector, one can overcome problems during the change-over selector operation and change of winding connections between phases of the system voltage [6].

During power transformer design process, one has to calculate all of the above mentioned values in order to choose the appropriate regulation unit. Also, the selected regulation unit has to satisfy the OLTC type / selector type matrix shown in Appendix 1. Since the goal is also to find the optimal solution (technically as well as economically), this trial and error process can take up to several hours, even for an experienced electrical designer.

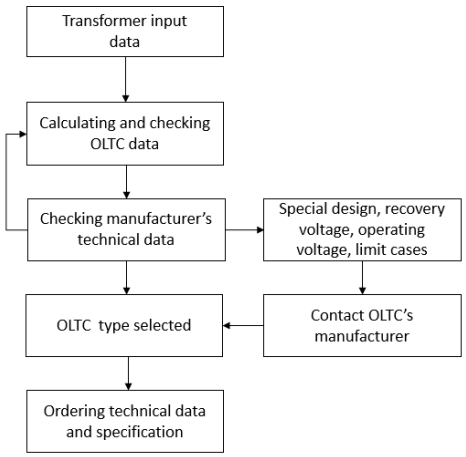

Figure 4: Workflow for manual regulation unit selection

IV. TAP CHANGER SELECTION APPLICATION AND DATABASE

Due to the complexity of the regulation unit technical limits and cross-dependencies between different types, a relational database is developed in such an architecture that an algorithm can quickly go though all of the possible permutations and compare the actual calculated values with every combination of regulation unit's limits. A small part of the relational database tables and relationships architecture can be found in Appendix 2. Also, the database management user interface (UI) is developed in *MS Access* environment. Within the database, SQL is used for querying data and sending it to the application for further analysis in the TCS algorithm (**T**ap **C**hanger **S**election). The algorithm then compares the queried data with the calculation results which are calculated in the background as thoroughly described in chapter III. The algorithm also takes into account different possibilities of transformer regulation: for example, a three phase transformer can either be regulated with a single three-phase regulation unit or three single-phase regulation units. Furthermore, autotransformer can be designed with regulation in main winding, meaning that the regulation unit does not have a common neutral end. Therefore, autotransformers with such regulation can only be regulated with three single-phase regulation units (three-phase regulation unit requires a neutral end common point). Also, different regulation concepts have different possibilities for number of positions and number of contacts.

All of the mentioned above is automatically checked for every single regulation unit combination queried from the database. This is achieved using a *foreach* loop which (in each step) calls for different modules used for this purpose. All of the modules and functions are developed in C#, following object-oriented software development principles (Model-View-Controller, MVC pattern). The input for the algorithm that is expected from the application user is the same data that the electrical designer uses in power transformer design (MVA rating, rated voltages and required regulation range, regulation concept, connection of regulating winding, LI and AC voltage levels i.e. external insulation levels to ground and number of tap positions), making the application very user-friendly for any power transformer designer. This data model also makes automatic data import from transformer design software very simple. The algorithm output is the list of all the possible solutions for regulation units (tap changers) that satisfy the given input.

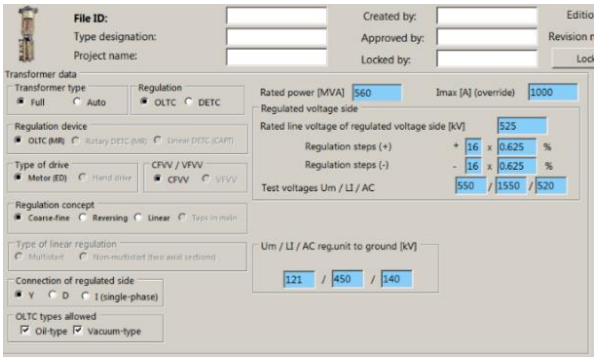

Figure 5: TCS example input data

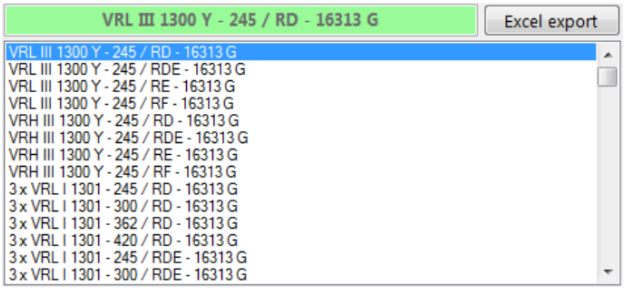

Figure 6: TCS results

The results are finally sorted according to the expected total cost. Therefore, the application user can simply choose the first regulation unit from the generated list knowing that this is the optimal solution. Other regulation units from the list are not optimal but are also technically acceptable. These can be selected in case of a specific request (e.g. higher external insulation level requested by the customer). Finally, a report containing all the calculations together with the technical limits (example values in Table 1) can be generated automatically.

Workflow for the tap changer selection process (from data input to generating report) for the transformer offer stage and for the final order stage is given in Fig. 7.

Table 1: Calculated and limit values for selected regulation unit

VRL III 1300 Y - 245 / RD - 16313 G

Calculated / Input data					Regulation unit limit values				
Imax =	1249	[A]			Imax =	1300	[A]		
Ustep =	2425	[V]			Ustep =	4500	[V]		
Psc =	3029	[kVA]			Psc =	5850	[kVA]		
Um / LI / AC	245	950	395	[kV]	Um / LI / AC	245	1050	460	[kV]
[kV]	LI	AC	SI	Upog	[kV]	LI	AC	SI	Upog
a_0					a_0	150	20	100	10
a_1					a_1	150	30	100	15
a	469	88	210	40	a	500	145	325	73
b	469	88	250	48	b	500	160	325	80
c_1	372	102	218	62	c_1	590	210	385	105
c_2	479	176	374	108	c_2	590	230	385	115

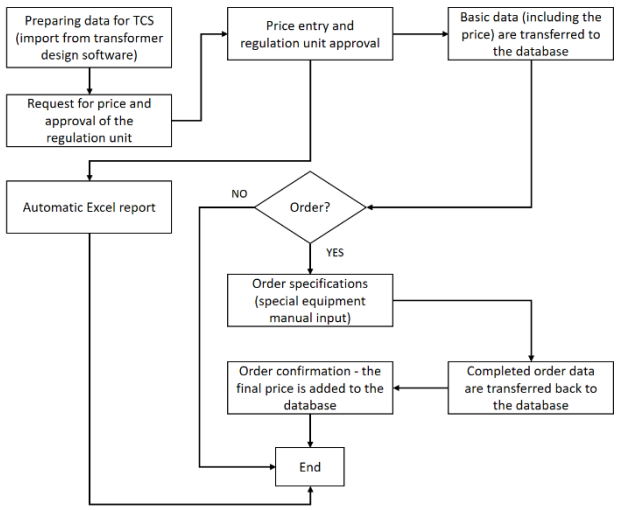

Figure 7: Workflow for automated regulation unit selection

V. WEB INTERFACE

Together with the Tap Changer Selection application, an additional tool is developed for accessing the final order data through a Web interface. The *RSB Base* application allows reading all the necessary technical data from the ordering data sheets, saves this data to the database and gives the possibility to search, analyze and report in a user-friendly manner. When transferring the data from a fulfilled PDF form (order sheet) to the database, the original document for ordering the regulation unit is uploaded to the server as well. Web aplication is developed using Model - View-Controller design pattern, Framework 4.5 technology, Bootstrap and Entity-Framework as a data access technology for SQL Server database for this project.

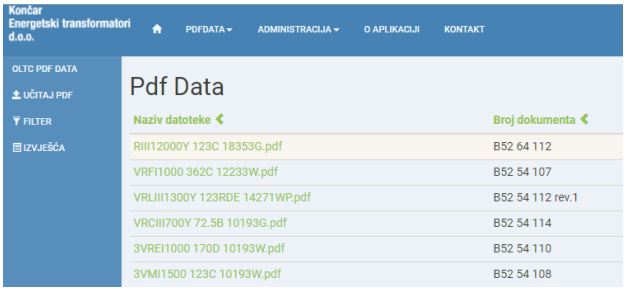

Figure 8: Web interface – homescreen

VI. CONCLUSION

The importance of regulation in power transformers shows that optimizing and choosing the appropriate regulation unit may have a significant impact on the transformer overall cost, making it one of the essential parts of power transformer design. In TCS application, dozens of tables and diagrams, as well as hundreds of pages of technical data from different manufacturers are incorporated in the database. Nevertheless, the developed algorithm performs all the calculations and searches through all of the possibilities in a matter of seconds. Also, the application allows printing out a report with all the relevant calculation data and technical limits almost instantly, regardless of the regulation unit manufacturer. This represents significant time savings and reduced possibility of errors during power transformer design process.

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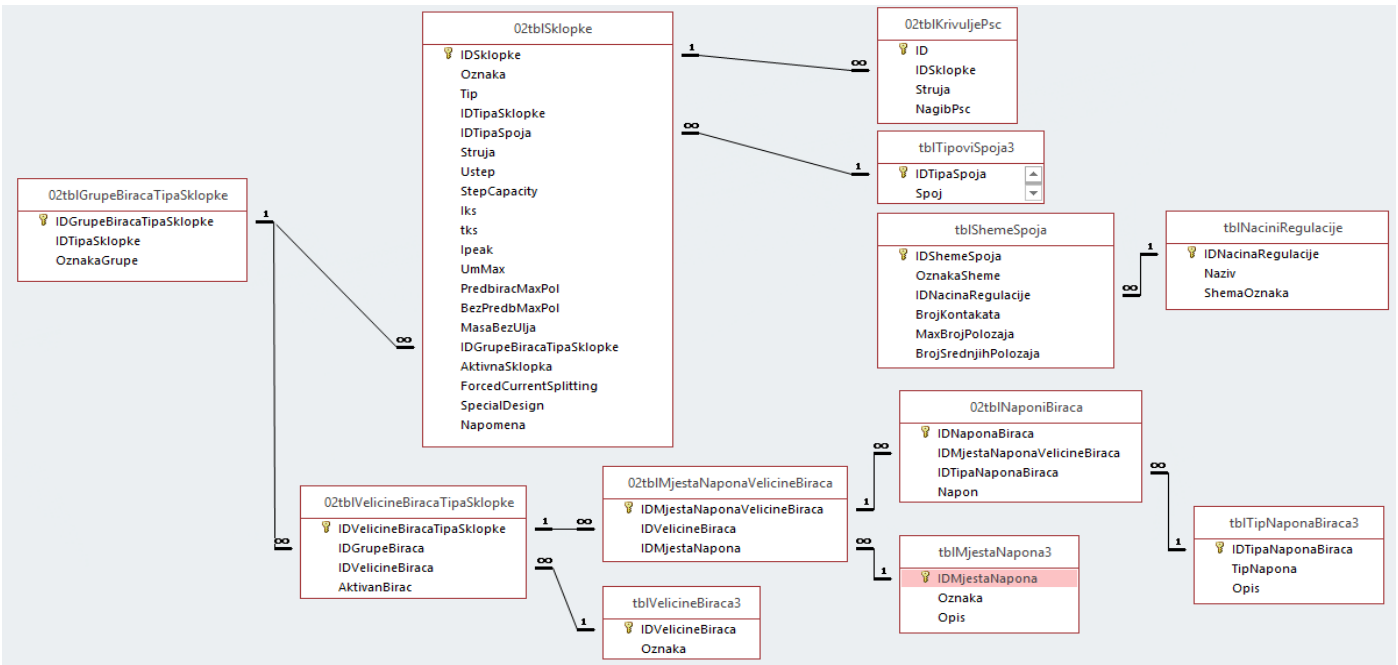
APPENDIX 1: Available combinations of regulation units with the corresponding tap selector sizes for all *MR* OLTCs

Selector type / OLTC type	valid for	„MS“ type selector	„M“ type selector	„R“ type (old) selector	„R“ type (new) selector
MS	(all MS OLTCs)	B	-	-	-
M	(all M OLTCs)	-	B, C, D, DE	-	RC, RD, RDE
RM	(all RM OLTCs)	-	C, D, DE	-	
R	(all R OLTCs)	-	-	C, D, E	RC, RD, RDE, RE, RF
VRC, VRE	(all VRC, VRE OLTCs)	-	B, C, D, DE	-	-
VRD, VRF	Imax < 1600 A	-	-	C, D	-
VRG	Imax < 1600 A	-	-	E	-
VRF	Imax = 1600 A	-	-	C, D	RC, RD, RDE
VRG	Imax = 1600 A	-	-	E	-
VRF, VRG	Imax =1800 A	-	-	-	RC, RD, RDE
VM	Imax = 300 A	B	-	-	-
VM	300 A < Imax < 650 A	-	B, C, D, DE	-	-
VM	Imax ≥ 650 A	-	B, C, D, DE	-	RC, RD, RDE
VRS, VRM	Imax ≤ 700 A	-	B, C, D, DE	-	RC, RD, RDE, RE, RF
VRS, VRM, VRL	Imax > 700 A	-	-	-	RC, RD, RDE, RE, RF
VRH	all VRH	-	-	-	RC, RD, RDE, RE, RF
VRX	VRX I 652	-	-	-	RES

APPENDIX 2: Relational database architecture



Primjena determinističkog pristupa u rješavanju problema automatskog kreiranja rasporeda nastave

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***Sažetak* - Kreiranje rasporeda nastave predstavlja proces raspoređivanja nastavnih jedinica u zadatom vremenskom intervalu, uzimajući u obzir raspoloživost nastavnog osoblja, studentskih grupa i prostorija u kojim se nastava izvodi. Ovaj proces podrazumijeva i druga ograničenja o kojim je potrebno voditi računa. Problem automatskog kreiranja rasporeda nastave obično se svrstava u NP (*eng. Non-deterministic Polynomial*) probleme. Iz tog razloga većina modernih tehnika koje rješavaju ovaj problem koriste nedeterminističke, odnosno stohastički pristup pri njegovom rješavanju. U ovom radu predstavljen je novi, deterministički, algoritam za rješavanje problema automatskog kreiranja rasporeda nastave. Pored toga, u radu je predstavljen i alat koji implementira predloženi algoritam, a izvršena je i njegova uporedna analiza sa Unitime alatom koji implementira algoritam zasnovan na stohastičkom pristupu.**

Ključne riječi – algoritam; raspored nastave; NP problem; deterministički pristup; stohastički pristup; preference

I. UVOD

Ručno kreiranje rasporeda nastave, pogotovo na univerzitetima, zahtjeva dosta vremena i osoblja, gdje se treba uzeti u obzir velik broj ograničenja. Danas postoji velik broj softverskih rješenja koja djelimično [13] ili u potpunosti mogu automatizovati ovaj proces [7], [14]. Kvalitet ovih rješenja ogleda se, prvenstveno, u sljedećim karakteristikama:

- Raznovrsnosti ograničenja koja se mogu definisati pri kreiranju rasporeda
- Nivo zadovoljavanja postavljenih ograničenja u dobijenom rasporedu

A. Opis problema

Razlika između obrazovnih sistema u svakoj državi, pa čak i između pojedinih ustanova u istoj državi, utiče na različitu formulaciju problema kreiranja rasporeda. U skladu s tim, postoje i različiti modeli koji problem kreiranja rasporeda rješavaju na različite načine [15]. Uprkos činjenici postojanja velikog broja modela i formulacija, veoma mali broj njih uzimaju u obzir realna ograničenja koja se pojavljuju u obrazovnoj ustanovi. U drugoj sekciji rada dat je pregled ograničenja koja predstavljaju realni okvir za odabir adekvatne tehnike za rješavanje problema automatskog kreiranja nastave.

Većina modernih tehnika za rješavanje problema automatskog kreiranja rasporeda nastave, kao što su tabu pretraga [8], simulirano kaljenje [9], evolucijski algoritmi [10], koriste stohastički pristup tokom cijelog procesa kreiranja rasporeda. Manji broj tehnika koristi deterministički pristup samo pri kreiranju inicijalnog rasporeda koji zadovoljava fiksna ograničenja [11, 12], a u ostatku procesa se opet koristi stohastički pristup radi optimizacije inicijalnog rasporeda.

U ovom radu predstavljen je novi algoritam koji koristi deterministički pristup tokom cijelog procesa kreiranja rasporeda nastave, pri čemu je uzeto u obzir zadovoljavanje svih fiksnih, te maksimalno zadovoljavanje zadatih varijabilnih ograničenja. Isti je prilagođen realnim potrebama za kreiranje rasporeda nastave na Tehničkom fakultetu, Univerziteta u Bihaću. Zatim će se prikazati rezultati testiranja i uporedne analize sa Unitime alatom. Ovim alatom je moguće formulisati i riješiti većinu problema automatskog kreiranja rasporeda različitih obrazovnih sistema, poput:

- MIT, USA [17]
- Purdue Univesity, USA [5]
- Masaryk University, Czech Republic [18]

što ga svrstava u grupu „*state-of-the-art*“ alata.

U sekciji 2 opisana su fiksna i varijabilna ograničenja pri kreiranju rasporeda. Predloženi algoritam detaljno je opisan u sekciji 3, dok su rezultati njegovog izvršavanja dati u sekciji 4. U istoj sekciji izvršena je i komparativna analiza predloženog rješenja sa Unitime alatom. Na kraju rada dat je zaključak.

II. OGRANIČENJA

Prema [1], ograničenja (eng. *contstraints*) pri kreiranju rasporeda se mogu podjeliti u dvije grupe:

- *Fiksna ograničenja,* koja se moraju zadovoljiti u svim okolnostima. Npr. jedan nastavnik ne može se rasporediti istovremeno u dvije učione. Za raspored koji ne narušava ovu vrstu ograničenja kažemo da je izvodljiv raspored.
- *Varijabilna ograničenja,* koja se trebaju zadovoljiti u što većem procentu. Npr. nastavnu jedinicu treba rasporediti u terminu koji je definisan kao veoma poželjan za nastavnika.

A. Fiksna ograničenja

Pored podrazumijevanih fiksnih ograničenja [6], kao npr. da se jedan nastavnik ne može rasporediti istovremeno u dvije ili više učiona, predloženi algoritam podržava kreiranje rasporeda i sa dodatnim skupom fiksnih ograničenja, i to:

- *Raspoloživost nastavnika, učione i studijske grupe* – ovom vrstom ograničenja moguće je definisati u kojem vremenskom periodu su dostupni ili nedostupni pomenuti elementi raspoređivanja
- *Zajedničko izvođenje nastave* – ovom vrstom ograničenja mogu se grupisati nastavne jedinice koje izvodi isti nastavnik različitim studijskim grupama, te ih rasporediti u isti termin i učionu
- *Kontinuirano izvođenje nastave* – ovom vrstom ograničenja može se definisati skup i redoslijed nastavnih jedinica koje se moraju rasporediti u uzastopne termine. Kao dodatni parametar moguće je definisati i to da li će se nastava kontinuirano izvoditi u istoj učioni.
- *Dijeljena nastava* – najčešće zbog prostornih resursa, odnosno njihovog kapaciteta, neophodno je studijsku grupu podijeliti u manje podgrupe. Kao dodatni parametar ovom ograničenju, moguće je definisati i to da li pojedine podgrupe sadrže iste studente, te omogućiti da se podgrupe koje ne sadrže zajedničke studente rasporede u isti termin i različite učione, uz pretpostavku da tu nastavu izvode različiti nastavnici
- *Predefinisani termini* – ovom vrstom ograničenja unaprijed se dodjeljuje termin nastavnoj jedinici, a koji se dalje ne smije mijenjati u procesu kreiranja rasporeda
- *Ekskluzivitet učiona* – ova vrsta ograničenja omogućava da se određene učione, najčešće laboratorije, izuzmu pri dodjeljivanju onim nastavnim jedinicama koje nemaju definisan inkluzivitet učiona
- *Inkluzivitet učiona* – ova vrsta ograničenja omogućava da se u nastavnoj jedinici definiše skup učiona u kojima je dozvoljeno izvođenje nastave
- *Virtualna učiona* – ova vrsta ograničenja, omogućava da se nastava iz više nastavnih jedinica istovremeno izvodi u istoj virtualnoj učioni, npr. u slučaju kada se nastava izvodi putem *online* platforme.

B. Varijabilna ograničenja

Varijabilna ograničenja zasnivaju se na definisanju preferenci za pojedine termine i učione. Kako parametar raspoloživosti određenog resursa (npr. nastavnika, učione, itd.) ne zadovoljava realne potrebe za preciznijim definisanjem potreba fakulteta, neophodno je uvesti širu skalu između poželjnih i manje poželjnih termina i učiona, odnosno skalu preferenci. Skala preferenci sastoji se od sedam različitih preferenci prikazanih u tablici I. Preference „Neophodan“ i „Zabranjen“ predstavljaju fiksna ograničenja. Ako se nastavnoj jedinici definiše termin od 8h – 10h sa preferencom „Neophodan“, ostali termini neće biti uzeti u obzir pri raspoređivanju. Ujedno je, sa predstavljenim preferencama, moguće određenom nastavniku definisati termin od 8h – 10h kao veoma poželjan.

Tablica I. SKALA PREFERENCI

	Neophodan
2	**Veoma poželjan**
1	**Poželjan**
0	**Neutralan**
-1	**Nepoželjan**
-2	**Veoma nepoželjan**
	Zabranjen

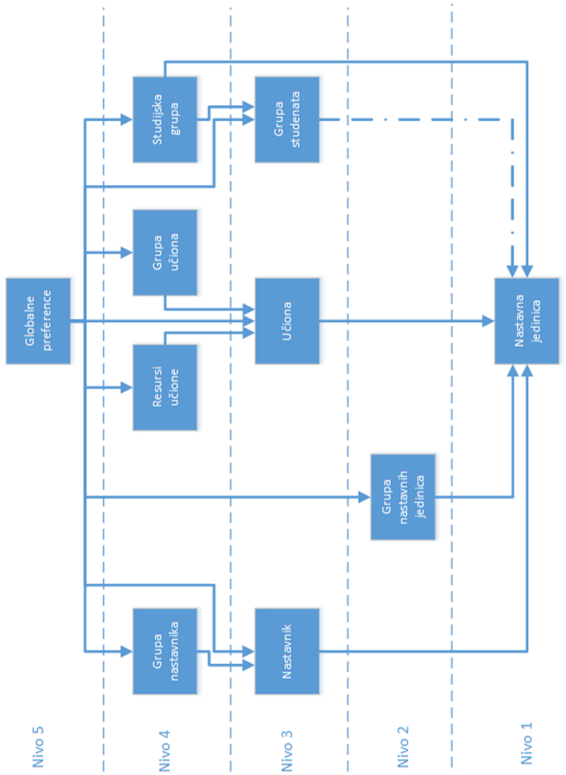
Svakoj od preferenci dodijeljena je numerička vrijednost na osnovu koje algoritam može izvršiti evaluaciju kreiranog rasporeda, te boja koja će se dalje koristiti pri vizuelnom prikazivanju preferenci.

Kako bi se omogućilo fleksibilnije definisanje varijabilnih ograničenja koja opisuju realna očekivanja kreiranog rasporeda, preference termina, odnosno vremenske preference je moguće definisati nad raznim elementima raspoređivanja prikazanim na dijagramu sa slike 1. Pored preferenci termina, u algoritmu je moguće definisati i preference učiona. Na slici 2 prikazan je dijagram distribucije preferenci učiona, za koje vrijede ista pravila kao i za distribuciju vremenskih preferenci.

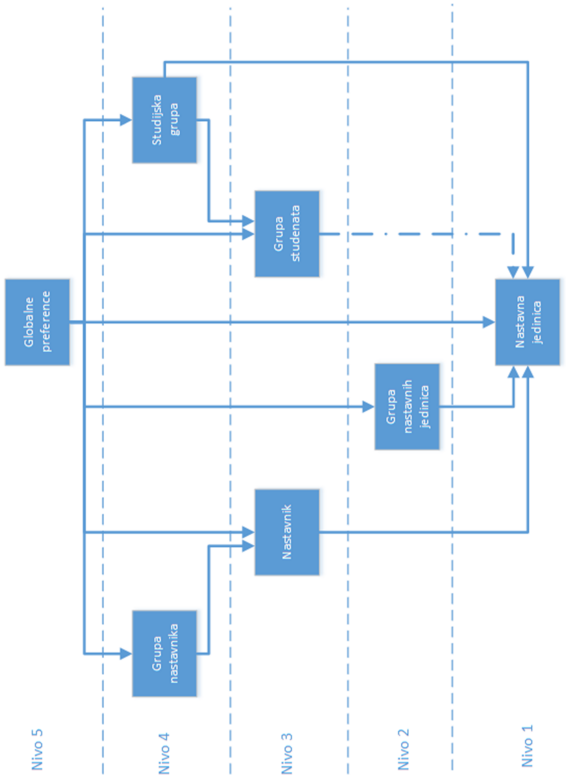
Kao što je vidljivo na slikama 1 i 2, određene elemente kao npr. nastavnike, moguće je grupisati, te nad grupom definisati preference.

Ukoliko nad elementom nisu definisane vremenske preference, on ih nasljeđuje od povezanog elementa sa višeg nivoa, ukoliko takav element postoji, u suprotnom se nad elementom definiše „neutralna“ vremenska preferenca. Dalje, definisanje vremenskih preferenci nad elementom posmatra se kao redefinisanje (eng. *override*) vremenskih preferenci povezanog elementa iz višeg nivoa. U ovoj situaciji važno je napomenuti da je, pri redefinisanju preferenci elemenata iz višeg nivoa, nemoguće redefinisati preference tipa „Neophodan“ i „Zabranjen“. Npr. ukoliko se globalnim preferencama

definiše pauza od 12h – 13h sa preferencom tipa „Zabranjen“, niti jedan element iz nižeg nivoa ne može redefinisati ovu preferencu, tj. u konačnici niti jedna nastavna jedinica ne može se rasporediti u terminu pauze.



Slika 1. Dijagram distribucije vremenskih preferenci



Slika 2. Dijagram distribucije preferenci učiona

U tablici II prikazani su rezultati operacija *override* i *crossover* preferenci.

Tablica II. REZULTATI *OVERRIDE I CROSSOVER* OPERACIJE

A	**B**	**A *override* B**	**A *crossover* B**
Neop.	Neop.	Neop.	Neop.
V. pož.	Neop.	Neop.	Neop.
Pož.	Neop.	Neop.	Neop.
Neut.	Neop.	Neop.	Neop.
Nepož.	Neop.	Neop.	Neop.
V. nepož.	Neop.	Neop.	Neop.
Zabr.	Neop.	Zabr.	Zabr.
Neop.	V. pož.	Neop.	Neop.
V. pož.	V. pož.	V. pož.	V. pož.
Pož.	V. pož.	Pož.	Pož.
Neut.	V. pož.	V. pož.	V. pož.
Nepož.	V. pož.	Nepož.	Neut.
V. nepož.	V. pož.	V. nepož	Neut.
Zabr.	V. pož.	Zabr.	Zabr.
Neop.	Pož.	Neop.	Neop.
V. pož.	Pož.	V. pož.	Pož.
	Pož.	Pož.	Pož.
Neut.	Pož.	Pož.	Pož.
Nepož.	Pož.	Nepož.	Neut.
V. nepož.	Pož.	V. nepož.	Neut.
Zabr.	Pož.	Zabr.	Zabr.
Neop.	Neut.	Neop.	Neop.
V. pož.	Neut.	V. pož.	V. pož.
Pož.	Neut.	Pož.	Pož.
Neut.	Neut.	Neut.	Neut.
Nepož.	Neut.	Nepož.	Nepož.
V. nepož.	Neut.	V. nepož.	V. nepož.
Zabr.	Neut.	Zabr.	Zabr.
Neop.	Nepož.	Neop.	Neop.
V. pož.	Nepož.	V. pož.	Neut.
Pož.	Nepož.	Pož.	Neut.
Neut.	Nepož.	Nepož.	Nepož.
Nepož.	Nepož.	Nepož.	Nepož.
V. nepož.	Nepož.	V. nepož.	Nepož.
Zabr.	Nepož.	Zabr.	Zabr.
Neop.	V. nepož.	Neop.	Neop.
V. pož.	V. nepož.	V. pož.	Neut.
Pož.	V. nepož.	Pož.	Neut.
Neut.	V. nepož.	V. nepož.	V. nepož.
Nepož.	V. nepož.	Nepož.	Nepož.
V. nepož.	V. nepož.	V. nepož.	V. nepož.
Zabr.	V. nepož.	Zabr.	Zabr.
Neop.	Zabr.	Zabr.	Zabr.
V. pož.	Zabr.	Zabr.	Zabr.
Pož.	Zabr.	Zabr.	Zabr.
Neut.	Zabr.	Zabr.	Zabr.
Nepož.	Zabr.	Zabr.	Zabr.
V. nepož.	Zabr.	Zabr.	Zabr.
Zabr.	Zabr.	Zabr.	Zabr.

U slučaju da je element povezan sa više elemenata iz višeg nivoa, npr. jedan nastavnik pripada dvijema ili više grupa, te ako nad njim nisu predefinisane preference višeg nivoa, tada se prije nasljeđivanja preferenci vrši *crossover* operacija nad preferencama elemenata višeg nivoa. Zatim element nižeg nivoa nasljeđuje rezultat pomenute operacije.

III. ALGORITAM

Jedna od bitnih karakteristika algoritma za automatsko kreiranje rasporeda nastave jeste vrijeme potrebno za njegovo izvršavanje. U začetku rješavanja problema automatskog kreiranja rasporeda, procesni i memorijski kapaciteti računara su bili relativno mali, te su se zbog toga istraživanja u ovoj oblasti okrenula prema tehnikama koje su zahtjevala minimalne resurse za njihovo izvršavanje. U većini slučajeva, to su bile tehnike koje koriste stohastički pristup. Međutim, zbog brzine njihovog izvršavanja gubi se na kvaliteti, potpunosti, preciznosti i/ili tačnosti dobijenog rješenja. Nagli porast pomenutih kapaciteta u zadnjih 10 – 15 godina otvorila su vrata novim tehnikama i algoritmima za rješavanje ovog problema, koje se temelje na determinističkom i sistematičnom pristupu.

Pretpostavit ćemo, zbog jednostavnosti, da problem kreiranja rasporeda nastave predstavlja proces dodjele vrijednosti iz ograničenog domena, odnosno termina i učiona, skupu varijabli, odnosno nastavnim jedinicama [2].

Vodeći se ovom pretpostavkom svaki algoritam se može svesti na 3 osnovna koraka, a to je:

- Selekcija varijable (nastavna jedinica)
- Selekcija vrijednosti (par termin-učiona)
- Propagacija dodjele odabrane vrijednosti odabranoj varijabli

Predstavljeni algoritam u ovom radu kombinira *backtracking* tehniku sa tehnikom redukcije domene vrijednosti (eng. *domain reduction*). U algoritmu 1 prikazan je pseudo kod korištenog algoritma, čije ćemo elemente detaljnije obrazložiti u nastavku.

Izvršavanje algoritma započinje generisanjem vrijednosti domene (linija 2) za svaku neraspoređenju nastavnu jedinicu. Vrijednost domene predstavlja par termin – učiona, a pri generisanju vodi se računa da ista ne narušava fiksna ograničenja. Prema definisanim preferencama, kao varijabilnim ograničenjima u ulaznim podacima, svakom paru se računa i pridružuju vremenska preferenca i preferenca učione. Nakon toga, vrši se redukcija domene, u kojoj ostaju samo vrijednosti sa najvećim preferencama, odnosno najpoželjnijim terminima i učionama.

Algoritam 1: Pseudo kod predstavljenog determinističkog algoritma

```
1:  for every X in unassignedVarList l
2:      generateDomain(X)
3:  end for
4:  while(not empty unassignedVarList l)
5:      V = selectUnassignedVariable(l)
6:      D = selectValueFromDomain(V)
7:      if(D ≠ null)
8:          if(propagateAssignment(V,D) ≠ DEAD_END)
9:              assignValue(V,D)
10:             l.remove(V)
11:         else
12:             if(isDomainEmpty(V))
13:                 backtrackFrom(V)
14:             end if
15:         end if
16:     else
17:         if(isExtendableDomain(V))
18:             extendDomain(V)
19:         else
20:             markVariableAsUnassignable(V)
21:             l.remove(V)
22:         end if
23:     end if
24: end while
```

Odabir neraspoređene nastavne jedinice (linija 5) vrši se najčešće na temelju veličine njene domene, tj. odabire se ona nastavna jedinica sa najmanjom domenom. Ovim načinom odabira varijable, smanjuje se mogućnost pojave *dead-end* situacije. Svakako, algoritam može u toku izvršavanja prioretizirati varijable na drugi način, npr. ukoliko je prethodno raspoređena nastavna jedinica koja treba da se izvodi u kontinuitetu sa drugom nastavnom jedinicom, u tom slučaju druga nastavna jedinica u nastavku dobija prednost pri odabiru.

Odabir vrijednosti iz domena odabrane varijable (linija 6) vrši se na osnovu njenog utjecaja na redukciju domene ostalih neraspoređenih nastavnih jedinica (eng. *look-ahead*), tj. odabire se ona vrijednost koja će imati najmanji utjecaj. Nakon odabira vrijednosti, ista se uklanja iz domene i sprema u listu testiranih vrijednosti. Uspješnim odabirom vrijednosti (linija 7), vrši se propagacija dodjele iste odabranoj varijabli. Glavni cilj propagacija jeste redukcija, odnosno uklanjanje vrijednosti iz domena drugih **neraspoređenih** varijabli koje direktno narušavaju fiksna ograničenja, čime se postiže *ARC*-konzistentnost[1] istih. Na temelju

[1] Varijabla x_i je ARC-konzistentna sa drugom varijablom x_j, ukoliko za svaku vrijednost a iz domena varijable x_i postoji vrijednost b iz domena varijable x_j, tako da (a, b) zadovoljava ograničenja između varijabli x_i i x_j [3].

navedenog, može se zaključiti da u svakom trenutku parcijalno rješenje zadovoljava sva fiksna ograničenja. Također važno je napomenuti, da nakon izvršene redukcije domena *affected* varijabli, iste se provjeravaju da li su prazne, te ukoliko jesu, rezultat propagacije je *dead-end* situacija, pri kojoj se odabire sljedeća vrijednost iz domena i ponavlja postupak. U slučaju da nakon redukcije, u domeni ostane samo jedna vrijednost, ponavlja se postupak propagacije dodjele preostale vrijednosti pripadajućoj varijabli [4].

Ako je domena prazna nakon *dead-end* situacije, tj. sve vrijednosti su testirane, tada se vrši *backtrack* (linija 13), odnosno poništavaju se prethodne dodjele vrijednosti **raspoređenim** varijablama u obrnutom slijedu njihove dodjele, i to svim varijablama u nizu zaključno sa zadnjom varijablom čija dodjela je utjecala na redukciju domena tekuće varijable. Zatim se, zbog poništenja dodjele, vraćaju vrijednosti u domene pripadajućih varijabli, koje su bile uklonjene tokom propagacije. Nakon izvršenog *backtrack*-a, postavlja se prioritet nad tekućom varijablom pri odabiru naredne neraspoređene varijable, te se sve testirane vrijednosti vraćaju u domenu.

Ukoliko sve vrijednosti domena vode do *dead-end* situacije, vrši se provjera i proširenje domene (linija 18) sa manje poželjnim vrijednostima. Ako proširenje nije moguće, tada se varijabla označava kao *nerasporediva* (linija 20) sa odgovarajućom porukom, te se ista uklanja iz liste neraspoređenih varijabli.

IV. REZULTATI

Kako bi rezultati uporedne analize bili što mjerodavniji, testiranje je izvršeno nad realnim parametrima za kreiranje rasporeda nastave za zimski i ljetni semestar 2016/2017. godine na Tehničkom fakultetu Univerziteta u Bihaću. U tablici III prikazani su detalji tih parametara. Nastavne jedinice trebalo je rasporediti u periodu od ponedeljka do subote od 08h – 20h prema globalnim vremenskim preferencama, koje su ujedno iskorištene kao glavni faktor pri evaluaciji kvaliteta dobijenog rasporeda. Rezultati testiranja su upoređeni sa rezultatima dobijenim sa Unitime alatom, u kojem je implementiran IFS (eng. *Iterative Forward Search*) algoritam prikazan pseudo kôdom u algoritmu 2 [5]. Iako je algoritam baziran na CP tehnici (eng. *Constraint Programming*), ovaj algoritam pripada grupi stohastičkih algoritama, jer se selekcija varijable i vrijednosti (linije 4 i 5), najčešće vrše proizvoljnim odabirom [16].

Algoritam 2: Pseudo kod stohastičkog algoritma

```
1:  function IFS(ω)
2:       σ = ω
3:       while canContinue(ω) do
4:            v = selectVariable(ω)
5:            d = selectValue(ω,v)
6:            γ = hardConflicts(ω,v/d)
7:            ω = ω\γ ∪ {v/d}
8:            if better(ω,σ) then σ = ω
9:       end while
10:      return σ
11: end function
```

Tablica III. PREGLED PARAMETARA ZA KREIRANJE RASPOREDA

	Zimski semestar		Ljetni semestar	
Broj nastavnih jedinica	**253**		**256**	
Broj zajedničkih jedinica	**Br. grupa**	**Br. jedinica**	**Br. grupa**	**Br. jedinica**
	10	**35**	**18**	**59**
Broj nastavnih jedinica za raspoređivanje	**228**		**215**	
Broj nastavnih sati	**527**		**534**	
Broj kontinuiranih nastavnih jedinica	**10**		**20**	
Broj nastavnika	**72**		**72**	
Prosječan broj dostupnih učiona po nastavnoj jedinici	**4.41**		**4.35**	
Prosječan broj nastavnih jedinica po nastavniku	**3.51**		**3.56**	

U tablici IV prikazani su rezultati uporedne analize ova dva pomenuta algoritma. Rezultati izvršavanja Unitime algoritma su predstavljeni kao prosječne vrijednosti 10 uzastopnih izvršavanja od 30 minuta. U rezultatima su prikazani sljedeći uporedni parametri:

- **Vrijeme potrebno za kreiranje inicijalnog rješenja (s)** predstavlja vrijeme u sekundama potrebno da se kreira kompletan i izvodljiv raspored nastave.
- **„Vrijeme potrebno za pronalazak najboljeg rješenja (s)“** predstavlja vrijeme u sekundama potrebno da se pronađe rješenje koje najbolje zadovoljava varijabilna ograničenja.
- **„Broj nastavnika sa negativnim preferencama“** predstavlja broj nastavnika koji ima negativnu sumu preferenci u najboljem rješenju. Ciljna vrijednost treba da bude što manja.
- **„Suma negativnih preferenci nastavnika“** predstavlja sumu negativnih preferenci nastavnika iz prethodne kolone.
- **„Broj studijskih grupa sa negativnim preferencama“** predstavlja broj studijskih grupa koje imaju negativnu sumu preferenci u najboljem rješenju.
- **„Suma negativnih preferenci studijskih grupa“** predstavlja sumu negativnih preferenci studijskih grupa iz prethodne kolone.
- **„Suma preferenci svih nastavnih jedinica“** predstavlja ukupnu sumu preferenci svih raspoređenih nastavnih jedinica. Ciljna vrijednost treba da bude što veća.

Sa stanovišta kompleksnosti predstavljenog algoritma, jedan od bitnijih faktora koji utječu na vrijeme izvršavanja je svakako broj nastavnih jedinica koje se raspoređuju. U najboljem slučaju, kada nema definisanih ovisnosti između nastavnih jedinica (različit nastavnik, učiona i studijska grupa), kompleksnost algoritma bi bila O(N), gdje je N broj nastavnih jedinica.

Međutim, upravo definisana ograničenja i ovisnosti među nastavnim jedinicama povećavaju kompleksnost algoritma na $O(N^C)$, gdje konstanta C predstavlja utjecaj pomenutih ograničenja na ukupnu kompleksnost algoritma [19].

Tablica IV. REZULTATI UPOREDNE ANALIZE DETERMINISTIČKOG I STOHASTIŠKOG ALGORITMA

	Vrijeme potrebno za kreiranje inicijalnog rješenja (s)	Vrijeme potrebno za pronalazak najboljeg rješenja (s)	Broj nastavnika sa negativnim preferencama	Suma negativnih preferenci nastavnika	Broj studijskih grupa sa negativnim preferencama	Suma negativnih preferenci studijskih grupa	Suma preferenci svih nastavnih jedinica
ZIMSKI SEMESTAR							
Deterministički algoritam	**352.0**	**352.0**	**14**	**-31**	**1**	**-3**	**270**
Stohastički algoritam (Unitime alat)	**10.6**	**1328.5**	**14.6**	**-50.0**	**0.7**	**-3.6**	**230.1**
LJETNI SEMESTAR							
Deterministički algoritam	**63.8**	**63.8**	**18**	**-36**	**0**	**0**	**334**
Stohastički algoritam (Unitime alat)	**9.1**	**1031.8**	**13.2**	**-44.9**	**0.8**	**-2.4**	**233.3**

V. ZAKLJUČAK

U radu je predstavljen novi deterministički algoritam za automatsko kreiranje sedmičnog rasporeda nastave, u kojem su uspješno primjenjene neke od jednostavnih heurističnih tehnika i princip ARC-konzistentnosti između varijabli, odnosno nastavnih jedinica.

Rezultati izvršavanja algoritma su upoređeni sa rezultatima dobijenim Unitime alatom i prikazani u 4. poglavlju. Odabir alata za uporednu analizu je sveden na Unitime alat, jer je samo u njemu trunutno bilo moguće definisati identična ograničenja kao u predstavljenom algoritmu. Iz rezultata uporedne analize može se zaključiti da u relativno kratkom vremenskom periodu deterministički algoritam kreira ne samo izvodljiv raspored nastave već i raspored nastave koji zadovoljava varijabilna ograničenja na zavidnom nivou. Međutim, važno je istaći da je glavni nedostatak predstavljenog algoritma njegova prilagodba realnim potrebama Tehničkog fakulteta Univerziteta u Bihaću, te zbog toga isti nije bilo moguće testirati sa već postojećim „benchmark“ podacima.

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S P

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PAPERS

Photovoltaic plants in Bosnia and Herzegovina - State and perspectives -

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Abstract – **This paper describes the current state of photovoltaic plants (PV) in Bosnia and Herzegovina (B&H). It describes the ongoing trends in this domain and the ongoing legislation. It gives a certain insight of the future development in this domain. The first PV plant in B&H was built in 2012. Since then 180 PV plants were built and connected to the power grid containing installed capacity of 18MW. This makes 0.37% of installed capacity in B&H. Because of these particular reasons B&H must, with the utmost seriousness, begin implementing projects of construction in the field of renewable energy and other forms of green energy. When considering renewable energy, solar energy it far most impressive and promising area of investments. This paper has analyzed the potential that B&H has in the construction of PV plants. Four areas of interest were analyzed: the roof tops of apartment buildings, certain protective parts around the highways, water surfaces made by accumulation lakes and agriculturally inefficient surfaces. The total estimation of the power provided from the PV plants is: 3.27GW for the roof tops, 0.034GW for the highways, 1.15GW for the water surfaces and 4.52GW for the agriculturally inefficient surfaces.**

Key words – photovoltaic plants; renewable energy; incentives; legislation

I. INTRODUCTION

Solar energy represents the energy foundation of life on Earth. The biggest part of conventional energy sources originate from the energy that Earth is receiving or has received from the Sun via electromagnetic radiation. The increase in the energy consumption, the decrease in the fossil fuel reserves and ecological factors imply the need to build new sources of energy based on the principals of renewability and ecological acceptability, so called green energy.

Technologically acceptable forms of using the solar energy, those that are considered green are: production of heat energy via collectors, production of electricity via solar thermal power plants and direct production of electricity via photovoltaic plants. Solar thermal power plants are facilities built from a large number of mirrors and lenses used to focus light towards a central tower, where the produced heat turns water into steam, the steam is then trusted trough a turbine which produces electricity. This type of a facility takes a lot of space to build, so it is usually built in deserts. The biggest solar thermal power plant in the world, Ivanpah, containing power of 392MW, is located in the Mohave Desert in California [1].

When converting solar power into electrical power directly a certain effect occurs, called photovoltaic effect. It forms electric voltage on the *pn* junction of the photovoltaic cell. In order to make the desired electrical voltage and electricity of a solar module, basic *pn* cells are combined in series or in parallel, or in the combination of the two. These modules are placed in certain protective housing and they are then used to build photovoltaic plants.

Photovoltaic (PV) plants are placed on roof tops of apartment buildings and other business facilities, on vacant surfaces on the ground, in parking lots, besides highways, on water surfaces, etc. Five biggest PV plants built in the world are: 1. Tengger Desert Solar Park, 1500MW, China; 2. Datong Solar Power Top Runner Base, 1000MW, China; 3. Kurnool Ultra Mega Solar Park, 900MW, India; 4. Longyangxia Dam Solar Park, 850MW, China; 5. Kamuthi Solar Power Project, 648MW, India [2]. Apart from these PV plants built on the ground, there are other PV plants built on large water surfaces [3]. In the southern province Anhui with the power of 40MW a floating PV plant was built, placed on a water accumulation [4].

During the 2016. 76.6GW of solar plants were built worldwide, which is 50% more than in 2015. during which 50GW were installed. By the end of 2016. the installed capacity of all solar power plants in the world totaled at 306.5GW. The estimation for 2017. is an additional 80.5GW [5].

The number of newly built solar power plants varies throughout the years depending on the national incentives. Some European countries lowered the incentive for installation of PV plants and that reduced the PV plant market. In the other part of the world, like China, Japan and India, the implementation of the new incentives led to the expansion and development of PV plants. The top ten leading countries in the production of electricity via solar plants in the end of 2016. were: China (77.9GW), Japan (42.9GW), USA (42.4GW), Germany (41.1GW), Italy (18.9GW), Great Britain (11.5GW), India (9.5GW), France (7.1GW), Australia (5.8GW), Spain (5.5GW) [5].

This paper describes the application of photovoltaic technologies in B&H. In chapter II an estimation of solar potentials was made and sorted out in four groups: roof tops of private buildings, certain protective parts around the highways, water surfaces made by accumulation lakes and agriculturally inefficient surfaces. Chapter III presents the current state of the installed capacity PV plants, describes the legislative and gives examples of good and bad installation of PV plants.

II. POTENTIAL LOCATIONS FOR PV PLANTS IN B&H

Four groups of locations were analyzed as eligible locations for construction of PV plants in B&H: roof top surfaces of apartment buildings, large water surfaces (accumulation lakes), protective zone besides the highways, agriculturally unusable ground.

In order to get a numerical equivalent of the electrical power that will be provided by these PV plants all the groups of surfaces were accounted for, as well the radiation per square meter, emitted from the Sun.

A. The estimation of power gained from the Suns radiation per square meter of surface

To determine the mean value of solar radiation in B&H ($\overline{W}_I$), the arithmetic mean was calculated using the data concerning annual radiation from ten biggest cities in B&H. This numerical value totaled at 1328kWh/m^2 annually.

The meteorological data is presented in the table 1 [6]. This table shows the arithmetical mean of sunny hours for each chosen city. This table also provides the information of the total sunny days ($\overline{B}_{SSG}$) in the whole country in the terms of arithmetical mean which totals at 1981h.

TABLE1.THE ANNUAL MEAN OF SUNNY DAYS IN SOME CITIES IN B&H.

POSTAJA	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	Suma
Bihać	65	103	151	177	244	264	300	274	171	127	79	47	2002
Bugojno	67	93	137	151	189	221	245	241	151	123	71	49	1738
Gradačac	67	100	162	192	259	278	303	290	192	155	91	47	2136
Ivan Sedlo	66	87	146	159	195	219	242	250	176	139	76	46	1800
Jajce	56	76	125	152	192	215	238	219	148	124	78	36	1658
Livno	122	140	185	190	255	289	326	308	219	183	120	102	2439
Mostar	125	135	176	184	259	288	332	312	227	176	115	109	2439
Sanski Most	68	103	151	172	232	251	282	269	168	132	80	51	1958
Sarajevo	80	101	149	154	200	240	257	240	171	152	94	58	1895
Tuzla	72	91	152	171	218	235	262	261	174	147	89	54	1928
Zenica	54	92	148	164	215	240	270	252	151	114	63	39	1802

Using the data acquired so far, the mean power of solar radiation ($\overline{P}_{SI}$) can be calculated by dividing the mean value of solar radiation ($\overline{W}_I$) with the mean value of sunny days annually ($\overline{B}_{SSG}$). The value of the mean power of solar radiation in B&H is calculated at 0.67 kW/m^2.

$$\overline{P}_{SI} = \frac{\overline{W}_I}{\overline{B}_{SSG}} = 0.67 \frac{kW}{m^2} \quad (1)$$

B. The estimation of surface eligible for installation of PV plants

1) Apartment buildings

According to the population census from 2013 [7], the number of apartment buildings in B&H is 1,078,156. Most of the buildings include only one apartment, and that totals at 866,796 apartment buildings. Buildings including two apartments total at 165,603 apartment buildings, while the rest of the 45,757 building include three or more apartments. The mean quadrature of an apartment is 74.3 m^2.

In order to complete this analysis some assumptions must be made:

- Buildings that include only one or two apartments are houses with slant roof tops, and ones with three and more apartments are buildings.
- Houses with two apartments have two flats and each flat contains an average sized apartment.
- Each building flat contains an average sized apartment.

Considering the assumptions made it is calculated that 45,757 facilities have flat roof tops with the average surface of 74.3m^2 and 1,032,399 facilities have slant roof tops with the average surface over 74.3m^2.

Considering buildings with slant roof tops it is additionally assumed that these buildings have the roof width of 7m which gives the roof a total surface of 105m^2. Solar panels are usually placed only on one side of the roof top, so the usable quadrature of the roof top is 52.5m^2. With all these assumptions the numbers add up to 57,600,692m^2 from which there are 3,399,745m^2 of flat roof tops and 54,200,947m^2 of slant roof tops.

Figure1.An example of a residential area with marked object orientation

From several, randomly selected, Google Earth images of typical residential establishments in B&H (Fig. 1) it was deduced that the orientation of the object built, when building it, is determined by the ground slant. The orientation in accordance by the sides of the world is not commonly used. The reason why that is so rare is the hill relief shape of the ground in B&H. To accommodate such a situation it is assumed to have equal usage of each orientation throughout the whole country. In order to quantize the solar potential of the residential buildings in B&H, three groups of interest, in the terms of orientation, were distinguished: East-West (O1), North-South (O2) and Northeast-Southwest (O3). The most optimal orientation of the three is East-West (O1) and we will flag this group of interest with the number 1. The orientation North-South (O2) is the least efficient orientation so it will be flagged with the number 0.2. The remaining orientation (O3) has a medium efficiency rate so it will be flagged with the number 0.5. These so called flags represent coefficients and they are used to present the ratio between technological and economical aspect of construction of PV plants in the terms of object orientation 1:0.2:0.5=O1:O2:O3. If these coefficients are used to calculate the total estimated usable surface the calculations are:

$$P_{SOK} = 0.25 \cdot P_{SO}(1 + 2 \cdot 0.5 + 0.2) = 31.68km^2 \quad (2)$$

Estimated surface is calculated as the arithmetical value of the estimated orientations (O1,O2,O3) eligible for PV plant installation.

2) Aquatic surfaces of accumulation lakes

Accumulation lakes, especially man made ones, are extremely eligible for installation of solar plants [3,8]. This technology is already used worldwide and it is just slightly more expensive than the regular ground installation of the solar plants [8]. When using the aquatic implementation of the solar plants several advantages are secured: increased efficiency because of the newly acquired water cooling system, the water surface is gaining a new purpose, so it is being reused and water level management by reducing the water fumes.

TABLE 2. THE CHOSEN ACCUMULATION LAKES

	Surface, km^2	Elevation
Buško Lake	55.8	716 m
Jablaničko Lake	13.3	27 m
Modrac	17.1	200 m
Ramsko Lake	15.3	590 m
Bilečko Lake	33	400 m
In total	134.5	

Out of all man-made lakes in B&H only the biggest ones were considered for the estimation (Table 2), these lakes take up an area that totals at 134.5km2. The planned surface of project implementation is 20% of the total, which is 26.9km2. Reduction of the used surface by 80% still leaves lakes fully functional to their previous purpose of use, which includes water level management, fishing, tourism etc., as well as reducing the shadow effect from the surrounding objects and relief.

To illustrate the potential of the aquatic surfaces these images show Buško Lake. It is situated in the Southwest region of B&H. The mean solar radiation is 1650kWh/m^2, and the number of sunny days annually is 2439. The lake was built to serve as an accumulation for the Hydro power plant Orlovac located in the Republic of Croatia. The lake is placed in an area of small population, with a very desirable surrounding relief. The lake has 55.8km^2 of water surface, and the minimum of 15km^2 of a sunny area that can be used without compromising other lake functions. In this surface (marked with a square on Fig.2) it is possible to install a PV plant of 643MW. It is obvious that 643MW cannot suffice the electric power system needs in B&H, but if the produced energy would be rerouted to nearby reversible power plants then this example would make a great candidate for further consideration.

Figure 2. Google Earth image of Buško Lake

3) Protective zone around the highways

B&H has 160km of highways at the moment. A certain part of this number consists of tunnels and traffic loops but those numbers were not considered in this analysis. PV panels should be installed on both sides of the highway, but the surrounding relief makes it possible to use only one side. This analysis is made with an assumption of placing the panels 5m in width, making the surface of interest total at 80ha.

4) Macro locations – agriculturally unusable land

The problem of desirable macro locations for PV power plants installation was dealt with in detail in the study „The impact of solar power plants on the B&H power system“ [6]. This study was done by Parsons Brinckerhoff Ltd for NOS B&H. This paper uses the data from the study „The impact of solar power plants on the B&H power system“, directly and without any analysis.

Selection was made between numerous locations depending on their relief, existing power grid, population etc. Locations which were taken in consideration were larger than 150ha. Some of the things that were avoided in the selection process were densely populated areas, visible agriculturally active land and places of high altitude. The surfaces, that are eligible for PV plants installation, left after selection totaled at 105,000,000m^2

Figure 3. Image of Duvanjsko Field, a location eligible for a PV plant of 280MW [9].

The study stated that the selection process avoided agriculturally active land, but many of the chosen locations show otherwise. In Fig.3 there is an image of Duvanjsko Field, one of the chosen locations, found in these coordinates (43°37'39"; 17°16'31"). The estimated power is 280MW, the taken surface of flat and agriculturally active land is 550ha, while there is 400ha of mixed terrain, the altitude is 874m and the mean annual radiation is 1660kWh/m^2. Projects like this one should not be allowed.

C. Estimated power of the PV plants

According to the estimated data the total power of potential PV plants in the corresponding groups was calculated. In order to eliminate the shadow effect between the PV panels in flat ground, a surface of 2.5 m^2 is used to install a 1m^2 PV module (this is flagged with a efficiency coefficient of m = 0.4). On the roof top surfaces the ratio is treated as 1:1 (m=1). When thusly calculated surfaces (A), are multiplied with the estimated power of solar radiation per square meter $(\overline{P}_{SI})$, and with the efficiency coefficient of PV modules the result is

presented as the power which would be produced by the installed PV plants.

$$P_{SE} = m \cdot A \cdot \overline{P}_{SI} \cdot \eta \quad (3)$$

The market provides monocrystalline PV cells that have the efficiency ranging from 14-21% [10]. For this analysis the efficiency coefficient of 16% was used. The calculated power in corresponding interest groups is presented in the table 3.

TABLE 3. THE ESTIMATED POWER OF THE ANALYZED INTEREST GROUPS ELIGIBLE FOR THE INSTALLATION OF PV PLANTS

Type		Surface [m^2]	The calculated power [MW]
Apartment buildings	Slant roof tops	29,810,521	3,195
	Flat roof tops	1,869,859	80
Accumulation lakes		26,900,000	1,153
Highways		800,000	34
Macro locations		105,500,000	4,523
In total		164,880,380	8,985

III. THE CURRENT STATE OF PV PLANTS IN B&H

A. *Construction capacities*

First PV plant in B&H was built in 2012. in the city of Kalesija and it is the property of a firm Eko Energija d.o.o. It is placed on the roof top of the city hall. It takes up an area of 1,700m^2, and the installed power is 120kW [11].

Figure 4. PV plant on the roof top of the city hall, Kalesija [12]

By the end of the 2017. in B&H was installed 180 PV plants, with the total power of 18.6MW. Table 4 shows the structure of the installed PV plants regarding the administrative regions (RS and FB&H) they are placed in, as well as the incentive groups. Fig.5 is a graph that presents the growth ratio of installed power of the PV plants in B&H.

B&H as a country produced 16,509GWh electricity in 2016., and 10,608GWh (64.25%) from that total was produced in thermal power plants, 5,469GWh (33.12%) was produced in big hydro power plants, and the new renewable sources (Small Hydro Plants SHP, PV and Wind Plant VP) produced 400.8 GWh (2.42%). Regarding the renewable sources the plants with the biggest impact in production are SHP with 374,27GWh (93.3%) of produced electricity, while the PV plants contribute with 26.5GWh (6.6%) of produced electricity, this is shown in Fig. 6 [13].

TABLE 4. CATEGORIES OF PV PLANTS DIVIDED BY THEIR INCENTIVE GROUPS

F B&H		RS	
Micro, < 23 kW	959kW 59 PV plants	In the roof, up to 50 kW	752kW 21 PV plants
Mini, 23-150 kW	8432kW 68 PV plants	In the roof, 50-250 kW	2537kW 16 PV plants
Small, 150-1000 kW	1916kW 2 PV plants	In the roof, 250-1000 kW	1584 kW 3 PV plants
		On the ground, up to 250 kW	2484kW 11 PV plants
In total	11307kW 129 PV plants		7354kW 51 PV plants
In total B&H	18661kW, 180 PV plants		

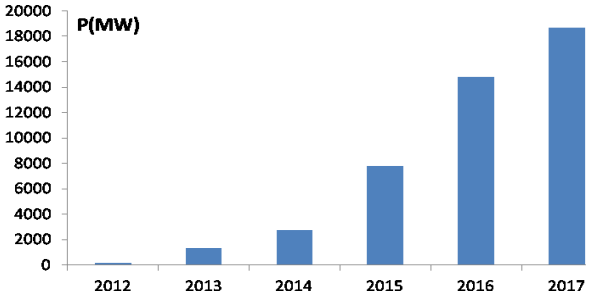

Figure 5. The growth ratio of the installed PV plants in B&H, 2012-17.

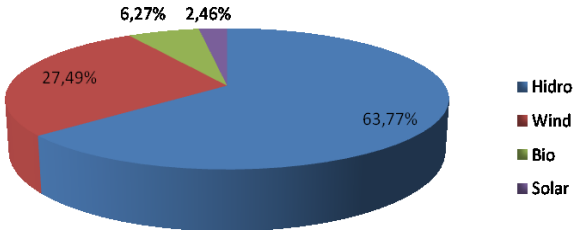

Figure 6. The contribution of PV plants in the total incentive of renewable energy in B&H in 2016 [13].

The biggest installed PV plant in B&H has the power of 0.998 MW, and it is a property of a domestic company Bingo d.o.o. and it is found in the city of Čitluk, placed on the roof top of a mall.

B. *Examples of good implementation of PV plants*

On the roof top of a elementary school in the city of Sarajevo a PV plant was build, with the power of 23kW. The plant is connected to a low voltage grid and all of the production is spent locally. The investor made a contract with the school, in order to use the flat roof top surface of the school, the roof top was reconstructed and according to the agreement the school makes 2% of the annual profit. This way a very positive cooperation was made between the investor and the local community without any disruption of the environment, Fig. 7 [14].

Fig 8. shows a PV plant built on a roof top of a regular household in the city of Tuzla. The PV plant has the power of 22kW [15]. It was installed on one side of the roof top with the surface of 150m^2. This particular building is specific because the investor of the project

adjusted the whole roof top of the building to the PV plant in the way the roof top was built as a whole sunny unity. In this way the investor chose to use and produce renewable energy, and the expanses of the investment in this PV plant were included in the expanses of the building construction.

Figure 7. PV plant on a roof top of an elementary school, Sarajevo [14].

Figure 8. PV plant on a private roof top, Tuzla [15].

C. *Examples of bad implementation of PV plants*

Self standing PV plants are frequently built on agriculturally usable locations. This possibility was not recognized by the legislator as a harmful one. The owners of the land can easily get legal means to build PV plants on their agriculturally usable land by simply promulgating their land as a building site.

Figure 9. PV plants installed on agriculturally usable ground [16].

These kind of plants do not make new work places, do not produce any product in excess, and instead of that they take a lot of agriculturally valuable land and they reduce the employment rate. Fig. 9. shows 150 kW of installed PV plants on agriculturally valuable surface. These PV plants are installed in the proximity of the city Stolac and they are taking up around 3,500 m^2 of surface.

D. *Incentives and legislation*

B&H is a signatory of the Agreement of the foundation of Energy community from 2009. and it has obligated itself to support producers of energy from renewable sources. This support resides in the means to let the investors access the power grid with certain benefits, some of them including the easy access, and guaranteed contract of electricity repurchase with a guaranteed price for the same electricity. B&H was administratively divided by the Dayton Agreement on entities of FB&H and RS whose jurisdiction dictates the energy legislation in B&H. On the state level the transmission of electrical power is dealt by (Elektroprijenos BiH), and the Regulator and the System Operator (NOS) which work by the rules set by the state regulatory committee for electrical power (DERK). The production, distribution and the trading of the electrical power is regulated in the entity level of FB&H and RS. In FB&H the job is regulated by the Regulatory Committee for Energetic (FERK), and in the RS Regulatory Committee for Energetic of Republic of Srpska (RERS). The governments of FB&H and RS have, in 2010. and 2011., made regulations, and the Parliaments of FB&H and RS have, in 2013., made laws for the use of renewable energy sources and efficient cogeneration [17,18]. With the law from 2013. and 2014. in the FB&H was formed a body that deals with renewable energy sources called the Operator for renewable energy sources and efficient cogeneration – OIE&EK. In the RS was formed an Operator of the incentive system.

With the stated laws producers of electrical power have gained the right for guaranteed privileged repurchase price, which number depends on the size of the power plant, lawfully valid for the period of 12 years.

To gain the permit for construction of a PV plant it is needed to:

- Register the activity of „production of electrical power“ at the judges office,
- Acquire the eco permit from the ministry of environment and tourism,
- Elaborate of the technical and economical justification to build the PV plant (the conditions and justification of construction, the list of the used equipment, the choice of the equipment, the description of the applied technology, dynamics of the construction plan and etc.),
- From the legislation institutions (the construction permit, the consent from Elektroprivreda),
- Build the investment and technical documentation and to resolve the legal issues concerning the construction location.

After the construction it is needed to gain the usage permit from the authorized institution, and after that file a request to FERK or RERS to gain the operation permit.

The investor becomes a qualified producer of electrical power when he gains the operation permit. The right to be a privileged producer of electricity can be acquired if the subject owns a operation permit and if his PV plant has the power below 1 MW including 1 MW.

The request to gain the status of a privileged producer, the qualified producers submit to the Operator for the renewable energy sources and efficient cogeneration OIE&EK, or to the Operator of incentive systems. The privileged producer sells the electrical energy by the guaranteed repurchase price which is determined by multiplying the corresponding heading coefficient and the reference price which is the same for all primary sources. The reference price is the price of electricity gained from renewable sources and which production is not incented. Headed coefficient for every group of plants is determined once in every 18 months. The incentive prices for the privileged producers for the PV plants in 2017. are shown in the table 5.

TABLE 5. PRICES BY THE INCENTIVE GROUPS

F B&H		RS	
Micro, < 23 kW	0.31653 EURO	In the roof, < 50 kW	0.13979 EURO
Mini, 23-150 kW	0.24235 EURO	In the roof, 50-250 kW	0.11969 EURO
Small, 150-1000 kW	0.20137 EURO	In the roof, 250-1000 kW	0.0949 EURO
		On the ground, up to 250 kW	0.1109 EURO

If the PV plant is fulfilling all the criteria and if the plants complete installed power matches the dynamical quota expected for the type of the plant in the moment of the file request, then the Operator will grant the status of a privileged producer of electricity. If the dynamical quota, in the moment of the request filling, is filled, then the plant can be placed on a waiting list with the consent from the applicant.

The means for the incentive are billed from the consumer based on electricity consumption. In 2017. the average charge was 0.00163 EURO (0.00101 EURO in FB&H [19] and 0.00225 EURO in RS [20]) by the kWh of electricity spent. This is 2.17% of average price of electricity in B&H (0.075 EURO/kWh [21]). The means collected from the charge is a specially booked income that is spent on: incentive part of the guaranteed agreement of the price for privileged producers, covering expenses of the Operator work, paying the expenses of balancing the power grid system that are made by the deviations in the values planned in comparison to the values produced in the power plants that use renewable sources, and to the foundation for protection of the environment and energy efficiency.

IV. CONCLUSION

The installed capacity of PV plants in B&H is around 18MW. The amount of incentive annually is 2 MW which is the same value of the annual growth of the installed PV plants. According to the action plans for the next period these numbers will not change. The analysis conducted in this paper shows that there are significant unused capacities in the form of residential buildings and aquatic surfaces.

The trend of filing applications to build PV plants by private investors is evident. Such plants are usually built in surfaces which are agriculturally usable which is not a good implementation of the PV plants installation. This paper shows that there are significant reserves of unused surfaces eligible for the purpose of PV plant installation and dictates the use of them.

The power policy in B&H regarding renewable energy is determined by the obligation taken from the membership in the Europe power community. The illusion of good results in the power department comes from the excess energy produced and distributed combined which comes largely from the hydro power sources. This illusion is obviously the result of weak industry. According to [13] the share of electricity produced from renewable resources in 2016. in B&H was 50.3% of the total production. According to the action plan B&H is obligated to increase this number to 56.9% until 2020. This obligation is planned to be resolved with the construction of new hydro power plants, and wind power plants, which means there are no existing plans of any greater investments in the PV plants installation [22].

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Simulator for Testing Algorithms for Estimation of Parameters of Power System

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Abstract – In the paper, realized simulator for testing parameters estimation of the power system was described. Simulator allows definition of the test conditions like amplitude and phase, activity of decreasing direct component, variation of number of samples, variation of harmonic components, and change of frequency of the basic harmonic. The test criterion takes the error of the estimated value in relation to the default value and then time of convergence of the estimated value. As an illustration of algorithm functioning, the time format of the input signal and the timing response of the estimated amplitude and phase of signals are shown. In the simulator, algorithms for amplitude and phase estimation are implemented. For amplitude estimation, algorithms that were implemented: algorithm based on the Fourier bandwidth filter and algorithm based on the least squares method. For phase estimation, algorithms that were implemented: zero crossing algorithm and algorithm based on the Fourier bandwidth filter. All of the implemented algorithms are described and given with their mathematical models. Simulator was made in Matlab and can be expanded with addition of the noise, implementation of other algorithms, development and testing of new algorithms. For the demonstration of the usability of the simulator, results that were obtained by testing are shown.

Key words: simulator, amplitude, phase, parameters estimation of power system, algorithm testing.

I. INTRODUCTION

Amplitude and phase estimation, in real time, of the current and voltage levels in the power system is of fundamental importance for the functioning of these systems. Measurement, protection, control and management of power systems require these values for the realization of their basic functions. Numerical device technology is based on sampling at a given frequency, AD conversion of the sampled values and estimation of the required values using appropriate algorithms. Signal forms of primary voltage and current signals due to various causes are not always sinusoidal. A special problem are short circuits, switching electronic consumers, DC/AC converters of new energy sources, large energy sources inclusion, major consumers switch off. All the listed causes will significantly deform the signal by introducing higher harmonic content [1] and the direct exponential component [2]. In general, after a sudden change of network condition (short circuit, inclusion of the new source, major consumer switch off) the current or voltage signal at the secondary of the measuring transformer can be displayed in the form [3]:

$$x(t) = \sum_k X_k \sin(k\omega_0 t + \varphi_k) + X_0 e^{-\frac{t}{\tau}} + x_s \qquad (1)$$

Where X_k - amplitude of k harmonic, k - number of harmonic, ω_0 - frequency of basic harmonic, φ_k - phase of k harmonic in relation to the reference signal, X_0 - amplitude of DC signal at the time of the change of state, τ - time constant of equivalent electric circuit of the network in which the signal is measured, x_s - noise signal.

There are many different algorithms developed for the purpose of estimating the amplitude and phase of the current and voltage in the power system [4,6]. In practical realization there is a problem of implementation of these algorithms on specific micro-computer structures. The problem is reflected in the complexity of algorithms, which requires a lot of computer power, choice of the right processor, understanding of algorithms itself, and so on [4,5]. Also, there is a need to develop new algorithms. In this development, simulation tools play an important role, which can offer a good response to the question of functioning algorithms as well as the question of the required computer power [3,6,9].

This paper describes a realized simulator designed specifically for the development and testing of algorithms for amplitude and phase estimation of current and voltage in power system. The simulator is realized in Matlab. The choice of Matlab has been done with the aim of ensuring the necessary expansion, adaptation to specific requirements, and implementation of new algorithms.

The work is structured by describing the realized simulator in the first chapter. The second chapter describes the models of implemented algorithms. The third chapter gives the test results.

II. SIMULATOR DESCRIPTION

As a software package for the simulation Matlab was used, in which a GUI (Graphical User Interface) was implemented which is shown in Figure 1, within which it is possible to adjust the various input signal parameters and to select algorithms for estimating amplitude and phase difference.

Two algorithms for the amplitude estimation were implemented: the non-recursive Fourier algorithm and the non-recursive LSE (the Least Square Estimator) algorithm, and two algorithms for the phase difference between the voltage and current signals: zero crossing method and a method based on discrete Fourier transformation.

The model consists of four parts:

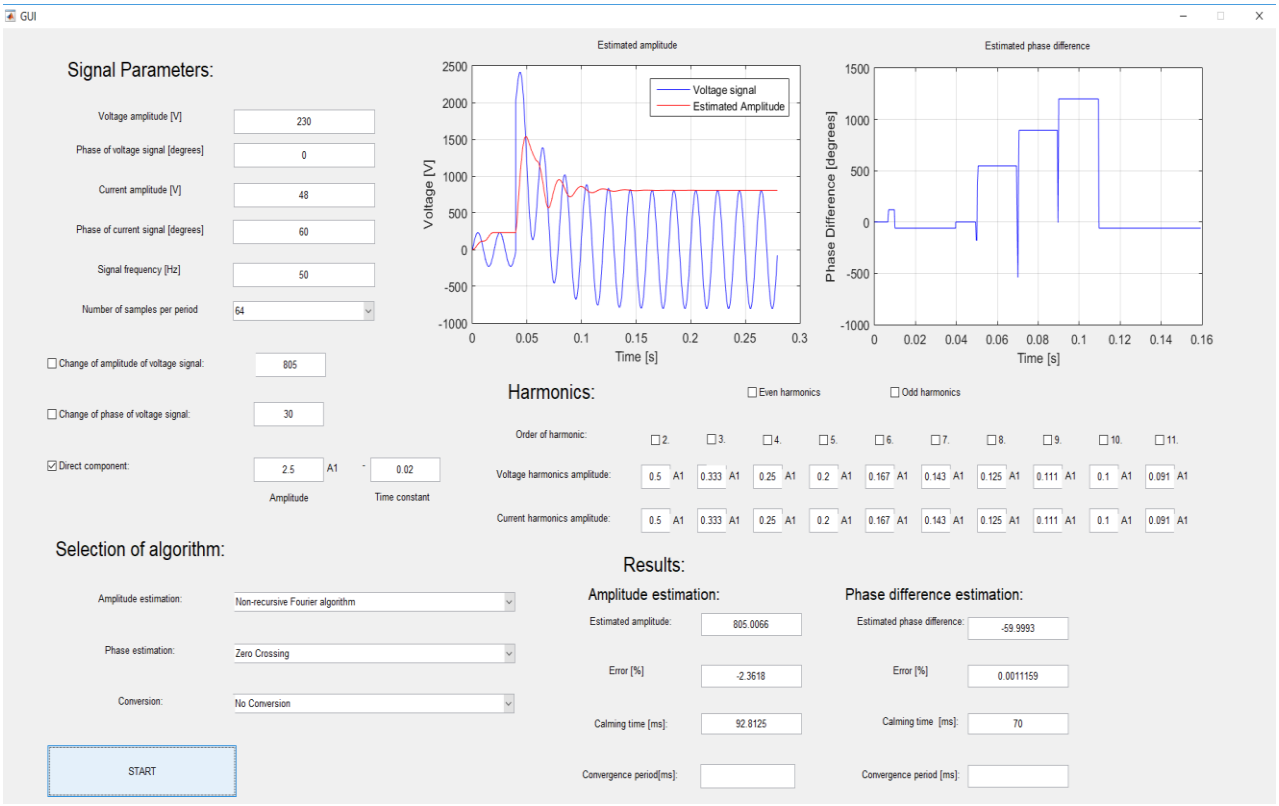

Figure 1. Graphical User Interface (GUI) of simulator

- Adjusting signal parameters over which to estimate amplitude and phase difference;
- Selecting algorithms for estimation of amplitude and phase difference between voltage and current signals;
- Incorporating harmonics into the voltage and current signals;
- Display of the estimated amplitude of the voltage signal and the estimated phase difference between voltage and current signal, and display of the estimation on the diagram.

In the part for adjustment of the signal parameters, it is possible to change the amplitude of the voltage and the current signal, the initial phase shift of the two signals, the frequency of the base harmonic of both signals, and the number of samples in one period. Also, it is possible to include a change in the amplitude of the voltage signal after two periods, the change of phase shift of the voltage signal after two periods, as well as the action of the direct exponential decay component after two periods.

In the second part, the algorithm for the amplitude estimation and the algorithm for estimating the phase difference between voltage and current signals are selected. Here, too, the conversion of the A / D converter is made and can be adjusted to 12, 14 or 16 bits.

In the third part, the harmonic content of the generated voltage and current signal can be adjusted. It is possible to select the effect of all the even and / or odd harmonics (up to the 11th harmonics), whose amplitude can be individually defined for each harmonic.

The fourth part shows the results of the amplitude estimation and phase difference estimation between the voltage and the current signals, and the error expressed in percentages. In the case of a direct component, the calming time or time of convergence, is shown. Also, diagrams for estimated amplitude and phase difference are shown during a given time interval.

III. DESCRIPTION OF TESTED ALGORITHMS

The tested algorithms are described in detail in [7,8,9] and will be fully described here to demonstrate the use of a simulator.

A. Non-recursive Fourier algorithm for amplitude estimation

We'll be watching signal *x(t)*:

$$x(t) = U_m \cos(\omega t + \varphi) + R(t) \quad (2)$$

where U_m - maximum value of the basic harmonic, ω - angular frequency of the basic harmonic, φ - initial phase of the basic harmonic, *R(t)* - part of the signal that consists of higher harmonics. This signal differs from the signal under (1) for the direct component. The direct component is present in the real signal if the fault occurs and introduces some error in the algorithm as we will see in the simulation results.

Signal (2) can be represented in Fourier order:

$$\underline{X} = \frac{2}{m}\left[\sum_{n=1}^{m} x_n cos\left(\frac{\omega_f T_f}{m} n\right) - j\sum_{n=1}^{m} x_n sin\left(\frac{\omega_f T_f}{m} n\right)\right] \quad (3)$$

$$\underline{X} = Re + jIm \quad (4)$$

where $\underline{X}$ evaluation of phasor of the basic harmonic of signal $x(t)$, ω_f assumed frequency of the base harmonic of signal, m number of samples on period T_f, x_n sample n of signal $x(t)$, Re and Im real and imaginary phase component $\underline{X}$.

Relation (3) can be written in matrix form, which is more suitable for computation within Matlab:

$$\underline{X} = [COS][x]^T + j[SIN][x]^T = Re + jIm, \quad (5)$$

where [x] – vector of samples of signal $x(t)$:

$$[x] = [x_1 x_2 \dots x_m]. \quad (6)$$

Vectors COS and SIN are formed for the assumed signal frequency (f_f) and for the given sampling frequency (f_s) of the signal $x(t)$ and are depended on the number of samples in the period T_f. The assumed frequency of the signal (f_f) and sample frequency (f_s) must be chosen so that m is an integer:

$$m = \frac{f_S}{f_f} \quad (7)$$

Vectors COS and SIN are formed according to relations:

$$COS = \frac{2}{m}\left[cos\left(\frac{2\pi}{m}\right) cos\left(2\frac{2\pi}{m}\right) \dots cos\left((m-1)\frac{2\pi}{m}\right)\ 1\right]$$

$$SIN = \frac{2}{m}\left[sin\left(\frac{2\pi}{m}\right) sin\left(2\frac{2\pi}{m}\right) \dots sin\left((m-1)\frac{2\pi}{m}\right)\ 0\right] \quad (8)$$

Based on the calculated phasor of the base harmonic (X) of the signal $x(t)$, an amplitude estimation U_m of the base harmonic of the measured signal can be performed, according to relation:

$$U_m = \sqrt{(Re)^2 + (Im)^2} \quad (9)$$

where Re and Im are real and imaginary component of the estimated phasor of base harmonic of the signal $x(t)$, respectively.

Based on the real and imaginary component of the estimated phasor of base harmonic of the signal $x(t)$, phase of the base harmonic can be estimated using relation:

$$\varphi = arctg\left(\frac{Im}{Re}\right) \quad (10)$$

According to the (5) and (6), to calculate the estimated phasor of the basic harmonic of the measured signal, number of samples m is required in one measurement period.

B. Amplitude estimation with non-recursive LSE method (Least Square Estimation)

In practice, when determining the quality of electrical energy, the signal is usually the complex-periodic function of time that, in addition to the higher harmonics, also contains the direct component. This signal transmitted to the A / D converter may be represented by a mathematical model having the following analytical form:

$$v(t) = V_0 + \sum_{k=1}^{M} V_k \sin(k\omega t + \theta_k) + e(t) \quad (11)$$

where $v(t)$ - value of voltage in the moment t, V_0 - DC component of voltage, $\omega=2\pi f$ - angular frequency of the base harmonic, M - highest harmonic order in voltage signal, V_k - amplitude of k harmonic, θ_k - phase of k harmonic, $e(t)$ - additive noise signal.

The previous equation can be written in the following form:

$$v(t) = V_0 + \sum_{k=1}^{M} V_{rk} \sin(k\omega t) + \sum_{k=1}^{M} V_{ik} \cos(k\omega t) + e(t) \quad (12)$$

where $V_{rk}=V_k cos(\theta_k)$ and $V_{ik}=V_k sin(\theta_k)$ are real and imaginary component of k harmonic, respectively. Expression (12) can be linearized if functions $sin(k\omega t)$ and $cos(k\omega t)$ we develop in Taylor order in the vicinity of the supposed ω_0 (nominal) frequency. Linearized equation (11) in the vicinity ω_0 is given by the following expression:

$$v(t) = V_0 + \sum_{k=1}^{M}[V_{rk} \sin(k\omega_0 t) + V_{rk}\Delta\omega kt \cdot \cos(k\omega_0 t)] + \sum_{k=1}^{M}[V_{ik} \cos(k\omega_0 t) - V_{ik}\Delta\omega kt \cdot \sin(k\omega_0 t)] + e(t) \quad (13)$$

The previous relation can be briefly written as:

$$v(t) = V_0 + \sum_{j=1}^{4M} a_j(t) x_j + e(t) \quad (14)$$

Here, coefficients $a_j(t)$, are unknown x_j can be defined as:

$$\begin{aligned} a_1 &= 1 \\ a_{1+k} &= \sin(k\omega_0 t) \\ a_{M+1+k} &= kt \cdot \cos(k\omega_0 t) \\ a_{2M+1+k} &= \cos(k\omega_0 t) \\ a_{3M+1+k} &= -kt \cdot \sin(k\omega_0 t) \end{aligned} \quad (15)$$

$$\begin{aligned} x_1 &= V_0 \\ x_{1+k} &= V_{rk} \\ x_{M+1+k} &= V_{rk}\Delta\omega \\ x_{2M+1+k} &= V_{ik} \\ x_{3M+1+k} &= V_{ik}\Delta\omega \\ k &= 1,2,\dots,M \end{aligned} \quad (16)$$

If the signal for which we perform the estimation is viewed as a vector of m successive samples appearing at the output from the A / D converter and representing the value of that signal or voltage at the sampling moment, then the expression (14) can be written in matrix form:

$$V = AX + e \quad (17)$$

where $V = [v_1\ v_2 \dots v_m]T$ - vector of samples that make up the data window, $e = [e_1\ e_2 \dots e_m]T$ - vector of errors, $A_{mx}(4M+1)$ - the matrix of the coefficients defined by the relation (15) for appropriate discrete time sampling moments, $X_{mx}(4M+1)$ - vector of unknowns defined by relation (16).

The matrix coefficients A are calculated according to the following relationships:

$$\begin{aligned} a_1(n) &= 1 \\ a_{1+k}(n) &= \sin(k\omega_0 nT) \\ a_{M+1+k}(n) &= knT\cos(k\omega_0 nT) \\ a_{2M+1+k} &= \cos(k\omega_0 nT) \end{aligned} \quad (18)$$

$$a_{3M+1+k}(n) = -knT\sin(k\omega_0 nT)$$

$$n = 1,2,\ldots,m; T = 1/f_s$$

The least squares method yields an optimal estimate of the unknown vector A so that the elements of vector of errors e are minimal. Optimal estimation of unknown vector X is obtained from the relation:

$$X = [A^T A]^{-1} A^T V = \overline{A} V \tag{19}$$

Where $\overline{\mathbf{A}}$ is pseudo-inverse matrix of the matrix A. Elements of the matrix A depend on the sampling period T and presumed angular frequencies ω_0.

After evaluating the elements of matrix X, the following parameters can be calculated: direct voltage component, effective value and initial phase of the base and all the higher harmonics to the harmonic taken as the largest in the relation (11). The determination of these parameters is based on the following relationships:

$$V_0 = x_1$$

$$V_k = \sqrt{V_{rk}^2 + V_{ik}^2} = \sqrt{x_{1+k}^2 + x_{2M+1+k}^2} \tag{20}$$

$$\theta_k = arctg\left(\frac{x_{2M+1+k}}{x_{1+k}}\right)$$

C. *Zero crossing method for estimation of phase difference between voltage and current*

This method of phase difference estimation of two AC signals is based on measuring the time interval that runs between two consecutive passes through zero.

Method for detection of time moments when signals are passing through zero is shown in Figure 2.

Relation for calculating phase difference of two AC signals with detected time moments when signals are passing through zero is [9]:

$$\varphi = 2\pi \frac{t_2 - t_1}{t_3 - t_1}. \tag{21}$$

This method of estimation is subject to greater error in estimation when the higher harmonics or noise signals are active.

D. *Method of phase estimation between voltage and current based on discrete Fourier transformation*

The phase difference between the components of the basic harmonics of the two measured signals is found as the phase difference of the fundamental harmonics of the DFT phase spectral values of the two measured signals.

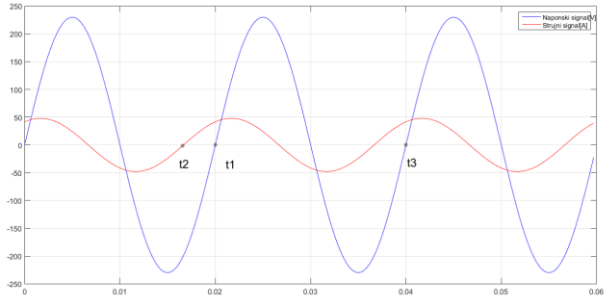

Figure 2. Zero crossing method for phase difference estimation

In the FTD spectrum discrete signals $V_1(nT)$ and $V_2(nT)$ are:

$$V_i(e^{j\omega T}) = \sum_{n=0}^{N-1} v_i(nT) e^{-j\omega_{sig} nT},\ \text{i=1,2} \tag{22}$$

Where N is number of samples, ω_{sig} angular frequency and T period of sampling. Equation (22) can be written as:

$$V_i(e^{j\omega T}) = \sum_{n=0}^{N-1} v_i(nT)(\cos(\omega_{sig} nT) - j\sin(\omega_{sig} nT)) \tag{23}$$

DFT spectrum was formed by FTD spectrum samples at angular frequencies $\omega_k = k$ (ωs /N) and therefore can be written as:

$$V_i\left(\frac{k\omega_s}{N}\right) = \sum_{n=0}^{N-1} v_i(nT)\left(\cos\left(\frac{k\omega_s}{N} nT\right) - j\sin\left(\frac{k\omega_s}{N} nT\right)\right) \tag{24}$$

The phases of these two sinusoidal signals $v_1(nT)$ and $v_2(nT)$ can be found as [9]:

$$\varphi_i = arctg\frac{\mathrm{Im}\left(V_i\left(e^{-j\omega_k T}\right)\right)}{\mathrm{Re}\left(V_i\left(e^{-j\omega_k T}\right)\right)} = \frac{\sum_{n=0}^{N-1} v_i(nT)\sin\left(\frac{k\omega_s}{N} nT\right)}{\sum_{n=0}^{N-1} v_i(nT)\cos\left(\frac{k\omega_s}{N} nT\right)}$$

$$i = 1, 2 \tag{25}$$

IV. RESULTS OF TESTING

A. *Testing results of algorithms for voltage amplitude estimation*

For the demonstration of the usability of the realized simulator, the algorithms described were tested for the test signal of the following characteristics: amplitude of test signal is set to 230V, after two periods, amplitude is increased 3,5 times, with direct decreasing component with initial amplitude of 2,5 times bigger than 230V and time constant of 20ms. A series of tests with a change of 12-bit, 14-bit, and 16-bit AD conversion, were done. The results have shown that the dependence on the number of bits is negligible. Therefore, results tables only show results for b=12. Error in estimation is calculated 4 periods after the activation of direct component. The number of samples in the period was changed: 8, 16, 20, 32 i 64. The tables show results for all sample numbers. In first test, frequency of the signal was 50Hz, in second 49 and in third 51. The first three tables show the results for the change of the above parameters. In the fourth test, in addition to the basic harmonics, 2nd, 3rd and 4th harmonics were added to the input signal. Results with the effect of higher harmonics are given in last table. As a measure of performance, a relative error of the estimated value was taken relative to the default value and the time of convergence. The time of convergence was calculated as the time for which the algorithm, after changing the input signal, takes up the value with the error less than 1% of the correct value. In addition to the numerical results given in the tables, Figures 3 and 4 show the time diagrams that demonstrate the results of the algorithms mentioned. The diagram shows the input signal and the estimated amplitude value. Time diagrams are suitable for

algorithm behavioral analysis when changing signal and determining convergence time.

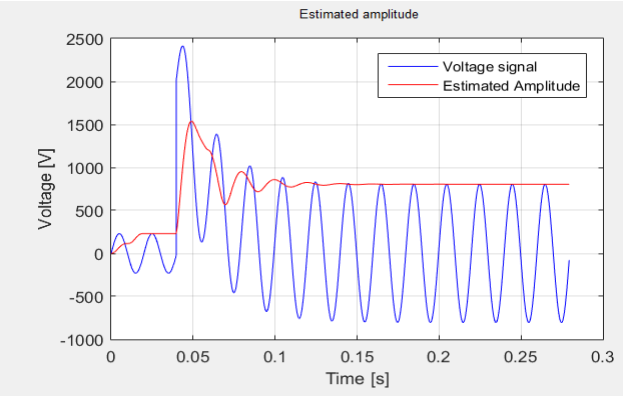

Figure 3. Non-recursive Fourier algorithm for amplitude estimation

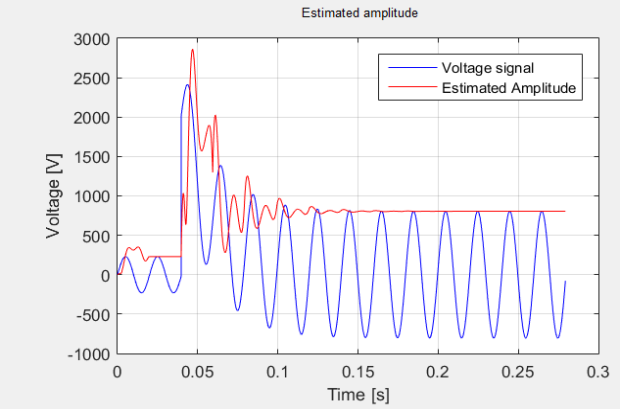

Figure 4. Non-recursive LSE algorithm

Table 1. RESULTS OF AMPLITUDE ESTIMATION FOR TESTED ALGORITHMS

bit = 12, f = 50Hz						
	Non-recursive Fourier			Non-recursive LSE		
m	A [V]	g [%]	t_k[ms]	A [V]	g [%]	t_k[ms]
8	811.0	-0.75	92.5	770.58	4.4667	102.5
16	821.1	-1.9623	92.5	786.00	2.4184	107.5
20	822.3	-2.1081	93	791.95	1.6484	121
32	823.6	-2.2643	92.5	802.25	0.34278	121.25
64	824.2	-2.3379	92.812	811.49	-0.7999	109.062
bit = 12, f = 49Hz						
	Non-recursive Fourier			Non-recursive LSE		
m	A [V]	g [%]	t_k[ms]	A [V]	g [%]	t_k[ms]
8	791.41	1.7178	230	730.80	10.1531	237.5
16	809.55	-0.56225	230	710.77	13.2571	237.5
20	813.38	-1.0304	230	720.53	11.7234	238
32	818.78	-1.6834	230	745.67	7.9561	237.5
64	822.76	-2.1592	230	774.25	3.9711	234.0
bit = 12, f = 51Hz						
	Non-recursive Fourier			Non-recursive LSE		
m	A [V]	g [%]	t_k[ms]	A [V]	g [%]	t_k[ms]
8	819.02	-1.7115	237.5	890.81	-9.6333	237.5
16	817.44	-1.5213	236.25	885.10	-9.0494	238.7
20	817.34	-1.5092	236	876.47	-8.1539	239
32	817.46	-1.5245	236.25	859.93	-6.3883	235.6
64	817.81	-1.5662	236.25	844.41	-4.6668	236.5
bit = 12, f = 50Hz, signal + 2nd, 3rd, 4th harmonics						
	Non-recursive Fourier			Non-recursive LSE		
m	A [V]	g [%]	t_k[ms]	A [V]	g [%]	t_k[ms]
8	811.08	-0.75001	92.5	810.94	-0.7340	92.5
16	821.11	-1.9623	92.5	819.07	-1.7177	92.5
20	822.34	-2.1081	93	820.56	-1.8967	93
32	823.65	-2.2643	92.5	812.74	-0.9524	100
64	824.27	-2.3379	92.812	817.94	-1.5818	100.6

B. *Algorithms for phase difference estimation*

The same test signal as in section A was used when testing the phase estimation algorithm. Phase of the voltage signal was set to 0°, and phase of the current signal to 60°. Tables are shown in which the values of phase difference estimation of the two previous described algorithms, where: φ - estimated phase difference, t_k - convergence time and g - relative error.

f = 50Hz						
	Zero crossing			DFT		
m	φ [°]	g [%]	t_k [ms]	φ [°]	g [%]	t_k[ms]
8	-60.34	-0.57775	/	-59.99	0.0004463	0
16	-59.95	0.071753	/	-59.99	0.0002837	63.75
20	-60.02	-0.036641	/	-59.99	0.0002516	85
32	-60.00	-0.008933	/	-59.99	0.013	116.8
64	-59.99	0.001115	/	-59.99	0.0001640	23.43
f = 49Hz						
	Zero crossing			DFT		
m	φ [°]	g [%]	t_k [ms]	φ [°]	g [%]	t_k [ms]
8	-455.6	-86.832	/	-138.93	-56.8113	/
16	-237.4	-74.7338	/	-138.69	-56.7367	/
20	-221.5	-72.9132	/	-138.65	-56.7246	/
32	-203.1	-70.4672	/	-138.59	-56.7079	/
64	-191.4	-68.6622	/	-138.55	-56.6956	/
f = 51Hz						
	Zero crossing			DFT		
m	φ [°]	g [%]	t_k [ms]	φ [°]	g [%]	t_k [ms]
8	18.08	231.8671	/	19.12	213.8093	/
16	-98.86	-39.3059	/	18.99	216.0058	/

20	-98.83	-39.2877	/	18.96	216.374	/
32	18.93	217.0153	/	18.93	216.8845	/
64	19.08	214.4381	/	18.91	217.2724	/
f = 50Hz, signal + 2nd, 3rd, 4th harmonic						
	Zero crossing			DFT		
m	φ [°]	g [%]	t_k [ms]	φ [°]	g [%]	t_k [ms]
8	-79.89	-24.8953	/	-59.99	0.00044635	/
16	-71.42	-15.9955	/	-59.99	0.00028371	63.5
20	-69.98	-14.26	/	-59.99	0.00025161	85
32	-69.95	-14.2194	/	-59.99	0.0002037	116.
64	-69.53	-13.706	/	-59.99	0.00016401	23.4

V. CONCLUSION

A simulator has been implemented which enables efficient testing of algorithms for estimating the parameters of the power system such as the amplitude of the base harmonic and the phase between the two signals. Several different algorithms are implemented that can be used for different types of input signals. Based on the analysis of the algorithms for the amplitude estimation we can conclude that the algorithms behaved well when the amplitude changed with the action of the direct component. The errors shown in the table are taken after 4 periods of direct component action and are reduced by decreasing the effect of the direct component. The algorithms have shown quite robust for changes in the frequency of the base harmonic as well as on the content of the higher harmonics.

By analyzing the algorithms for the phase difference between voltage and current, we found that the conversion of the A / D converter does not affect the results of estimation and is therefore not taken into account. Both methods have proven to be very bad when changing the frequency for one degree. The zero crossing method could not achieve a 1% error even when the frequency of basic harmonic is 50Hz. Also, DFT was insensitive to the content of higher harmonics in the signal.

The simulator is easily expandable, requires direct implementation of algorithms, which provides information on the complexity of algorithms, about the required computing power of the processor when implemented on micro-computers.

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Optimal threshold selection for threshold-based fall detection algorithms with multiple features

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Abstract - **As people get older, their bodies go through multiple changes that make them more fragile and susceptible to falls. The population of elderly people living alone is increasing worldwide, and this imposes a risk that a potential fall may happen without receiving prompt attention of a healthcare provider or caregiver. To solve this problem, various solutions for automatic fall detection have been proposed that recognise when a person falls and send alarms to someone that could provide quick help. One group of automatic fall detectors use wearable sensors attached to a person's body to measure body accelerations and then to distinguish falls from normal activities of daily living (ADLs) with some of the threshold or machine learning based algorithms. In threshold-based algorithms, features are calculated from measured accelerations and they are evaluated with a set of rules to check whether a fall has happened. The choice of fixed thresholds is thereby important for the overall efficiency of the algorithm. In our previous works in the field of fall detection, we have analysed methods for the determination of appropriate threshold levels for algorithms based on one acceleration-based feature. In this paper, we present a method for setting optimal thresholds in algorithms that use multiple acceleration-derived features. We demonstrate the efficiency of algorithms with thresholds set according to the newly presented method when tested on our dataset of accelerations measured during simulated falls and ADLs.**

Keywords - fall detection, acceleration, threshold, Receiver Operating Characteristics

I. INTRODUCTION

The percentage of elderly people (aged over 65 years) in the overall world population steadily grows and is expected to reach 28% by 2050 [1]. A lot of effort is put today in the research of means to improve the life quality of that population group. Of particular interest are a better healthcare service and solutions that could assist in the independent living of elderly people.

Unintentional falls are one of the major problems of the elderly people. The risk of experiencing an unintentional fall increases with age and according to the statistics, 28-35% of people over 65 years, experience a fall every year [2]. These falls have both negative physical and psychological consequences, leading to a decrease of a person's independence due to injuries or a fear of falling again. After a person experiences a fall, the negative consequences can be reduced by a prompt reaction of a caregiver or healthcare provider, and for this purpose various systems for automatic fall detection have been researched and developed [1]. The main goal of these systems is to automatically detect when a person falls without the need of any additional intervention and to alert caregivers and/or healthcare providers.

A broad range of technologies has so far been proposed for the automatic fall detection purposes [3, 4, 5]. Generally, systems for fall detection can be divided into three group depending on the technologies they are using: ambient based, vision-based and wearable. In vision-based systems, a video camera is used to record a person's movements and image processing algorithms are used to classify falls from regular daily activities. Ambient systems rely on measurements of various sensors set in a person's environment to analyze whether a fall has happened. In wearable systems, a person carries a device attached to his/her body and data is gathered from sensors embedded on the device. Algorithms are then used to detect possible falls from sensor measurements.

In wearable systems for fall detection, mostly accelerometric sensors are used, although the use of other sensors like gyroscopes, magnetometers and barometers have also been explored in the literature [6, 7, 8]. This study focuses only on wearable fall detection systems that utilize acceleration sensors.

In wearable, acceleration based fall detection systems, sensor measurements are fed to an algorithm that detects fall events. The aim of fall detection algorithms is to correctly detect falls and not to generate false alarms during activities of daily living (ADL). The algorithms proposed in the literature can mainly be divided into two categories: threshold-based algorithms and machine learning algorithms [9]. In threshold-based algorithms, features are calculated from acceleration measurements and they are compared to threshold values to determine if a fall has happened.

The choice of threshold values is essential for the algorithm's efficacy. The influence of various methods used to select algorithm's thresholds have not yet been thoroughly explored in the literature. In our previous work [10] we proposed a method for the determination of thresholds for various single features used for fall detection. In this work, we analyze the threshold selection process for two algorithms that use two features for fall detection. For this purpose, two threshold selection methods were implemented and their performance was tested with a dataset of acceleration measurements assessed with a wearable device during ADLs and simulated falls. The performance of the algorithms is mutually compared with thresholds selected using two different methods.

This paper is organized into five main sections. Section II presents a description of algorithms and methods used for choosing optimal threshold values. Section III describes results of the evaluation of proposed algorithms. Discussion and conclusion are given in sections IV and V respectively.

II. MATERIALS AND METHODS

A. Dataset

For the algorithm performance evaluation, a dataset containing acceleration measurements obtained with a wearable sensor unit was used. The dataset was acquired from 16 young subjects (15 to 44 years) that wore the sensor unit attached to their waist while performing ADLs and simulated falls in a safe laboratory environment. A commercially available sensor unit Shimmer3 (Shimmer Sensing, Dublin, Ireland) was used in the experiments, with the acceleration sensor set to ±8g range and 204.8 Hz sampling rate. In total, subjects performed 15 tasks: 12 ADL and 3 falls, as described in our previous paper [10].

B. Features

Each file in the dataset consisted of 3-axial acceleration measurements of a single task performed by one subject in one experiment trial. From acceleration measurements, two features were calculated: :

-Sum Vector Magnitude (*SVM*)

$$SVM(n) = \sqrt{a_x(n)^2 + a_y(n)^2 + a_z(n)^2} \quad (1)$$

-Euler angle (*THETA*) between the direction of Earth gravitational field and the device's vertical axis (y):

$$THETA\ (n) = \text{atan2}(\frac{\sqrt{a_x(n)^2 + a_z(n)^2}}{a_y(n)}) \quad (2)$$

where $a_x(n)$, $a_y(n)$ and $a_z(n)$ represent the *n*-th sample of acceleration in the corresponding sensor axes. Atan2 is an inverse tangent function that returns values in the [-π, π] interval.

C. Algorithms

Two simple threshold-based algorithms, based on the ideas from [11], were implemented: THETA&SVM and SVM&THETA. The first algorithm (THETA&SVM) consists of observing whether the value of the angle feature *THETA* surpasses the threshold value assigned to the *THETA* feature (*theta_threshold*) within a time interval of 0.5 seconds. If the THETA value exceeds the *theta_threshold*, then the *SVM* values in the same time interval window are compared to the threshold set for the *SVM* feature (*svm_threshold*). Finally, if a *SVM* value is found that is greater than the *svm_threshold*, a fall is detected. The reasoning behind this approach is that a person would first experience the angle change when a fall starts, detected with a THETA threshold and followed by an impact that would cause a peak in the SVM feature.

The second algorithm (SVM&THETA) also relies on comparing feature values with their corresponding thresholds. First the *SVM* values for every sample are compared with the *svm_threshold*. If the *svm_threshold* value is surpassed, then the THETA feature is analysed in the following samples. The idea behind this approach is to first detect the impact with the ground and after that the lying orientation of the falling person. If an THETA angle greater than *theta_threshold* is detected, an additional condition is checked to reduce the number of false positives. In a time frame of 1s around the sample at which the THETA angle is found to be greater than the threshold, the mean value of SMV is calculated. If this value is less than 1.2, indicating that a person is at rest, a fall is detected.

D. Performance Evaluation

The algorithms were tested with measurements contained in our dataset to evaluate their performance. Confusion matrices (error matrix, contingency table [12]) were generated by varying the threshold values and testing the algorithms' success in detecting and distinguishing fall events from ADL. Thresholds were chosen from a limited set of values containing: for THETA feature, all values from 0° to 175° in increments of 5°; for SVM feature, all values from 0.1g to 12g in increments of 0.1g. For every combination of thresholds the appropriate numbers in the confusion matrix were updated:

- the number of true positive events (TP) – fall happened, algorithm detected fall
- the number of false negative events (FP) – no fall happened, algorithm detected a fall
- the number of true negative events (TN) – no fall happened, algorithms did not detect a fall
- false negative events (FN) – fall happened, algorithm did not detect a fall

The results of the algorithms' evaluation contained in the confusion matrix were used to calculate three performance metrics as follows:

$$sensitivity = \frac{TP}{TP+FN} \quad (3)$$

$$specificity = \frac{TN}{TN+FP} \quad (4)$$

$$meanSESP = \sqrt{SE * SP} \quad (5)$$

E. Optimal Threshold Selection

The optimal threshold values for the algorithms were selected from the Receiver Operating Characteristics (ROC) curve. The ROC curve is obtained by plotting *sensitivity* (true positive rate) versus 1-*specificity* (false positive rate) values. Optimal thresholds were selected from the ROC curve as values that minimize the distance between the curve and then point (0,1) which represents the ideal case of 100% sensitivity and specificity rates. Two methods of choosing the two threshold values for the algorithms were analyzed.

In the first method (MET1), optimal thresholds for each feature used in the algorithms were selected separately and set to values determined in our previous work (optimal thresholds determined for *theta* and *SVM*) [10]. With the *svm_threshold* and *theta_threshold* chosen in this way, the performances of both algorithms were evaluated and the performance metrics were calculated.

For the second method (MET2), confusion matrix was generated for all combinations of the two threshold values. Thus, a single ROC curve was plotted for each of the algorithms and by the optimal threshold selection

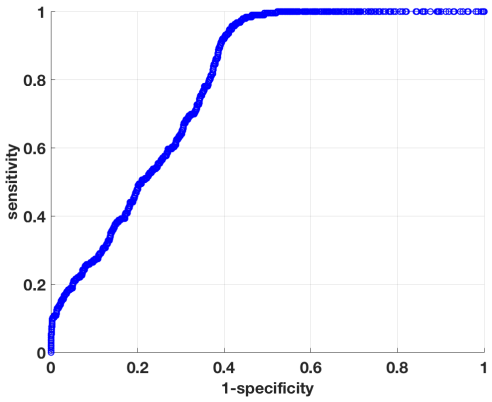

Figure 1. ROC curve of the THETA&SVM algorithm obtained by analyzing all threshold pairs

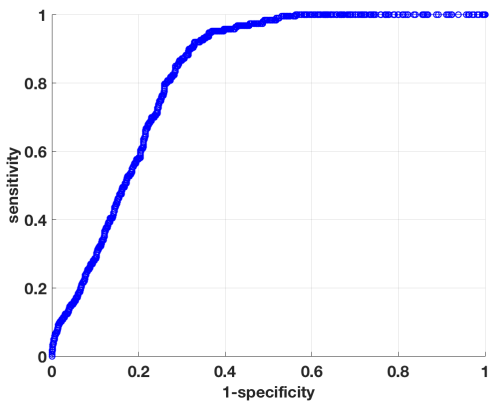

Figure 2. ROC curve of the SVM&THETA algorithm obtained by analyzing all threshold pairs

procedure described above, a pair of optimal threshold values (*svm_threshold, theta_threshold*) was sought.

III. RESULTS

The two implemented algorithms, THETA&SVM and SVM&THETA, were evaluated using our dataset and corresponding confusion matrices were generated. From the confusion matrices, performance metrics were calculated and ROC curves were plotted. ROC curves obtained for both algorithms by analyzing all threshold value pairs (MET2) are given in Fig. 1 and Fig. 2.

Optimal threshold values for both algorithms were chosen by the two methods described in the previous section. Values of the selected thresholds along with the performance metrics calculated for them are given in TABLE I.

IV. DISCUSSION

Among the analyzed algorithms and threshold selection methods in this study, the algorithm SVM&THETA with thresholds set according to MET2 showed the best results with the sensitivity of 86.0%, specificity 80.1% and *meanSESP* 83%.

In our previous work [10], we calculated the performance metrics (sensitivity, specificity) for a set of features used individually for fall detection. From the analyzed features, the best results were achieved with the *GSVM* feature. *GSVM* is calculated as a normalized product of *THETA* and *SVM* for a given sample. With the threshold set at 3g, the GSVM feature was tested with the same dataset as used in this study and sensitivity of 90.3% and specificity of 88.5% were achieved (*meanSESP* 89.4%). Comparing these results to the ones obtained with the algorithms tested in this study, in all cases fall detection based on the GSVM feature outperforms the tested multi-feature algorithms.

The THETA and SVM feature were also among the features analysed individually in [10]. For the THETA feature, sensitivity of 94% and specificity of 63.5% were achieved (*meanSESP* 77.2%) and for the SVM feature sensitivity of 88.7% and specificity of 67.8% were achieved (*meanSESP* 77.5%). Thus, the algorithm SVM&THETA with thresholds set with MET2, outperformed the single features of THETA and SVM in fall detection tasks. On the contrary, the THETA&SVM algorithm performed similarly or even slightly worse than THETA and SVM individually. This showed once more the potential benefits of combining multiple features in the algorithm and the importance of the methods used to combine the features.

Since both algorithms use some fixed time intervals or thresholds (time window of 0.5 s in THETA&SVM, time window of 1 s and threshold for mean SVM in SVM&THETA), the performance of the algorithms should also be tested with various values for these variables. In our

TABLE I. PERFORMANCE OF THE ANALYZED ALGORITHMS

Algorithm	Method	Optimal threshold	*sensitivity*	*specificity*	*meanSESP*
THETA&SVM	MET1	*svm_threshold*=4,3g *theta_threshold*=120°	61.3%	69.3%	65.2%
	MET2	*svm_threshold*=4,4g *theta_threshold*=45°	86.6%	65.6%	75.4%
SVM&THETA	MET1	*svm_threshold*=4,3g *theta_threshold*=120°	20.4%	89.9%	42.8%
	MET2	*svm_threshold*=4,1g *theta_threshold*=70°	86.0%	80.1%	83.0%

future work, we plan to set these variables to optimal values and assess the algorithms' performances to see whether in this way their efficacy could be improved.

V. CONCLUSION

In both tested algorithms, the optimal thresholds and thus the performance metrics changed with the change of methods used to determine the thresholds. The algorithms performed better with the thresholds set combined (MET2) than with the thresholds set separately (MET1). The proposed method (MET2) for optimal threshold selection in multiple feature algorithms may therefore be beneficial for the overall algorithm performance compared to the standard method of choosing the threshold individually (MET1), however further experiments must be carried out to make stronger conclusion.

In conclusion, we implemented two algorithms for fall detection based on the analysis of two acceleration derived features. We analyzed their performance with the use of our dataset for fall detection comprised of acceleration measurements. For each algorithm, we examined the effects of using two different methods for the selection of optimal threshold levels. The best results were obtained for the SVM&THETA algorithm with thresholds set according to the method MET2: *sensitivity* of 86.0%, *specificity* 80.1% and *meanSESP* 83%.

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Implementation of an electronic platform for aiding the waste management process

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***Abstract* – This paper describes the implemented system for detecting the state of the containers for collection of municipal waste. The data that is being collected contains following: fullness of the container, the position of the cover, and battery status. The data is transmitted via the Wi-Fi module ESP8266-12E to the broker, where an available management application system utilizes the transmitted data. The communication protocol that was used for that purpose is Message Queue Telemetry Transport (MQTT). The module operates autonomously, with a battery or solar powered source. Defect of efficient waste management has caused serious environmental problems and cost issues. A possible implementation of the system will be presented on the use case of the city of Sarajevo.**

Keywords – waste management system; WiFi module ESP8266-12E; MQTT protocol; sensors

I. INTRODUCTION

Communal waste management is an important component of modern living. The problem is multidimensional. Communal companies, who are solving this problem, mostly operate in an old-fashion way. The problem should be considered integrally to the way waste is generated, how to dispose it, how to arrive on the depot and how to recycle it. The complete problem could benefit the following fields: legal, cultural, educational, financial, ecological, and other aspects. Only one aspect of this complex problem is analyzed here: communal waste disposal. The idea that was realized and described in this paper starts from the thesis that it is necessary to have information on the state of landfill data for the application of improved waste management.

The Internet of Things (IoT) technologies that have emerged over the last 10 years offer certain, economically and technologically acceptable solutions to similar problems [1]. The idea is to add a wireless sensor module to the standard waste disposal container to estimate the state of the container and forward it to the appropriate base (eContainer). The term 'landfill status' is not treated in this paper in a studious way, as there is no standard that defines this problem. The following parameters could be of interest: smoke, fire, temperature, humidity, toxic gas, fullness of the container, waste type, etc. To not generalize the problem we have opted for only one parameter: the fullness of container. By the same principle and with a certain hardware expansion it is possible to collect data projected via the above mentioned parameters. The problem of disposal and waste management is not elaborated in this paper. One of the guiding ideas is forming a picture of the condition in a given area that can serve to take certain actions, such as changing the route of the transport vehicles, sending of additional vehicles, etc. The work is primarily based with the usage of a dedicated Wi-Fi sensor with the task of estimating the state at the landfill and the transmission of data to the application. The data is transmitted through the available wireless network to the broker. The application collects data from the broker and presents it to the user in a suitable form. The Message Queue Telemetry Transport (MQTT) is used as a protocol.

The problems about this subject are analyzed in [2,3,4,5,6].

II. BLOCK SYSTEM STRUCTURE

The block system structure is shown in Fig. 1. The system consists of a hardware module for collecting and transmitting data from an object to a broker which accepts and temporarily stores the data. The hardware module consists of power supply, sensors, control units and module for Wi-Fi communication. For this implementation, a waste collection container was selected, which is used as standard in Sarajevo [7].

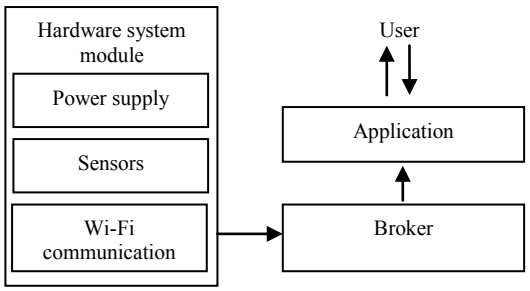

Figure 1. Block system structure

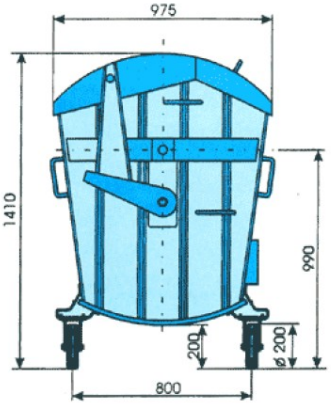

Figure 2. Waste container [7]

They are characterised by robustness, metal implementation, mobility, etc. The dimensions are shown in Fig. 2. The sensor module is connected from the underside of the cover by fastening the module housing to the cover. The solar module is installed on the top of the cover. The idea is to avoid large interventions on the existing container. The assumption is that the location where the container is placed is also covered by Wi-Fi internet access.

III. HARDWARE MODULE

The hardware module is organized around the 32-bit processor Tencilica L106 32-bit, which is a processor core of Wi-Fi communication module with built-in 10-bit AD converter [8]. The Hardware module is designed in the Altium development tool and the 3D model is shown on Fig. 3.

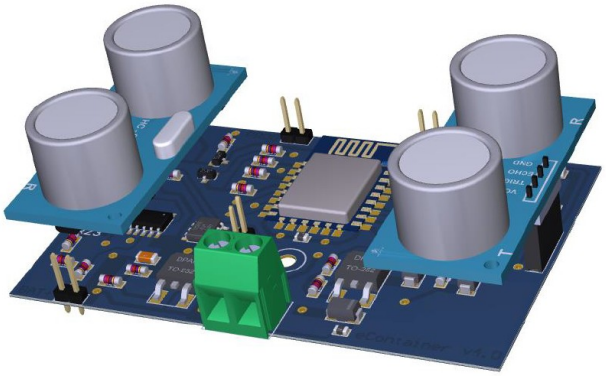

Figure 3. 3D representation of the hardware module

The module is designed so that it is able to use distance sensors, smoke detectors, temperature sensors, light sensors and battery charge sensors. In this implementation, only a distance sensor, a light sensor, and a battery charge sensor are implemented, while the other sensors, are provided via suitable connectors with which the device can be upgraded. The block structure of the hardware module and the implemented and tested system are shown in Fig. 4 and Fig. 5, respectively.

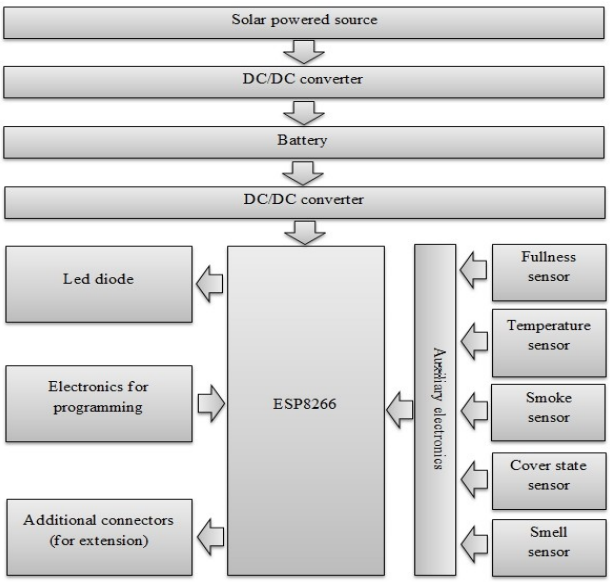

Figure 4. The block structure of the hardware module

In the basic realization the charging of the module is performed with a battery. If the container is in such position to enable the usage of a solar power, then there is a possibility to charge the battery from the solar module. The module uses small amounts of electricity, in working mode uses <180mA and in standby mode uses <1mA. The system stays in the working mode for 85ms, from which 40ms are spent on measuring the distance, 20ms are spent measuring the batteries voltage, 20ms are spent on measuring the lighting and 5ms for the data transfer. The analyzed application allows the measurement to be performed repeatedly with a time period of 30 minutes. With this regime the system can use a battery of 4400 mAh (2x2200 mAh) up to six months.

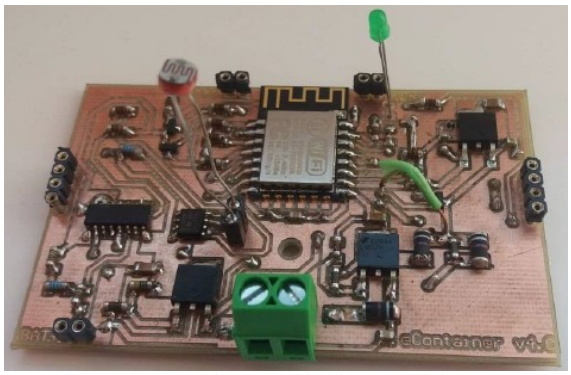

Figure 5. The created hardware module

A. *Wi-Fi controller ESP8266-12E*

The basic characteristics of the ESP8266-12E controller are given in Table 1, and the pin diagram is given on Fig. 6 [8].

TABLE 1.THE BASIC CHARACTERISTICS OF THE ESP8266-12E CONTROLLER

Power supply voltage	3.3V
Required current	10µA-170mA
Flash memory	16M max (512k normally)
Processor	Tencilica L10632-bit
Processor speed	80-160MHz
RAM	32k – 80k
Number of pins	16
ADC	10 –bit
Wi-Fi	2.4GHz
Temperature range	-40°C do 110°C
Integrated TCP / IP stack protocol	
Serial communication	SPI, I2C, SDIO 2, GPIO

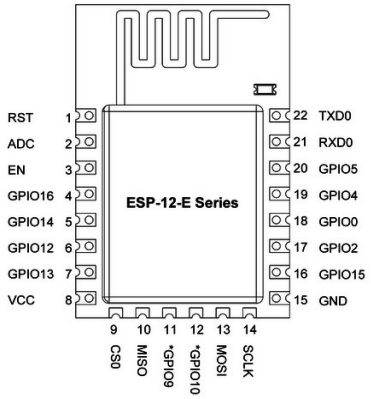

Figure 6. Pin diagram ESP8266-12E [8]

The Wi-Fi controller ESP8266-12E is programmed with the Arduino IDE environment, which is a free open-source platform. This development environment supports the C and C ++ programming languages, using specialized rules for code organization. A useful option is the built-in serial monitor for tracking the print on serial connection. Also, in order to extend functionality, the environment provides the ability to use additional program libraries through the built-in browser for the available software libraries, or from the ZIP archive. Every suitable installed software library comes with the examples that can be activated and translated on the Arduino device. Adding a new board ESP8266 module and the PubSubClient library for the implementation of the MQTT protocol, setting the bit rate in communication and selecting ports were the preparations for programming the ESP8266 controller. The conversion of the ESP8266 module into the programming mode takes place as follows :

- GPIO0 – switch from 3.3V to GND,
- RST – short circuited on GND (swiftly),
- GPIO0 – switch from GND to 3.3V.

B. *Ultrasonic sensor for measuring amount of charge in the container*

An ultrasonic sensor HC-SR04 [9] was used to measure the capacity of the container. Distance is estimated from the measurement of the return time of the ultrasonic wave with the equation:

$$S(m) = \frac{1}{2} V\left(\frac{m}{s}\right) \cdot t(s)\,, \qquad (1)$$

where V stands for the speed of sound, t for the time that passes from the moment the sound wave has been emitted until it has returned. Optimal performance of the sensor is in the range up to ±22.5 °. The spatial characteristic of the ultrasonic sensor is shown in Fig. 7 [9].

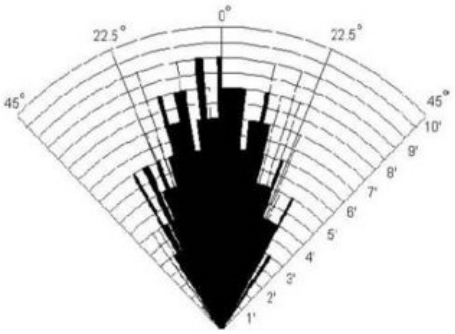

Figure 7. Spatial characteristic of the ultrasonic sensor [9]

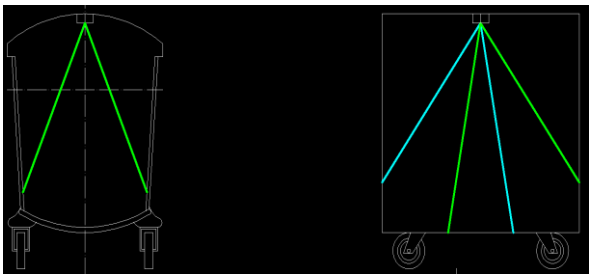

Figure 8. Area of coverage with two HC-SR04 sensors

Two such sensors were used to cover the entire space inside the container, Fig. 8. Ultrasonic sensors are directly connected to the power supply and to the pins of microcontroller (TRIG and ECHO).

C. *GL5549 photo-resistor*

A photo-resistor GL5549 was used as an indicator of the status of the container cover [10]. Two voltage dividers and an operational amplifier were used to determine the amount of light, as shown in Fig. 9. The resistor R6 and the photo-resistor are connected in series. A photo-resistor is mounted on a connector X3 with a conductor in a way that it can be secured on the lid of the container later on. The voltage on the divider is proportional to the intensity of light that falls on the photo-resistor, and is connected to the analog input of the controller via the voltage follower and the additional divider (R7-R8). The voltage follower eliminates the influence of the resistors R7 and R8 on the voltage that is formed on the photo-resistor.

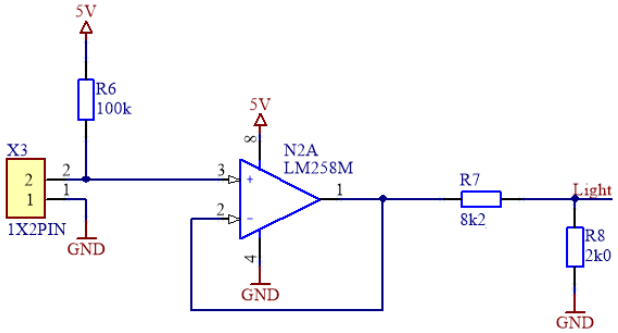

Figure 9. Circuit diagram for measuring the light intensity

A light quantity of 10 lux can be expected on the photo sensitive part of the sensor, when opening the eContainer cover. From the characteristics, we conclude that for the amount of light of 10 lux, the resistance of the sensor ranges from 100kΩ to 200kΩ. When the cover is closed, the value of the resistance of the photo sensor is of the order MΩ. In that case the photo-resistor voltage is near 5V (>4V). When the container is open that voltage is less than 3V.

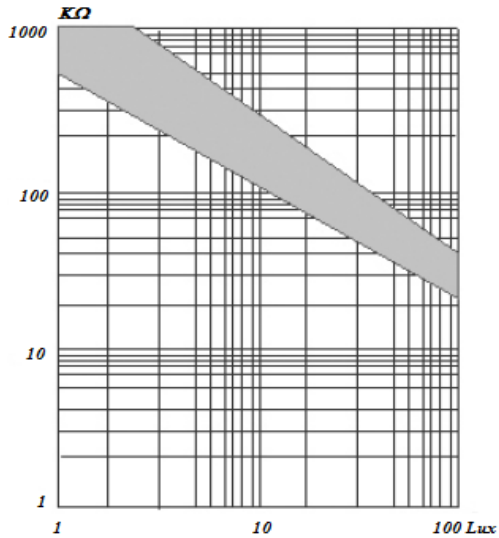

Figure 10. Static characteristic of GL5549 photo resistor [10]

D. *Measuring battery voltage*

Battery voltage is measured, for battery status detection purposes. With the voltage dividers R4 and R5 a voltage adapted to the AD converter range is being formed and as such is brought to the AD converter input. Because the ESP8266 module has only one analogue channel, a multiplexer was used. With it, via an analog switch, signal from one of the two implemented sensors is being sampled.

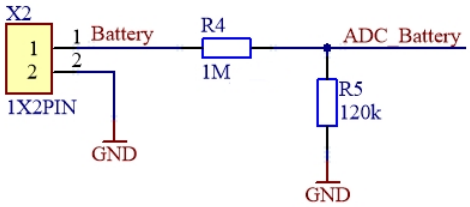

Figure 11. Circuit for measuring battery voltage

For the power supply of the system, two serial-bound Li-Ion batteries of 2200mAh, 3.7V are used. Batteries are complemented by a solar panel, which is installed from the outside. If there is no possibility of installing a solar panel then the batteries are changed as needed. Solar panel voltage is 8.7V including if the resistance is over 5Ω, 5W is connected to batteries. Linear regulators HT73xx form the necessary voltages for the controller and sensors.

IV. MQTT Protocol

For the purpose of enabling more efficient data transfer, with less battery consumption, the MQTT protocol was used [11]. Its advantage is that it is open source, extremely lightweight and easy to implement on light hardware systems. It is ideal for this problem because of its small size, low power usage, minimised data packets and efficient distribution of information to one or many receivers. Low energy usage is one of the most important criteria for solving this problem. MQTT is a protocol with a post-subscription architecture. The final destination of the posted message is determined by an intermediary who transmits the relevant information, on the basis of a subscription to specific topics. A broker is a mediator between clients, who can be publishers and a subscribers. The client-publisher transmits a message specifying the topic on which he publishes. On the other hand, the client names the topic to which he is subscribed so that the broker knows which messages he needs to forward. In this way, message publishers do not know which clients will receive a message that removes the dependance between clients and increases system performance.

For the realization of eContainer the *cloudmqtt.com* broker was used. Broker currently offers four packages: 10, 100, 1000 i 10 000 connections on one broker and „listens“ the data on the ports:

1. 1883 – MQTT connection without encryption,
2. 8883 – MQTT connection with encryption,
3. 8884 – MQTT encryption connection with certificate request,
4. 8080 – MQTT connection via WebSockets without encryption protocol,
5. 8081 – MQTT connection via WebSockets with encryption protocol.

When establishing a connection between the client and the broker, it is necessary to specify the address of the broker to which it is connected, the port, the username and the password.

A. *MQTT topics*

The theme is UTF-8 character string that the broker uses to distribute messages correctly. Topics need not to be instantiated, it automatically happens if a client sends a package to a non-existent topic. The theme may contain several hierarchical levels with a separate "/" sign, as in the example:

/Sarajevo/TrgMedjunarodnogPrijateljstva100/ID-2/Kapacitet.

Also, if the client wishes to receive notifications from multiple topics, it is possible to use substitute characters to shorten the subscription process on the topic. There are two substitute characters in the MQTT protocol:

+, subscribes to all topics that are on a given level of hierarchy,

#, subscribes to all hierarchical suburbs that belong to the level before the character #.

V. Results Of Prototype Testing

To show the results of prototype testing, the first step was to create an MQTT broker who would be notified by the pre-realized prototype. Messages are analyzed and forwarded to the clients subscribed to receive notification of appropriate topics. The broker was created on the site (www.cloudmqtt.com). The created prototype is actually a client publisher that delivers information about the fullness of the container, battery voltage, and the state of the container cover. Information is published on the following topics respectively:

/Sarajevo/ZmajaOdBosnebb/ID-1/Kapacitet,

/Sarajevo/ZmajaOdBosnebb/ID-1/StanjeBaterije,

/Sarajevo/ZmajaOdBosnebb/ID-1/StanjePoklopca.

The serial port is used for "debugging", and after successful programming, a successful connection to the broker is recognized. Instead of the "deep-sleep" mode, periodic publishing on the topics is set for testing purposes every 5 seconds. The prototype notifies the status of the container only if the cover appears to be closed. Fig. 12 shows printing on the MQTT broker.

Received messages

Topic	Message
/Sarajevo/ZmajaOdBosnebb/ID-1/StanjePoklopca	Zatvoren
/Sarajevo/ZmajaOdBosnebb/ID-1/StanjeBaterija	8.61
/Sarajevo/ZmajaOdBosnebb/ID-1/Kapacitet	89
/Sarajevo/ZmajaOdBosnebb/ID-1/StanjePoklopca	Zatvoren
/Sarajevo/ZmajaOdBosnebb/ID-1/StanjeBaterija	8.62
/Sarajevo/ZmajaOdBosnebb/ID-1/Kapacitet	94
/Sarajevo/ZmajaOdBosnebb/ID-1/StanjePoklopca	Zatvoren

Figure 12. The print on the broker

On Fig. 13 is a view of a client's WEB page using the data that the sensors pass on to the broker. The figure shows five containers with a graphic representation of the fullness level. The application may otherwise use the downloaded data.

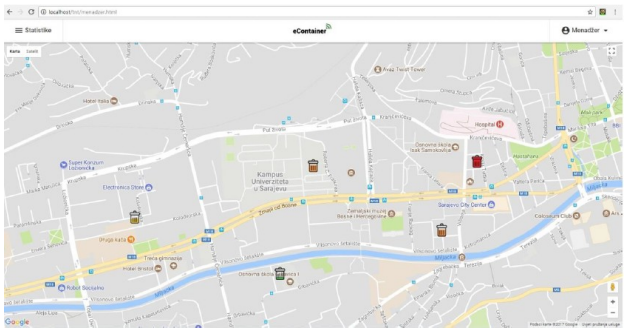

Figure 13. WEB page as a MQTT client

VI. CONCLUSION

A hardware module has been implemented that enables the estimate of the state of the communal waste landfill. The completed Wi-Fi modules are used for the realization of the system and the necessary hardware is designed to provide the necessary functioning of the system. For the demonstration of the work, the MQTT protocol was used, which without the intentional infrastructure allows the exchange of data between the clients. Based on this data, it is possible to create applications with different services. The visual presentation of the state of the landfill on a given space is shown. By the same principle, simple hardware expansion can also estimate other data. Using the MQTT protocol turned out to be the right solution to this problem. A prototype was announced that informs the main center of the container fullness, battery status, and status of the container cover. The prototype could be applied in urban areas where Wi-Fi connectivity is available. For rural areas, it is recommended to upgrade the system with the GSM module.

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Optimization of PID Controller in AVR System by Using Ant Lion Optimizer Algorithm

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***Abstract* - In this paper a novel optimization algorithm is proposed for efficient tuning of AVR controller in a closed loop generator control model. Ant lion optimizer is applied for fine tuning of PID controller parameters through model simulation and testing. A proposed algorithm uses single objective optimization method for acquiring an objective function's minimum. Several testing cases are used for simulation purposes and in all these cases a novel optimization method is compared with other swarm intelligence algorithms which have already been implemented as AVR controller optimization methods.**

Keywords - Ant Lion Optimizer, Automatic Voltage Regulation, PID Controller

I. INTRODUCTION

A proportional–integral–derivative (PID) controller is a widely used type of regulator that is present in feedback control. In today's industrial applications, process control, motor drives are all included in a type of regulation that uses proportional-integral-derivative type of regulator for maintaining desired output variable in a continuous observation of a controlled system. One such system, described in this paper, is an automatic voltage regulator (AVR) of a generator unit. In this system, terminal voltage is maintained by minimizing a difference between a desired set point and measured voltage.

Tuning of a PID controller in regulation feedback systems is a complex task, as it involves knowing the mathematical model of a regulated object and its appropriate elements. Higher order functions, time delays and other nonlinearities present a significant challenge in tuning of controller parameters. Heuristic methods, such as the Ziegler-Nichols method, can be of use, but they rarely find an even near optimal solution to a specific problem.

In recent years, several artificial intelligence (AI) techniques in tuning a PID controller have been proposed to extend its capabilities. Algorithms that include neural networks, fuzzy control and swarm intelligence have been implemented for intelligent PID control and have yielded successful results.

With the latest boom in new swarm intelligence algorithms, automatic voltage regulator (AVR) has been one such standard testing system, benefited by its simple structure and the fact that it can be effectively tested. These swarm intelligence algorithms include: genetic algorithm (GA), particle swarm optimization (PSO) and its variants [1-3], anarchic society optimization (ASO) [6] and bacterial foraging algorithm (BFOA) [8]. In this paper, one novel algorithm, called ant lion optimizer (ALO) [4] is tested, evaluated and compared with some previously used algorithms, such as PSO, ASO and artificial bee colony (ABC) algorithms [7].

II. ANT LION OPTIMIZER

Ant lion optimizer [4] is a novel nature inspired swarm intelligence algorithm that mimics the interaction between ant lion and its prey, during the ant lion larvae life cycle. Foraging behavior of ant lion larvae includes several phases which include positioning in space, building a trap, trapping and catching an ant and repositioning for better hunting through communication with space and other predators.

Ants, as a prey, move stochastically in a search space and their position is saved in a matrix:

$$M_{ant} = \begin{bmatrix} ant_{1,1} & \cdots & ant_{1,d} \\ \vdots & \ddots & \vdots \\ ant_{p,1} & \cdots & ant_{p,d} \end{bmatrix}, \quad (1)$$

where d stands for dimension of an ant, and p for population size. Since ants in ALO are similar as particles in PSO, they have fitness, which they obtain during their random walks in the same way as ants become fitter with finding a food source. Random walk is mathematically described as:

$$x(t) = [0, cumsum(2r(t_1) - 1), \dots, cumsum(2r(t_n) - 1)], \quad (2)$$

where $cumsum$ calculates the cumulative sum, n is the maximum number of iterations, t shows the iteration step of a random walk, and $r(t)$ is a stochastic function defined as:

$$r(t) = \begin{cases} 1, & rand(0,1) > 0.5, \\ 0, & rand(0,1) \leq 0.5. \end{cases} \quad (3)$$

In (3) $rand(0,1)$ is a function that generates random number with uniform distribution in the interval $[0,1]$. Fitness evaluation of each ant is stored in matrix:

$$M_{OA} = \begin{bmatrix} f(ant_{1,1}, \dots, ant_{1,d}) \\ \vdots \\ f(ant_{n,1}, \dots, ant_{n,d}) \end{bmatrix}, \quad (4)$$

With ants defined, it is also assumed that ant lions are also somewhere in search space, and their position matrix is defined as:

$$M_{antlion} = \begin{bmatrix} antlion_{1,1} & \cdots & antlion_{1,d} \\ \vdots & \ddots & \vdots \\ antlion_{n,1} & \cdots & antlion_{n,d} \end{bmatrix}, \quad (5)$$

and their fitness matrix as:

$$M_{OAL} = \begin{bmatrix} f(antlion_{1,1}, \dots, antlion_{1,d}) \\ \vdots \\ f(antlion_{n,1}, \dots, antlion_{n,d}) \end{bmatrix}. \quad (6)$$

During algorithm execution, these conditions are met:

- ants use normalized different random walks in search space,
- random walks are affected by antlions traps,
- ant lions build traps in size proportional to their fitness,
- ant lions with larger pits have a higher probability to catch prey,
- each ant is being caught by one ant lion in one iteration,
- random walk range is decreased adaptively with latter iterations,
- if an ant becomes fitter than ant lion that caught it, the ant lion repositions to the ant's place,
- during optimization, the fittest ant lion is saved as an elite, and next random walks of prey are also being affected by it as well as with the selected ant lion.

A. Mathematical modelling of ALO [4]

Random walk of prey is defined as (2) and (3) and normalized in search space:

$$X_i^t = \frac{(X_i^t - a_i) \cdot (d_i^t - c_i^t)}{b_i - a_i} + c_i^t, \quad (7)$$

where X_i^t is a position of i-th ant in iteration t, a_i and b_i are minimum and maximum of random walk for i-th ant, and c_i^t and d_i^t are minimum and maximum for i-th ant at iteration t.

Random walk of prey is affected by ant lion's pits. This assumption is mathematically defined as:

$$c_i^t = antlion_j^t + c^t, \quad d_i^t = antlion_j^t + d^t \quad (8)$$

where c^t and d^t are minimum and maximum of all ants at iteration t, and $antlion_j^t$ is a position of j-th selected ant lion at iteration t. The selection of an ant lion is also a stochastic process defined by a roulette wheel selection function. This gives higher chances to fitter ant lions in catching better prey.

Catching of an ant in a pit is simulated through adaptive decrease of search space with latter iterations:

$$c^t = \frac{c^t}{I}, \quad d^t = \frac{d^t}{I}, \quad (9)$$

where I is the factor depending on a ratio of current iteration and the maximum number of iterations.

Repositioning of an ant lion takes place if a fitness of an ant is better than the fitness of a corresponding ant lion:

$$f(ant_i^t) < f(antlion_j^t) \rightarrow antlion_j^t = ant_i^t, \quad (10)$$

and in the same way is an elite ant lion change defined. After defining of an elite ant lion, every next random walk of a prey is defined with an elite ant lion and the selected ant lion taken into consideration:

$$ant_i^t = \frac{R_A^t + R_E^t}{2}, \quad (11)$$

where R_A^t is a random walk of prey around the ant lion selected through roulette wheel selection process, and R_E^t is a random walk of the same prey around the elite ant lion in iteration t. In this way, a common rule in a swarm intelligence approach, called the elitism rule, is applied.

In a simple way, ant lion optimizer (ALO) algorithm can be described as a three-tuple function $ALO(A, B, C)$, that approximates the global optimum for optimization problems. The three functions represent the initialization of population (A), an algorithm manipulation of initial population (B) and the end confirmation of an algorithm (C). These functions are defined as:

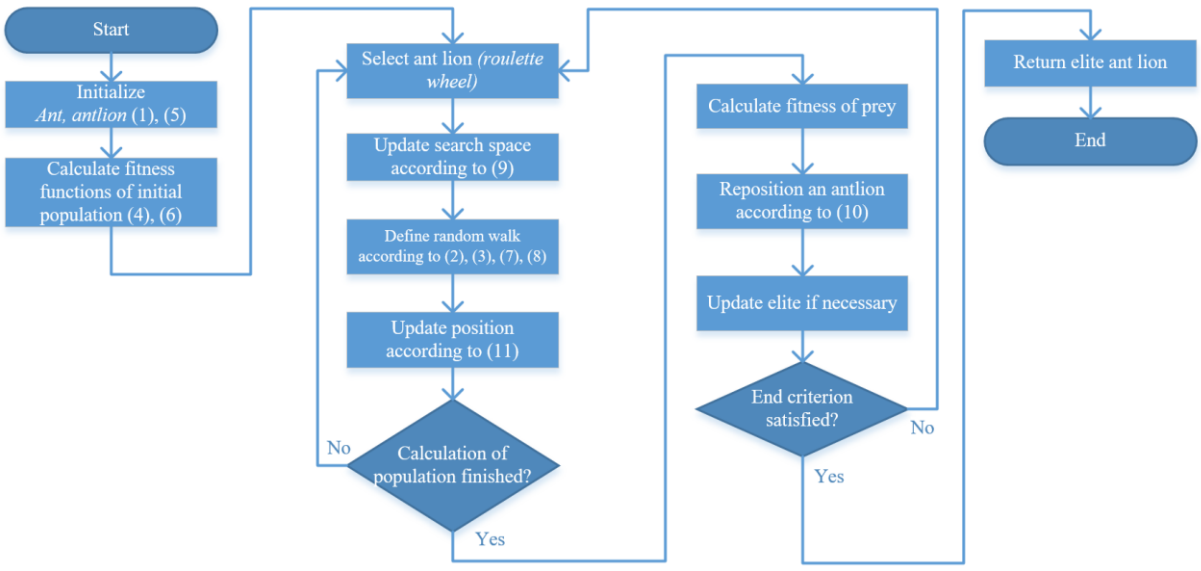

Figure 1. Algorithm flow chart of an Ant Lion Optimizer [4]

$$\emptyset \xrightarrow{A} \{M_{Ant}, M_{OA}, M_{Antlion}, M_{OAL}\},$$
$$\{M_{Ant},\ M_{Antlion}\} \xrightarrow{B} \{M_{Ant}, M_{Antlion}\}, \quad (12)$$
$$\{M_{Ant},\ M_{Antlion}\} \xrightarrow{C} \{true, false\}.$$

III. TESTING MODEL OF A GENERATOR AVR CONTROL WITH PID REGULATOR

Automatic voltage regulator is a control device used for stabilization of voltage levels on generator terminals in power stations. It is a feedback control system that compares output voltage measurement with voltage set point and according to the difference of set point and measured voltage adjusts the excitation voltage of a generator.

The model used for testing is a negative feedback loop control system of a synchronous generator which uses output information and takes the desired terminal voltage value as an input reference. In this feedback loop model exciter with an amplifier, generator and sensor are modeled with their transfer functions as a 1st order PT1 elements, while regulator has a transfer function associated with PID controller. This model is a linearized model with all major constants taken into account, while ignoring saturation and some other nonlinearities. A block diagram of the described model is shown on fig. 2. Amplifier, exciter, generator and sensor transfer functions are:

$$F_A(s) = \frac{V_R(s)}{V_e(s)} = \frac{K_A}{1 + s\tau_A}, \quad (13)$$

$$F_E(s) = \frac{V_F(s)}{V_R(s)} = \frac{K_E}{1 + s\tau_E}, \quad (14)$$

$$F_G(s) = \frac{V_t(s)}{V_F(s)} = \frac{K_G}{1 + s\tau_G}, \quad (15)$$

$$F_R(s) = \frac{V_s(s)}{V_t(s)} = \frac{K_R}{1 + s\tau_R}. \quad (16)$$

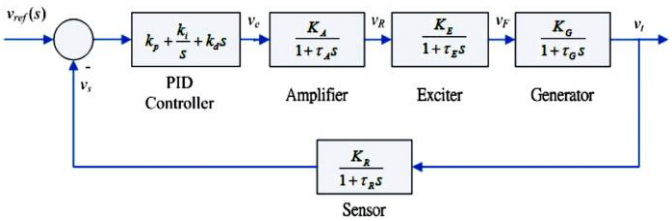

Figure 2. Closed loop model of a generator with AVR

Transfer function parameters used for testing are:

- Amplifier: $K_A = 10, T_A = 0.1\ s$,
- Exciter: $K_E = 1, T_E = 0.4\ s$,
- Generator: $K_G = 0.8, T_G = 2\ s$,
- Sensor: $K_R = 1, T_R = 0.01\ s$.

IV. SIMULATION

Testing of the model was done in MATLAB Simulink®. Tuning of PID controller parameters was done with PSO, ALO, ASO and ABC algorithms. The number of agents (particles, ants/ant lions, members or colony size) was set at 30. Number of iterations is 50. Total number of repeating trials for each algorithm is 5.

A. Initial parameters of algorithms

Initial parameters of PSO algorithm were $c_1 = 1.2$, $c_2 = 0.9$, $w = 1$ for velocity update. ASO initial factors for movement policies are: $\alpha = 0.9$, $\theta = 1$. For ABC, initial condition for number of food sources is equal to half the size of bee colony. Initial setting for ALO includes determination of search space adaptive decrease according to factor I from eq. (9). This ratio is defined as:

$$I = \begin{cases} 1, & i \le \frac{max_iter}{4} \\ 1 + 10^{\frac{i}{max_iter}}, & i > \frac{max_iter}{4} \\ 1 + 10^{\frac{2i}{max_iter}}, & i > \frac{max_iter}{2} \\ 1 + 10^{\frac{3i}{max_iter}}, & i > 0.75 \cdot max_iter \\ 1 + 10^{\frac{4i}{max_iter}}, & i > 0.9 \cdot max_iter \\ 1 + 10^{\frac{5i}{max_iter}}, & i > 0.95 \cdot max_iter \end{cases} \quad (17)$$

B. Objective functions used for testing

Six functions are being used as objective functions which minima are being searched for in optimizations. These include:

- integral of absolute error (IAE):

$$IAE = \int_0^{t_{sim}} |\Delta V_t(t)|\, dt, \quad (18)$$

- integral of squared error (ISE):

$$ISE = \int_0^{t_{sim}} \Delta V_t(t)^2\, dt, \quad (19)$$

- integral of time weighted absolute error (ITAE):

$$ITAE = \int_0^{t_{sim}} t \cdot |\Delta V_t(t)|\, dt, \quad (20)$$

- integral of time weighted squared error (ITSE):

$$ITSE = \int_0^{t_{sim}} t \cdot \Delta V_t(t)^2\, dt, \quad (21)$$

- objective function 1, proposed in [2]

$$F_1 = \alpha_1 \cdot (M_p - E_{ss}) + \alpha_2 \cdot (t_s - t_r), \quad (22)$$

- objective function 2, proposed in [1]

$$F_2 = (1 - e^{-\beta}) \cdot (M_p - E_{ss}) + e^{-\beta} \cdot (t_s - t_r). \quad (23)$$

where $\Delta V_t(t)$ is a difference between current terminal voltage and its steady state value, depending on iteration. M_p is relative maximum overshoot, E_{ss} is the steady state

error, t_r is the rise time and t_s the settling time. Factors α_1, α_2 and β are user defined. If one wants a smaller settling time without importance on overshoot and error indicators, then α_1 should be smaller than α_2 in (22) or β should be smaller than 0.69 in (23), and vice versa. In testing the following factors were used: $\alpha_1 = 10, \alpha_2 = 4, \beta = 0.7$.

C. Algorithm evaluation indicators

Analytic comparison of algorithms is made with several factors for total of 5 trials each. The first three comparison factors are: best fitness solution, mean value of fitness and standard deviation according to mean value:

$$f_{best} = min(f_1, \dots, f_5), \tag{24}$$

$$\mu = \frac{1}{5} \cdot \sum_{i=1}^{5} f_i, \tag{25}$$

$$\sigma = \sqrt{\frac{1}{5} \cdot \sum_{i=1}^{5} (f_i - \mu)^2}, \tag{26}$$

The next four factors are new proposed convergence quality indicators: convergence capability of an algorithm, mean value of convergence capability, best convergence capability and relative capability according to best one out of four algorithms:

$$C_A = \left(\int_{0.2 \cdot max_iter}^{max_iter} C(i) di \right)^{-1}, \tag{27}$$

$$C_{A,mean} = \frac{1}{5} \cdot \sum_{i=1}^{5} C_{A,i}, \tag{28}$$

$$C_{A.best} = max(C_{A,1}, \dots, C_{A,5}), \tag{29}$$

$$C_r = \frac{C_{A,best}}{C_{A,best,alg}} \cdot 100[\%]. \tag{30}$$

PID controller parameters are constrained to limits as follows:

$$\begin{aligned} 0.2 \le K_P \le 2, \\ 0.2 \le K_I \le 2, \\ 0.2 \le K_D \le 2. \end{aligned} \tag{31}$$

D. Simulation results

Results of simulations are summarized in table I. Convergence curves for functions F_1 and F_2 are shown on figures 3 and 4, respectively. Also, voltage response graphs for best obtained function are shown on figures 5 and 6.

While using standard objective functions (integral errors), all algorithms behave in a similar manner, reaching near global optimum. However, when algorithms use different functions, PSO shows poor convergence with being stuck in a local minimum. While ABC and ASO show fine convergence quality, they do not produce the best solution. ALO, on the other side, produces the best solution, and great convergence. ALO's adaptive limiting of search space proves a constant tendency to converge to better results. While in some cases this may show slow convergence, it reaches the better solution with more iterations making an algorithm more appropriate for fine tuning.

TABLE I. SIMULATION RESULTS: QUALITY INDICATORS (WITH HIGHLIGHTED BEST RESULTS) AND PID CONTROLLER PARAMETERS

Obj. function	*Algorithm*	f_{best} (9)	μ (10)	σ (11)	$C_{A.best}$ (14)	$C_{A,mean}$ (13)	C_r (15)	K_P	K_I	K_D
IAE (18)	PSO	3.6442	3.6549	0.0147	0.0046	0.0048	86.5399	2	0.822	0.7175
	ALO	3.6442	3.6442	0.0001	0.0054	0.0052	100	2	0.822	0.7173
	ASO	3.683	4.6557	0.5901	0.0033	0.004	61.8812	2	0.8213	0.7118
	ABC	3.6443	3.6523	0.0136	0.0045	0.0048	84.0638	2	0.8221	0.7168
ISE (19)	PSO	19.1194	19.1254	0.004	0.0011	0.0011	100	2	0.8284	0.92
	ALO	19.1176	19.1176	0	0.0011	0.0011	99.2021	2	0.8328	0.9297
	ASO	19.1188	19.1902	0.1262	0.001	0.001	94.5825	2	0.8277	0.929
	ABC	19.1176	19.1185	0.0017	0.0011	0.0011	99.5133	2	0.8327	0.9298
ITAE (20)	PSO	76.6906	76.6993	0.0122	0.0003	0.0003	100	2	0.9862	1.2849
	ALO	76.6844	76.6846	0.0003	0.0003	0.0003	99.5397	2	0.9879	1.2974
	ASO	76.6855	78.5861	3.7612	0.0002	0.0003	89.0525	2	0.9841	1.2937
	ABC	76.6844	76.6844	0	0.0003	0.0003	99.6881	2	0.9878	1.2974
ITSE (21)	PSO	827.2033	827.2035	0.0005	2.47E-05	2.46E-05	100	2	1.9854	2
	ALO	827.2033	827.2033	0	2.46E-05	2.47E-05	99.9302	2	1.9854	2
	ASO	827.2033	827.2033	0	2.46E-05	2.46E-05	99.8456	2	1.9854	2
	ABC	827.2033	827.2033	0	2.46E-05	2.46E-05	99.7406	2	1.9854	2
F_1 (22)	PSO	4.4482	4.896	0.2417	0.0042	0.0037	100	0.7757	0.2959	0.237
	ALO	0.2247	2.8398	1.8902	0.0036	0.0057	86.6188	1.0934	0.3597	0.3695
	ASO	3.0161	4.6032	0.8456	0.0029	0.004	68.7389	1.5473	0.7659	0.8584
	ABC	1.8909	4.0547	1.0954	0.0033	0.0043	78.3463	1.0107	0.3557	0.3386
F_2 (23)	PSO	0.1980	0.1201	0.0398	0.144	0.1181	58.09	1.5375	0.8638	0.6793
	ALO	0.0754	0.0947	0.0198	0.2237	0.1703	90.2639	1.3965	0.7639	0.6216
	ASO	0.0756	0.0772	0.0016	0.2479	0.2068	100	1.3856	0.7847	0.619
	ABC	0.0788	0.1198	0.0492	0.2164	0.1611	87.2901	1.3964	0.6346	0.5769

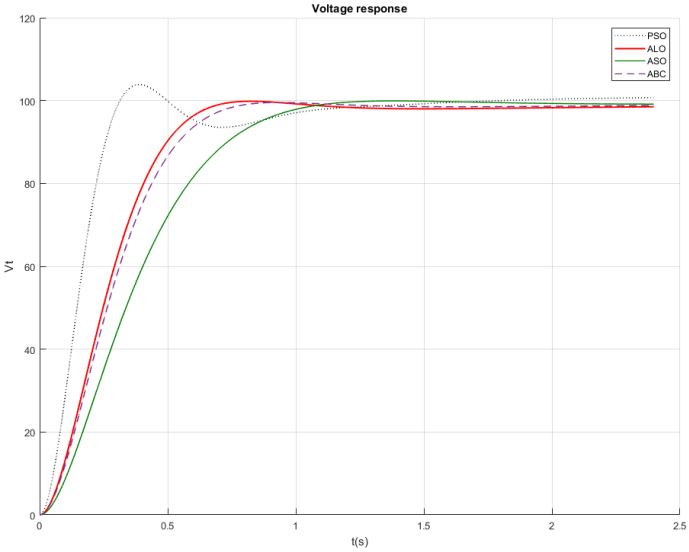

Figure 3. Voltage responses for objective function F_1

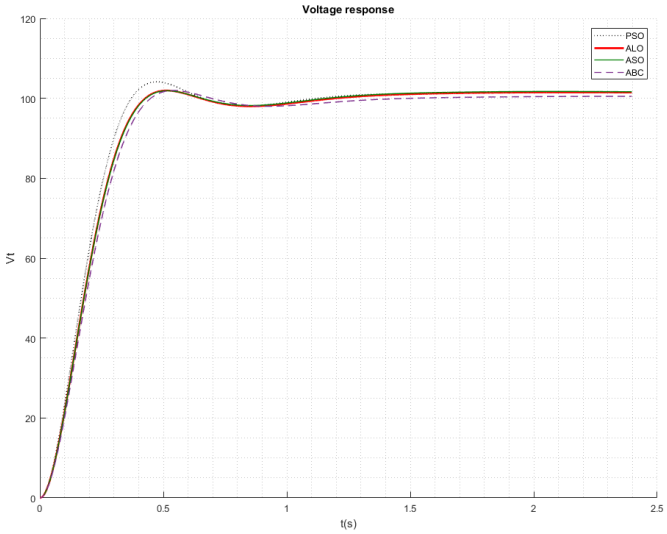

Figure 4. Voltage responses for objective function F_2

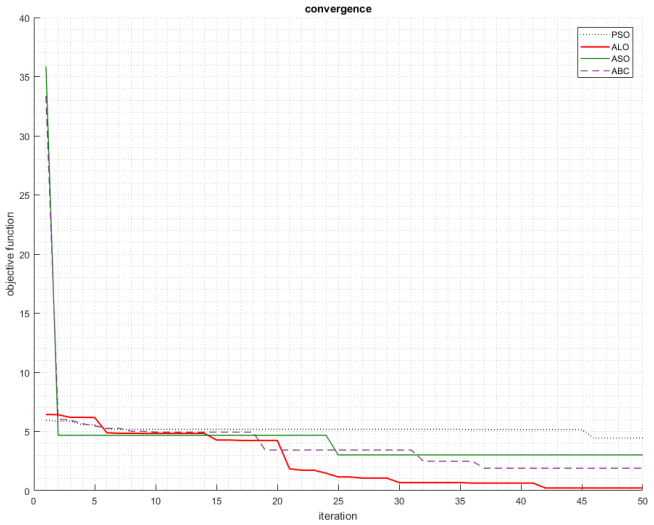

Figure 5. Convergence curves for objective function F_1

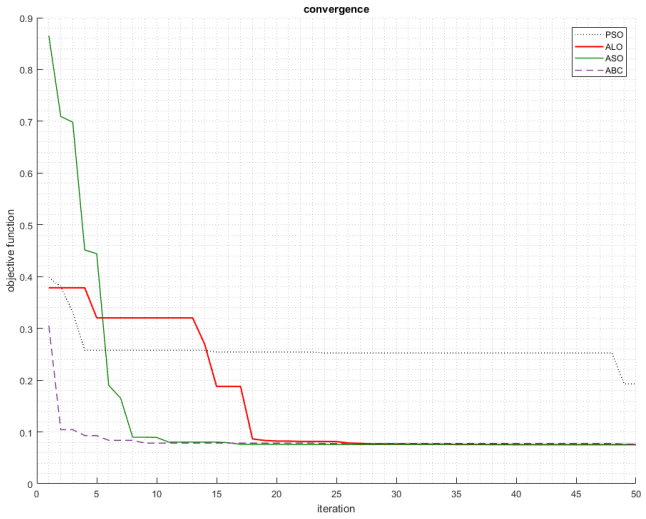

Figure 6. Convergence curves for objective function F_2

V. CONCLUSION

In this paper a novel algorithm called ant lion optimizer was tested by simulation of a AVR regulator in a generator loop control model. A comparison has been made with three other swarm intelligence algorithms. Four standard objective functions and two previously proposed time domain quality objective functions were used for comparison. In majority of the cases ALO was the best choice, while in others it proved to be very close to the best solution.

Analytical review regarding standard (best solution) and new proposed (convergence) algorithm quality indicators concludes the ALO as the best approach out of four tested swarm intelligence optimizers for PID controller tuning in a system with AVR regulator.

Suggestion for further testing includes testing with objective function containing frequency domain quality indication such as stability margins, or even a multi-objective approach with time domain and frequency domain objective functions, with Pareto optimal set of solutions.

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CT Image Registration in Acute Stroke Monitoring

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***Abstract* - We present a new system based on tracking the temporal evolution of stroke lesions using an image registration technique on CT exams of the patient's brain. The system is able to compare past CT exams with the most recent one related to stroke event in order to evaluate past lesions which are not related to stroke. Then, it can compare recent CT exams related to the current stroke for assessing the evolution of the lesion over time. A new similarity measure is also introduced for the comparison of the source and target images during image registration. It will result in a cheaper, faster and more accessible evaluation of the acute phase of the stroke overcoming the current limitations of the proposed systems in the state-of-the-art.**

Keywords - CT exam; image registration; stroke; similarity measure; pattern recognition

I. INTRODUCTION

Cardiovascular diseases (CVD) are today the main cause of death in developed countries (Europe and USA) and in some developing ones. According to World Health Organization (WHO), on 56.4 milions of deaths worldwide during 2015, about 15 milions were directly caused by CVD whose stroke represents about 6 milions. Fig. 1 shows the distribution of the main death causes worldwide during 2015. It is worth noting that stroke is at second position.

In Croatia, the annual mortality rate for stroke reached 197.4 per 100'000 people. Fig. 2 shows the trend of annual mortality rate over age in Croatia during 2013. The deadliness of stroke exhibited the lowest value for male subjects of 5-9 years old and rapidly increased with age. In 2013, the highest peak was reached at 75-79 years range with 2,559.7 deaths per 100,000 men and 2,424.3 per 100,000 women. It is worth noting that male subjects are more exposed to death risk for stroke than female ones.

Consequently, in Europe as well as in the rest of the world the stroke has represented and still represents a serious problem which needs to be taken into high consideration. For this reason, it is of great importance to aim resources in this direction in terms of research and development.

The general approach to stroke requires an immediate assistance in emergency units located in hospitals where the first medical aids are applied, including a first medical examination and other specific exams. After the hyperacute phase, the patient is moved to a stroke unit (if the gravity level is not too low or high) where further advanced aids are performed from an internal medicine point of view to neurological and cardiological ones. In the entire phase of the patient management, the role of medical imaging is essential to support the physician during all the steps of diagnosis and treatement decisions. During the days after the event (acute phase), it is really important to monitor the evolution of patient's conditions. It can be successfully accomplished by following the eventual evolution of encephalic lesions or the appearance of new ones using techniques of medical imaging.

A. Computed Tomography imaging

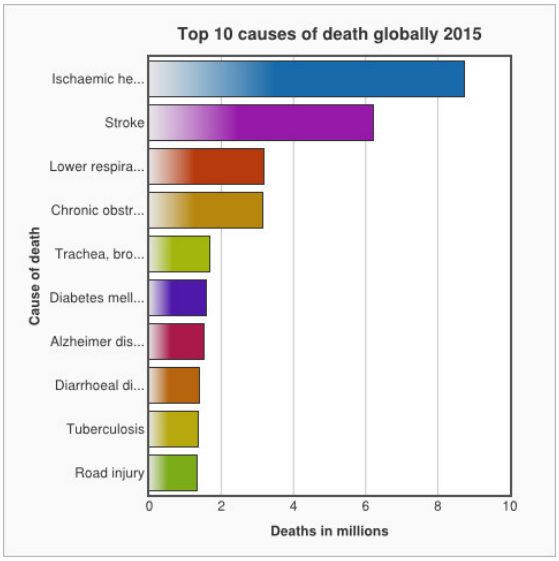

Figure 1. Histogram of the top 10 causes of death worldwide in 2015. Stroke is the second one in the order

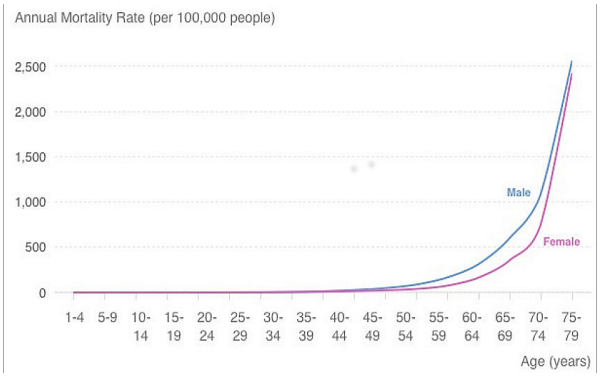

Figure 2. Annual mortality rate in Croatia during 2013

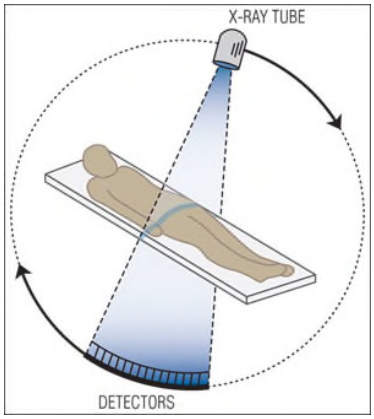

Figure 3. CT imaging procedure: x-ray source and detectors

Computed Tomography (CT) imaging is a type of medical imaging which generates a 3D view of internal body parts using x-ray and computer-aided tomographic imaging methods [1]. In particular, the patient is exposed to an x-rays beam. The projected image is captured on a semicircular x-ray detector. The patient is positioned between the x-ray source and the detector. Each detected image corresponds to an x-ray projection of a transverse slice of the body part. In order to generate the CT exam, the x-ray source and detector are rotated around the patient, and multiple images are generated and stored. Given an image depicting a single slice, each pixel represents the relative radio density of the patient along the line connecting the x-ray source to the pixel position. Fig. 3 shows a simplified procedure of capturing an image by a digital x-ray detector.

CT imaging is usually one of the most important and first exams which are generated for stroke evaluation. It is particularly useful in the hyperacute stroke phase in the emergency room [2]. In fact, a non contrast encephalic CT exam is essential for capturing the early signs of stroke, and for excluding intracerebral hemorrhage and lesions which could be mistaken for an acute ischemic stroke [3]. Also, a CT angiogram is particularly useful for monitoring the state of the blood vessels in order to identify possible occlusions, which supports the stroke diagnosis. In particular, it can be adopted for capturing eventual occlusions of the extracranical carotid arteries or even eventual occlusions of the blood vessels in the brain. Fig. 4 shows a brain CT image with stroke (see (a)), and a brain CT angiography image with occluded artery (see (b)).

B. Related Work

In the literature, monitoring the temporal evolution of the stroke is still poorly explored and captured using image registration techniques applied on medical imaging. This is a method of computer vision finalized to compare 2D or 3D images by mapping specific coordinates in a space of an image to the corresponding ones in another space of another image in order to define an alignment. In particular, the actually proposed image registration techniques for stroke analysis are used on MR (magnetic resonance) images and on CT angiography images for the study of the carotid state. In the context of MR imaging, Ref. [4] analysed the impact of nonlinear image registration in more accurately identifying the infarct on serial MR images captured at different time points than rigid body registration methods. Also, Ref. [5] introduced a robust method of stroke image registration which registered the ischemic lesion on follow-up MRI with the first generated MRI. Dalca et al. [6] proposed a new patch-based non-rigid image registration method of brain images which compared 3D patches in order to compute the similarity. It was tested on clinical MR images of stroke patients. Aganj and Fischl [7] introduced a noninformation-theoretic image registration method applied on MR images which used the error of segmenting both images with a single segmentation as the registration cost function. Crum et al. [8] proposed an affine registration method representing the MR image population as a rooted-tree chain graph. Edges of the graph were weighted according to a distance function. The nearest neighbour images in the graph were first registered. On the contrary, the images more distant by one edge in the graph were registered by transformation composition. Finally, Ref. [9] introduced an image processing system which included a phase of registration of brain MR images captured in different time points for the identification of the areas affected by the stroke. In the context of the CT angiogram, Ref. [10] proposed a pre-processing step for CT stroke diagnosis based on 3D image registration of dynamic CT exams and CT angiograms. Also, Ref. [11] introduced an image registration method for registering multi modal (CT or MR) brain exams and carotid arteries from ascending aorta to brain angiograms with multiple focus.

There are different main limitations in the aforementioned methods of the state-of-the-art:

1. the high costs related to MR imaging,
2. the low availability in different contexts of MR approaches,
3. higher times for MR image acquisition, and

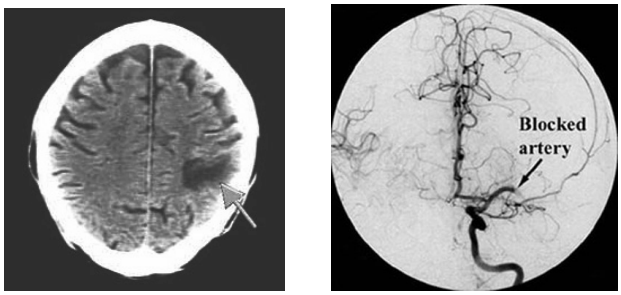

Figure 4. CT image samples: (a) brain CT image with stroke (green arrow on the right), and (b) CT angiography image with blocked artery

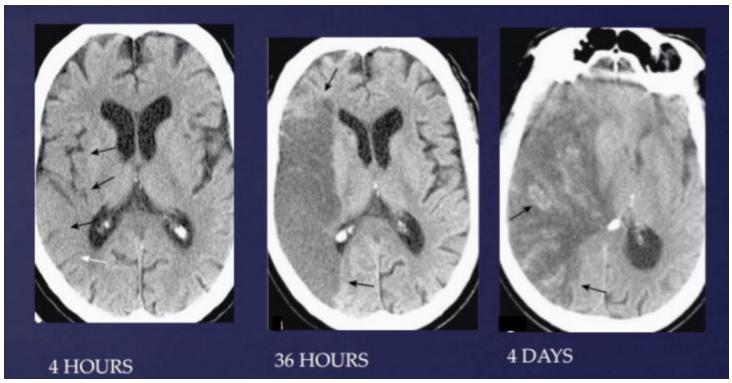

Figure 5. Progression of stroke at various time references on CT scans [12]: Radiology & Imaging, Saveetha University, Saveetha Medical College Hospital - Chennai/IN

4. the acute phase temporal monitoring of the stroke is rarely in the focus.

The paper is organised as follows. Section II describes our contribution and how it overcomes the current limitations in the state-of-the-art. Section III presents the proposed system, including the image registration method, the adopted similarity measure, and the image fusion method. Section IV discusses the expected results and benefits from the system. Finally, Section V concludes the paper and outlines future work directions.

II. Our Contribution

In this context, we propose a new automatic system that applies image registration techniques and subsequent image fusion to sequential encephalic CT exams in order to monitor the radiological patterns variation and determine the patient's situation step by step during the acute phase of the stroke. This will help the physician with the decision making process for a faster and more integrated management of the clinical state. In a first step, the system scans for patient's personal infomation in the hospital radiological database to identify eventual past CT exams which defines "source images" to compare with the pathological as recent as possible one. This is finalised to take over eventual past lesions which are not related to current stroke. In a second step, the system only compares the most recent CT scans of the current stroke in order to evaluate the variation, over time, of the encephalic lesions. The system employs a new similarity measure for the comparison of two CT exams during the registration process. This system will result in a cheaper, faster and more accessible evaluation and monitoring of patient's state during the acute phase of the stroke. Fig. 5 shows how the evolution of a stroke at different time points is visible on CT scans.

III. System Description

The proposed system consists in two main steps, which are depicted in Fig. 6. Initially, it takes the patient's information and checks for the presence into the radiological database. If data is found, the first step starts. In particular, CT exams of the patient are filtered and only brain CT ones are offered to the physician to be selected. The selection of a specific exam depends on the circumstances they were executed (diagnosis, date). After the exam is selected, it is compared with the most recent available brain CT exam related to stroke using image registration and image fusion. After the first step or if brain CT exams of the patient are not found in the database, the second step starts. In particular, the system takes the most recent brain CT exams related to the current stroke and temporally sorts them. After that, the system gives the possibility to select two exams to compare for assessing the stroke evolution during the acute phase using image registration and fusion.

A. Image registration

We employ an intensity-based image registration which calculates a transformation between two CT exams using the voxel values alone [13]. The aim of the registration is to compute a transformation T such that the selected similarity function S is maximised between the source CT exam A and a transformation of the target CT exam $T(B)$. The similarity measure is computed from the voxel values. Accordingly, the image registration problem is as follows:

$$T = \arg\max_{T \in \mathrm{T}} S(A, T(B)), \quad (1)$$

where T is a class of allowed transformations. Hence, the image registration is considered as an optimisation problem, where the target CT exam B is iteratively mapped to $T(B)$ by progressively estimating the transformation T. For a faster approach, we employ the class of global and rigid transformations, which are very used in the medical context with good approximation in most cases. They can include translation, rotation, scaling, affine transformation, and perspective projections, such that they preserve distances, lines and angles. The rigid transformation T is represented as [14]:

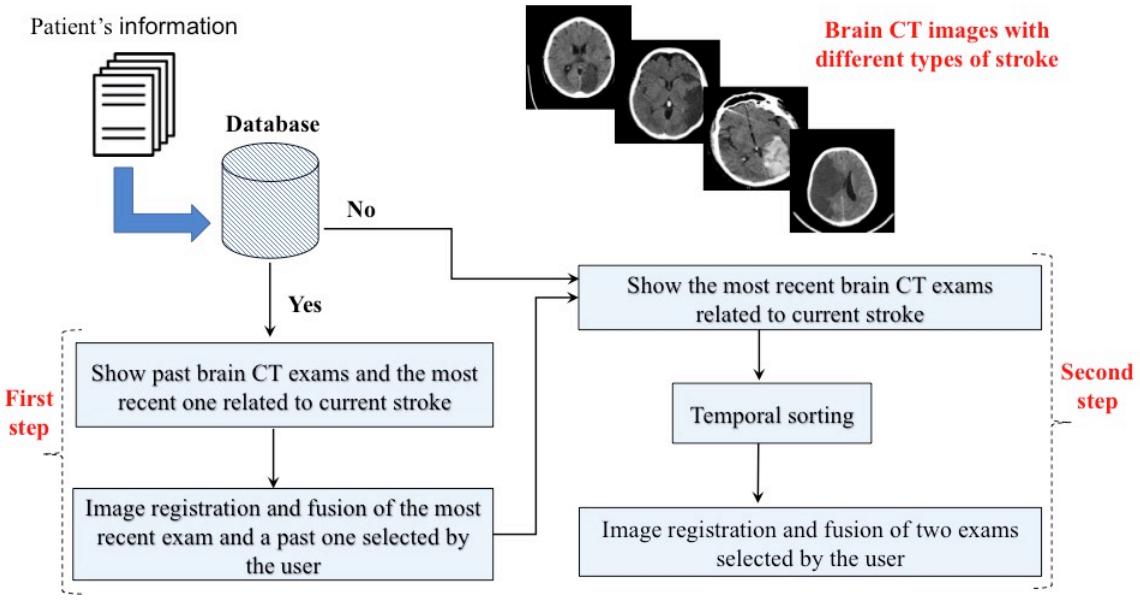

Figure 6. Overview of the proposed system

$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} w_{11} & w_{12} & w_{13} \\ w_{21} & w_{22} & w_{23} \\ w_{31} & w_{32} & w_{33} \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} \quad (2)$$

where w_{ij}, i,j=1,...,3 are the parameters of the transformation *T*.

Accordingly, we are searching for the parameters of the transformation *T* which maximise the similarity. In order to solve the optimisation problem, the similarity function is evaluated for multiple parameters.

Usually, only a subset of voxels is selected for the registration in order to speed-up the process. It corresponds to a sort of sampling of the CT exam in order to speed-up the registration. We do not provide any prior sampling of the CT exams. On the contrary, we introduce a new idea which embeds the sampling process inside the similarity evaluation. It automatically omits some voxels at regular spatial intervals from the similarity computation.

B. Approximate Average Common Submatrix

We compute the similarity between CT exams by using a new method that compares voxel patches where a portion of voxels is omitted at regular intervals. It represents an extension in 3D of the state-of-the-art *Approximate Average Common Submatrix* (A-ACSM) similarity measure [15], [16] used for comparing color or gray level 2D images. For an easier understanding of the approach, we describe the baseline A-ACSM procedure in 2D. Then, we explain the introduced modifications in 3D to the baseline method.

The advantage of A-ACSM is that it does not need to extract complex descriptors from the images to be used for the comparison. On the contrary, an image is considered as a matrix, and the similarity is evaluated by measuring the average area of the largest sub-matrices which the two images have in common. The principle underlying this evaluation is that two images can be considered as similar if they share large patches representing image patterns. Two patches are considered as identical if they match in a portion of the pixels which are extracted at regular intervals along the rows and columns of the patches. Hence, the measure is an easy match between a portion of the pixels. This concept introduces an approximation, which is based on the "naive" consideration that two images do not need to exactly match in the intensity of every pixel to be considered as similar. This approximation makes the similarity measure more robust to noise, i.e., small variations in the pixels' intensity due to errors in image generation, and considerably reduces its execution time

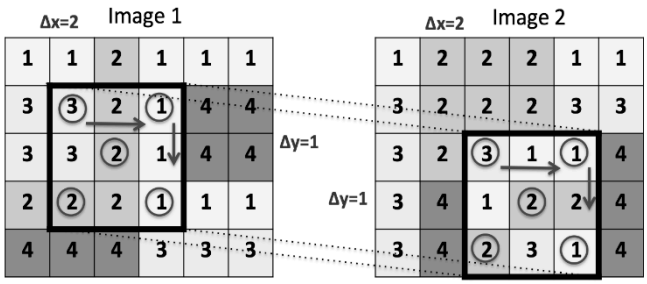

Figure 7. A demonstration sample of match between two patches belonging to images 1 and 2. Each image has four gray levels which are also numbered from 1 to 4. An interval of Δx=2 and Δy=1 is set respectively along the columns and rows of the patches. Accordingly, the match is only verified between the elements in the circles. The elements are selected as in a chessboard. In this case, the two image patches perfectly match because all the elements in the circles correspond to one another.

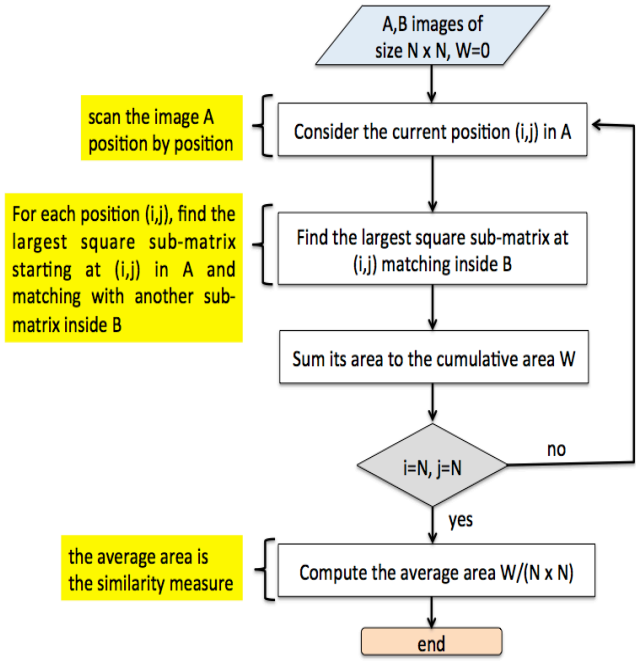

Figure 8. Flowchart of the A-ACSM algorithm

when it is applied on large images, because a portion of the pixels does not need to be checked. Fig. 7 shows a sample of match between two image patches with an interval of two along the columns and one along the rows of the patches. Fig. 8 depicts the algorithm for computing the A-ACSM similarity measure. Fig. 9 shows how to find the largest square sub-matrix at a sample position (5,3) of the first image.

C. 3D Approximate Average Common Submatrix

The extension of A-ACSM in 3D considers the input CT exams to be compared as parallelepipeds. Consequently, the similarity between two CT exams C1 and C2 is computed as the average volume of the largest sub-cubes which the two CT exams have in common. Two sub-cubes are considered as identical if they match in a portion of the voxels which are extracted at regular intervals along the x, y and z axes of the sub-cubes. We also introduce a further modification in the baseline algorithm depicted in Fig. 8 (see step 2). In particular, for each position (i,j,k), we search for the largest sub-cube in C1 starting from (i,j,k) and matching in a neighbourhood of given volume v from position (i,j,k) inside C2, where v is an input parameter. Hence, we verify the match only in a restricted neighborhood inside C2. It increases the sensitivity of the similarity measure to rigid transformations such as translation and rotation. Also, it provides the matching of corresponding or spatially contiguous CT scans in the two CT exams. Finally, it improves the time complexity of the procedure: the largest common sub-cube only needs to be searched in a restricted volume of the second CT exam, and only a subset of voxels in the sub-cube needs to be compared. At the end, we modify the similarity computation by introducing a normalisation step which divides the similarity value by the maximum, for having a range between 0 (no match) and 1 (maximum match). It simplifies the maximisation process of the similarity function during the registration.

D. Image fusion

After the registration process, the source CT exam and transformed target CT exam are fused into a single output representation, which keeps a higher quality information derived from the input exams. In particular, we use a simple pixel-based fusion which includes the typical arithmetic operator of subtraction, obtaining good results in some contexts of medical imaging [14]. It is able to easily visualize the eventual changes occurred over time in the different CT exams.

In particular, the method employs the subtraction operator [17] on the source and transformed target CT exams in order to determine a signed difference D as follows [18]:

$$D(x,y,z) = A(x,y,z) - \overline{B}(x,y,z), \tag{3}$$

where $\overline{B} = T(B)$ derives from the image registration process. Then, D is thresholded for generating a change map M as follows:

$$M(x,y,z) = \begin{cases} 1 & if\ |D(x,y,z)| > t \\ 0 & otherwise \end{cases}, \tag{4}$$

where t is the threshold parameter. Finally, the change map M is visualised by the system together with the aligned CT exams.

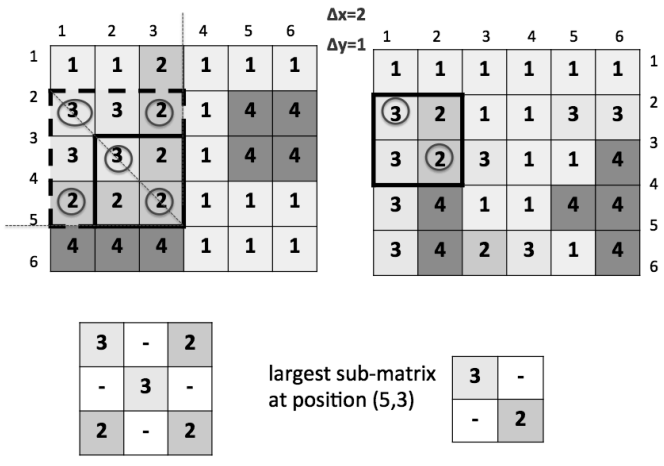

Figure 9. The largest square sub-matrix at position (5,3) of the first image. All the sub-matrices of different size along the main diagonal at (5,3) are considered to match inside the second image. In this case, the sub-matrix of size 3 has no match inside the second image. Hence, the sub-matrix of size 2 is considered. Because it has a correspondence at position (3,2) in the second image, it is the largest square sub-matrix at position (5,3).

TABLE I. EXPECTED RESULTS AND BENEFITS DERIVED FROM THE PROPOSED SYSTEM

Expected result	*Benefit*
Customised time-based monitoring of the stroke	Analysis of the patient's state according to the needs of the physician
New system in the state-of-the-art	High support for industrial partners as well as hospital structures
Robust to noise similarity measure for image registration	Higher accuracy in registering CT exams of stroke

IV. EXPECTED RESULTS AND BENEFITS

From an experimental point of view, the system is expected to be more accurate in registering CT exams of stroke than the current state-of-the-art systems. This is mainly due to the use of a common submatrix-based similarity measure, which revealed to overcome the performances of other distance or similarity measures on different types of images. These same measures are currently adopted for CT exam registration (e.g. entropy-based measures, like Mutual Information) [19]. Also, because of its robustness to noise due to the embedded sampling strategy, 3D A-ACSM is expected to be a reliable candidate measure for comparing CT exams in image registration.

Differently from the previous methods, the time-based monitoring of the stroke is here in the focus in a period of time which can be established by the physician by selecting the CT exams to compare. It will provide a more complete and customised analysis of the patient's state according to the needs of the physician.

Finally, the proposed system in its current form represents a novelty in the state-of-the-art and is expected to be primarily of high utility and support for industrial partners as well as hospital structures in Croatia and in the rest of the world. Table I summarises the main discussed expected results and corresponding benefits derived from the system.

V. CONCLUSION AND FUTURE WORK

This paper introduced a new system for the temporal monitoring of the stroke using an image registration method followed by image fusion of CT exams. A new similarity measure was also proposed for the comparison of CT exams during the registration phase. It will provide important benefits in terms of lower costs, faster and customised support in the diagnosis process, and higher accuracy and robustness in tracking the manifestation and evolution of the stroke.

Future work will provide results of evaluation and testing of the system.

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Analyzing the Influence of Player Tracking Statistics on Winning Basketball Teams

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Abstract - **Basketball player tracking and hustle statistics became available since 2013-2014 season from National Basketball Association (NBA), USA. These statistics provided us with more detailed information about the played games. In this paper, we analyze statistically significant differences in these recent statistical categories between winning and losing teams. The main goal is to identify the most significant differences and thus obtain new insight about what it usually may take to be a winner. The analysis is done on three different scales: marking a winner in each game as a winning team, marking teams with 50 or more wins at the end of the season as a winning team, and marking teams with 50 or more wins in a season, but considering only their winning games, as a winning team. The results of the analysis reveal a few categories that are significantly different between the winning and the losing teams, such as: the number of uncontested shots made, the number of assists and secondary assists, and the number of defensive rebound chances. Based on these results, we propose the effective passing ratio, a novel statistical category, which also demonstrates large differences between winning and losing teams.**

Keywords - player tracking statistics, hustle statistics, statistical analysis, correlation, winning team, basketball

I. INTRODUCTION

Basketball is a fast and dynamic game with many different kinds of events that are happening on the court very frequently. Every possession of the ball starts with a defensive rebound, steal or inbound pass, ends with shot, free throw or a turnover [1]. During ball possession, many different sequences of events can happen, including empty sequence, because right after the start of a possession the end of the possession may come. Although a single attack in basketball is limited to 24 seconds, a possession of the ball can last a minute or more. When a team misses a shot and grabs offensive rebound (ball retrieved after a missed field goal or free throw), a new possession is not started, only a new play is started. Therefore, a possession of the ball is not limited to 24 seconds [1]. Most of the events are happening around the ball, but some events like fouls or screens can happen away from the ball, anywhere on the court. Collecting complete statistics about all events in a game is therefore a challenging task.

National Basketball Association (NBA) is, incontestably, the best basketball league in the world, both on and off the court. On the court, we find many of the best players in the world. They prove their abilities every four year at the Olympic games, by winning a gold medal in the majority of cases. Off the court, there are specialized personnel who try to improve each segment of the game, e.g. doctors, psychologists, basketball experts and scouts. One of the most interesting facts is that the teams in the league, and the league itself, have expert teams for data analysis that provide them with valuable information about every segment of the game. There are a few teams who make all of their decisions exclusively based on advanced analysis of statistics. Few years ago, this part of organization became even more important, because NBA invested into a computer vision system that collects position of every player and the ball, 25 frames per second [2]. This system made data collection easier and more detailed. Many new statistical categories started to be measured and many of the existing categories were improved.

The goal of this paper is to analyze some of these new statistical categories and their relationship between the winning and the losing basketball teams. Categories that will be analyzed are grouped in the box score (structured summary of all statistics and results of each game) player tracking statistics and box score hustle statistics. Many interesting statistical categories are included in these groups. The aim is to get answers to questions like: “Is more passes always better?”, “Is more running better?”, and “Which one is more important, contested or uncontested shots?”. Statistics that measure defensive events were traditionally neglected compared to offensive statistics [3]. Statistics that are going to be analyzed in our paper contain several defensive types of statistics and we are going to identify the important ones. We intend to find some interesting correlations between these statistical categories, and based on the correlations, try to identify a winning formula, if there is one.

II. SIMILAR PAPERS

Many papers were written based on this new technology of collecting data. Most of the papers rely on positions of each player and the ball in each moment and then build interesting research around it. Franks et al. [3] used a combination of player tracking data and statistics to create a new model for evaluation of defensive plays. Lucey et al. [5] analyzed the information about position of all players 3 seconds before each 3-point shot was taken and tried to determine which features lead to an open 3-point shot.

Goldsberry [6] used the data to rank the best shooters in the NBA using "Court Vision", and, more recently, used it to rank individual defenders [7]. Wiens et al. [8] took a close look at situations in which teams should go for an offensive rebound.

These papers are interesting and they rely on position of each player in each moment, not on pure play-by-play statistics. There are far less papers that analyze only the new statistical categories, without information about players' positions. For example, Sampaio et al. [2] analyze the difference between all-star and non all-star players (each year fans and coaches pick the best individuals from each conference and then these two conference teams play against each other in an all-star game), based on pure play-by-play player tracking statistics. Before that, in 2003, they analyzed the statistics from Portuguese basketball league to determine the difference between winning and losing teams in different types of games [9].

III. DATA SET

The data that is going to be analyzed is freely available from the official web page of NBA [4]. We built a web scraper that got us all the needed information. Four games were removed from the data set, because there were no data recorded for player tracking statistics in these four games. Altogether, the data set consists of 1226 games from the 2016/2017 regular season. We analyze only team statistics, not individually for each player. Although statistics are measured per player, team level statistics are also calculated and freely available. We assume that team level statistics are calculated by aggregating player level statistics for categories for which this makes sense, while categories with percentages and averages were then calculated from the aggregated values. Below are explanations of every statistical category that is in our data set.

Player tracking statistics:

- DIST - Distance run (in miles)
- SPD - Average speed
- TCHS - Touches with the ball
- PASS - Passes
- AST - Assists
- SAST - A player is awarded a secondary assist if they passed the ball to a player who recorded an assist within 1 second and without dribbling
- DFGM - Field goals made by the opponent while the player or team was defending the rim
- DFGA - Field goals attempted by the opponent while the player or team was defending the rim
- DFG% - Percentage of field goal attempts the opponent makes while the player or team was defending the rim
- ORBC - Offensive rebound chances
- DRBC - Defensive rebound chances
- RBC - Rebound chances
- FG% - Field goal percentage
- CFGM - Contested field goals made
- CFGA - Contested field goals attempted
- CFG% - Contested field goal percentage
- UFGM - Uncontested field goals made
- UFGA - Uncontested field goals attempted
- UFG% - Uncontested field goal percentage
- FTAST - A player is awarded a free throw assist if they passed the ball to a player who drew a shooting foul within one dribble of receiving the pass

Hustle statistics:

- Screen Assists - The number of times an offensive player or team sets a screen for a teammate that directly leads to a made field goal by that teammate
- Deflections - The number of times a defensive player or team gets his hand on the ball on a non-shot attempt
- Loose Balls Recovered - The number of times a player or team gains sole possession of a live ball that is not in the control of either team
- Charges Drawn - The number of times a defensive player or team draws a charge (offensive foul)
- Contested 2PT Shots - The number of times a defensive player or team closes out and raises a hand to contest a 2 point shot prior to its release
- Contested 3PT Shots - The number of times a defensive player or team closes out and raises a hand to contest a 3 point shot prior to its release
- Contested Shots - The number of times a defensive player or team closes out and raises a hand to contest a shot prior to its release

Explanations of the categories are available on the official NBA stats API [4]. There are a few glossaries for all the categories, with minor difference between them (e.g. SAST in box score for player tracking glossary represents secondary assists, while in main help/glossary section it represents screen assists). To avoid any confusion, in this paper we will use the glossary as written above.

IV. EXPERIMENTS DESIGN

Since we are analyzing the relationship of the statistical categories between the winning and the losing teams, we will split the data set into several different separations. The first separation will compare statistics for all winning teams in each game and statistics for all losing teams in each

Table 1. Most significant results from first separation of data set.

Statistical category	Mean		Standard deviation		α	p-value
	Winning team	Losing team	Winning team	Losing team		
FG%	0.48	0.43	0.049	0.046	3.7E-4	1.79E-114
UFG%	0.46	0.40	0.074	0.073	3.7E-4	3.24E-67
AST	24.27	20.97	5.26	4.65	3.7E-4	2.72E-54
UFGM	18.52	16.04	4.06	3.88	3.7E-4	1.31E-49
CFG%	0.50	0.46	0.073	0.07	3.7E-4	2.10E-49
DRBC	59.51	53.99	9.04	9.61	3.7E-4	4.94E-48
SAST	5.90	4.89	2.79	2.33	3.7E-4	3.83E-19
CFGM	22.44	20.98	4.43	4.31	3.7E-4	2.02E-15
SCREEN ASSISTS	10.49	9.42	4.09	3.81	3.7E-4	1.99E-11
FTAST	2.24	1.98	1.55	1.43	3.7E-4	3.52E-05

Table 2. Most significant results from second separation of data set.

Statistical category	Mean		Standard deviation		α	p-value
	Winning team	Losing team	Winning team	Losing team		
SCREEN ASSISTS	10.89	9.17	4.08	3.60	3.7E-4	6.25E-17
FG%	0.47	0.45	0.05	0.05	3.7E-4	1.99E-14
UFG%	0.45	0.42	0.08	0.07	3.7E-4	5.11E-13
UFGM	18.36	17.04	4.33	3.93	3.7E-4	1.46E-09
AST	23.61	21.94	5.88	4.67	3.7E-4	2.28E-09
SAST	5.89	5.09	2.97	2.42	3.7E-4	3.89E-07
CFG%	0.49	0.47	0.07	0.07	3.7E-4	2.99E-05
DIST	16.59	16.92	0.72	0.73	3.7E-4	1.27E-22
TCHS	417.89	430.12	35.02	35.08	3.7E-4	4.29E-10
PASS	296.76	307.55	33.35	31.49	3.7E-4	7.51E-09

Table 3. Most significant results from third separation of data set.

Statistical category	Mean		Standard deviation		α	p-value
	Winning team	Losing team	Winning team	Losing team		
FG%	0.49	0.44	0.05	0.05	3.7E-4	6.66E-56
UFG%	0.48	0.41	0.08	0.07	3.7E-4	8.43E-38
AST	25.13	21.12	5.79	4.49	3.7E-4	2.52E-30
UFGM	19.47	16.43	4.13	3.84	3.7E-4	1.44E-30
CFG%	0.50	0.46	0.07	0.07	3.7E-4	9.08E-23
SCREEN ASSISTS	11.22	8.93	4.18	3.51	3.7E-4	8.98E-19
DRBC	58.79	53.81	8.43	9.42	3.7E-4	3.40E-19
SAST	6.42	4.89	3.08	2.37	3.7E-4	2.92E-16
DIST	16.63	16.94	0.74	0.74	3.7E-4	2.16E-14
DFG%	0.52	0.57	0.12	0.12	3.7E-4	1.31E-11
PASS	298.97	308.82	33.12	32.17	3.7E-4	2.70E-05

game. The second separation will be done by marking teams with 50 or more wins at the end of a season as a winning team, and on the other side, marking teams with 35 or less wins in a season as a losing team. This gives us groups that are comparable, because of a similar number of entities in each group. The third separation is the same as the second one, but this time, we are considering only the winning games for teams with 50 or more wins and only losing games for teams with 35 wins or less.

For every separation we make, we calculate the mean and standard deviation of each category. For establishing whether the differences between the distributions in each separation are relevant, we use the two-tailed Mann-Whitney U Test. This test is appropriate for establishing difference in means between two categories, regardless of the categories' data distribution and regardless of the direction of categories' relationship. In this way, we establish significance of each statistical category. Significance level alpha is set to $\alpha_0 = 0.01$, but since we are repeating our test for 26 statistical categories (plus one novel category, see section V.B), in order to establish relevance of each category, we will use Bonferroni correction to try to avoid false positive results. Bonferroni correction formula is

$$\alpha = \frac{\alpha_0}{m} \quad (1)$$

Where *m* is 27, so our new alpha is 3.7E-4.

Also, for every separation, correlations between categories are calculated and we try to identify some interesting rules between two features, or in a group of features.

V. Results and Discussion

In Tables 1–3, we show the most significant differences in statistical categories between winning and losing teams.

A. Interpretation of results

We can see that the field goal percentage (FG%) has a large significance (low p-value) in all three tables. This is expected, because the main goal of basketball is to score a basket, so the teams that cannot do it effectively may have smaller chances of winning. Field goal percentage is not a new statistical category, so it is not of our main interest, but it is good to establish its importance, so that we can compare it with the importance of percentages of other categories, such as uncontested and contested shots.

If we think about contested and uncontested shots before conducting the analysis, we can make two claims. First, we claim that everybody will make their uncontested shots with approximately the same percentage and that the difference between winning and losing teams would be a better percentage of contested shots. Second, we claim that better teams will have more uncontested shot attempts, which would lead them to gain easy points by making those uncontested shots and eventually to winning the game. However, if we take a look at the statistics, we can see that in the Tables 1–3, there is no uncontested shot attempts (UFGA). This means that there is no significant difference between winning and losing teams in this category, so the second claim is disproven. The results for uncontested field goal percentage (UFG%) in Tables 1 and 2 also refute the first claim.

It can be observed that uncontested field goal percentage shows larger difference between winning and losing teams than contested field goal percentage in all three tables. This could be confusing at first, but if we think about the game and the shots, we can say that most of the uncontested shots are shots for 3-points or shots of players who have weaker offensive skills, because defenses are leaving them free for shot deliberately, while contested shots attempts are mostly near the rim. This may be the most probable reason for this confusing difference in percentages.

Uncontested field goals made (UFGM) are significant in all three tables as well. The difference between winning and losing teams are around 2.5 per game. Contested field

Table 4. Correlation for all three separations.

Categories that correlate		Correlations					
		First separation		Second separation		Third separation	
		Winning	Losing	Winning	Losing	Winning	Losing
FG%	UFG%	0.62	0.59	0.70	0.65	0.67	0.61
FG%	CFG%	0.71	0.69	0.72	0.70	0.68	0.65
FG%	UFGM	-	-	0.51	-	0.44	-
FG%	AST	0.47	-	0.53	0.49	0.45	0.40
SAST	AST	0.55	0.48	0.61	0.49	0.60	0.50
UFGM	AST	0.47	-	0.54	-	0.49	0.43
UFGM	UFG%	0.68	0.70	0.70	0.68	0.65	0.67
CFGM	CFG%	0.59	0.65	0.60	0.62	0.58	0.62
ORBC	CFGA	0.47	-	-	0.48	0.42	0.47
PASS	SAST	0.36	-	0.37	-	0.37	-
PASS	TCHS	0.98	0.97	0.98	0.97	0.98	0.98
DIST	TCHS	0.48	0.55	0.50	0.57	0.51	0.59

goals made (CFGM) are significant only in the first separation of data, while in the other two cases, the significance level is negligible. With all this information, we can conclude that the uncontested shots are more important than contested ones for quantifying the difference, but this opens a new question: is it better to have a few uncontested field goals made more, but with a slightly lower percentage, or the other way around?

Screen assists (SCREEN ASSISTS) have significant differences in all three separations. Since Table 2 and Table 3 represent the differences between the best and the worst teams at the end of a regular season, this difference implies that season-round better teams are setting better screens. Two things can explain why this could be a case. The first one is that better teams have better and stronger players, so it is hard for a defender to get around the screen. The second one is that better teams have better offensive actions, so they easily create points with screens.

The other result that implies that winning teams have better players is distance covered (DIST). The difference is significant in Tables 2 and 3, but this time, winning teams have a lower average, which means that they run less than the losing teams. A possible explanation for this could be that their players have a better intuition for where at the court they should be, so they manage to do things with less effort in running.

Defensive rebound (DRBC) chances are significant in Table 1. There is also a high significance for defensive rebound chances in the third separation (Table 3). If an opponent team has a lower field goal percentage, then that leads directly to a higher number of defensive rebound chances. Significance of defensive rebound chances is just another confirmation for the importance of field goal percentage.

Additionally, we tried to find some connection between player quality and any of these statistical categories or winning teams by adding into the data set the average Player Efficiency Rating (PER) [10] of 4 players that played the most minutes in game. We choose PER as the currently best measure for quality of players. Unfortunately, there was no clear connection or correlation between any statistical category and the PER average.

Table 4 contains the largest and most interesting correlations between categories. Values that are missing were not written because they are too small for consideration (below 0.35). We were hoping to find the "winning formula" through correlations, but unfortunately, there is no such a thing, because the data set is too complex, having too many factors involved. Still, some moderately strong correlations exists, and based on them (for winning teams), we might say that more running leads to more touches and passes, and that leads to more assists and secondary assists. Finally, considering all that, we are getting better shots and our field goal percentages are larger, which leads to winning. However, this conclusion would be somewhat far-fetched, because the correlations are too small for this kind of conclusion and we can not be sure that this kind of chaining of correlations is appropriate, because some other factors that we did not take into consideration might be involved. Actually, significance levels of differences between those two distributions shown in Tables 1–3 are a confirmation that this conclusion would be wrong. So, we can say that we could not find a clear winning formula, at least not using correlation.

B. Suggestion of a novel statistical category

Assists have a high level of significance in Tables 1–3. If we consider only Tables 1 and 3, which contain only the individual winning games, we can see that the difference in average for assists is around 4 assists per game. Since assists in many cases create easy points, this represents a big difference between winning and losing the game.

A player is awarded a secondary assist (SAST) if he passed the ball to a player who recorded an assist within 1 second and without dribbling [4]. From the definition of SAST, we can say that there is a high correlation between AST and SAST and that means that a high number of secondary assists should also be a significant difference between winning and losing teams. Confirmation for this conclusion is shown in Tables 1–3.

Passes (PASS) also have significant differences in Tables 2 and 3. What is surprising is that winning teams have less passes then the losing teams. Every year, basketball is more and more played as a team sport (in terms of offensive actions), while isolations (offensive action where teammates back away to draw their defenders as far from the ball as possible and the ball-handler tries to beat a defender one-on-one) are less frequent. The first thing that could explain the fact that winning teams have less passes is that it is not enough to run and pass the ball, what losing teams often do, there still needs to be some clear plan on what is the goal of passing. The second explanation could be that winning teams have better individuals, who can attract double-team defense on them, and then just pass to an open player who then has a much easier job.

Since assists and secondary assists are passes, and also free throw assists (FTAST) have significant difference in

Table 5. Statistics for EPR.

Values for EPR in:	Mean		Standard deviation		Alpha	p-value
	Winning team	Losing team	Winning team	Losing team		
First separation	0.109173	0.09325	0.023968	0.021157	3.7E-4	3.38E-63
Second separation	0.106989	0.094896	0.027418	0.020208	3.7E-4	4.72E-20
Third separation	0.113273	0.090872	0.027674	0.019107	3.7E-4	2.08E-42

the first separation, the formula for the effective passing ratio (EPR) automatically imposes itself:

$$EPR = \frac{AST + SAST + FTAST}{PASS} \quad (2)$$

It is a simple formula that gives us a percentage of passes that are any kind of assists. Screen assists are not involved in this formula, because screen assists are not passing assists. If a passing assist is involved in the play with a screen assist, it would be added through AST. For example, if a player gets an open position by his teammate screen, he gets the ball and makes a field goal, that assist is already added within AST and adding it one more time within the screen assist would not be correct.

Since each factor in the formula is significant in at least one of first three tables, EPR is also significant. Significance level for EPR is shown in Table 5. We can observe that differences in all three categories are highly significant. Based on that, we can conclude that EPR is a very important difference between winning and losing teams. Although statistically significant differences in no way imply causality, it may be beneficial that teams become aware of the importance of EPR and try to adjust their game in order to improve it and thus potentially increase their chances of winning.

In order to demonstrate the significance of EPR, we build a logistic regression model based only on EPR of a single team in a single game and try to predict whether that team won or lost the game. We used 10-fold cross-validation for the purpose on the whole dataset and we compared the results with random model for each separation. Random model gave us around 50% accuracy, as expected. Logistic regression model based on EPR gave us the accuracy of 63.3% in first separation, 62.8% in second separation, and 65.7% in the third separation. Thus, the model achieves more than 20% improvement compared to random case, which confirms our supposition that EPR makes an important difference between winning and losing teams. Due to space limitation, future work with EPR would include a detailed comparison with simple assists, such as identification of teams that are good in one category but bad in the other one, observation of EPR on the player level and similar.

VI. CONCLUSION

The analysis has shown some significant differences between winning and losing teams. The most important differences are: 1) field goal percentage, especially uncontested (UFG%), but also contested (CFG%); 2) uncontested field goal made (UFGM) are perhaps even more important than uncontested field goal percentage and it is certain that the uncontested shots are more important than the contested ones; 3) better teams have lower distance covered; 4) better teams have less passes and touches with the ball, despite the current high popularity of motion attacks (type of offensive actions where all the players and the ball are constantly moving); 5) better teams have more defensive rebound chances, which can be linked to poor opponent field goal percentage; and 6) better teams have more assists and secondary assists, despite the fact that they have less passes.

Correlations between categories exists, but they are too small to make any kind of "winning formula". Based on the analysis, in order to become a winning team, the most prudent approach would be to concentrate on the categories that were mentioned in the paper and try to make some adaptations in the team in order to improve these categories. For instance, creating offensive plays with more efficient running, more effective passes with goal of creating uncontested shots.

Effective passing is a very important difference between winning and losing teams. For that purposes, we introduced the effective passing ratio (EPR) measure. We can safely conclude that this measure is one of the most important differences between winning and losing team. The current results suggest that teams start taking the measure of quality of their passes as a reliable indicator of their future success in the game.

For future work, we plan to analyze the data from several seasons more deeply using various data mining methods in order to find additional, previously undiscovered models of winning teams' success.

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Comparison of Garbage Collectors in Java Programming Language

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***Abstract* - Considering the need for continuous and uninterrupted service of modern software applications, it is valuable to analyze how garbage collection (GC) algorithms are handling memory challenges. Widely adopted general-purpose programming languages, like Java, represent an inevitable foundation for many modern application developments. In Java Platform, Standard Edition, and accompanying Java Virtual Machine (JVM), several GCs could be used. In the latest version 9.0.1 of Java SE Development Kit (JDK) default GC was changed to Garbage-First (G1) GC, now becoming widely adopted in addition to previously used Parallel GC and Concurrent Mark & Sweep (CMS) GC. Since GC is a vital part of the JVM, changes and upgrades to its implementation, which reflect upon performance results, are properties worth exploring. Using benchmarks to create non-trivial memory pressures, and with extensive data monitoring, this paper analyzes insights gathered about critical performance factors across several GC algorithms. With the evaluation of benchmark elements, such as object allocations from young area to old area and the duration of the collection time, it was possible to compare GC behavior and assess the overall memory management. This paper presents our preliminary research performed in an academic environment on several benchmark cases and our conclusion about it.**

Keywords - Garbage Collector; Memory Management; Garbage-First; G1

I. INTRODUCTION

Garbage collection (GC) is an automated process of memory management that scans through the heap space looking which objects are in use, and which are not. In some lower level procedural programming languages, such as C programing language, allocating memory is more of a manual process. However, in modern object-oriented programming (OOP) languages garbage collection is an essential part of memory management. For instance, garbage collectors in Java programming language are embedded as an important component of the runtime environment and Java Virtual Machine (JVM).

The main purpose of the GC is to release from the memory the objects that are no longer used, and thus have no active references that would in some part of the application maintain a pointer to that object [1]. These sweeping operations are performed automatically at regular intervals and last for a certain amount of time but result in benefits of reclaimed memory where Java occupies only the necessary amount of space. At the same time, the released memory is available for further usage.

Key components of the JVM that are essential to memory management [2], presented in Fig. 1, include:

- heap – a space where objects reside in memory
- garbage collector – an algorithm that directly manages the heap
- JIT compiler – a mechanism in charge of making dynamic memory optimization decision while the application is running.

With the current software architectural approaches, many modern software applications significantly depend on the continuous availability of the remotely deployed services. In production environments delaying the processing on the server side, due to any reason, might result from minor issues in reduced user experience, up to more severe critical system failures caused by memory overloads. Therefore, automated memory management, like GC, has to have very low overhead and require only the optimal amount of time for the sweeping operations.

In Java, there is a JVM's "stop-the-world" concept that halts all of the non-critical application threads in order to perform GC, which results in interrupted tasks resuming only when GC processes have been completed. Such events occur no matter which GC algorithm is selected but require different durations and a distinctive number of garbage collections [3]. As part of the latest update of Java SE Development Kit (JDK), the default GC algorithm was switched to Garbage-First (G1) Garbage Collector [4]. The main motivation for this decision was the G1's capability to limit the previously mentioned GC pause time to a predictable duration and to enhance the overall experience by operating concurrently, without requiring much larger heap size or processing power.

Because it is difficult to successfully achieve a setting in which memory management is handled in an optimal manner, for this comparison we've selected three widely used garbage collectors, included in the latest version of JDK. Currently, there several GCs available in the JDK:

- Serial Garbage Collector
- Parallel Garbage Collectors in several versions
- Concurrent Mark Sweep (CMS) Collector
- Garbage First (G1) Garbage Collector

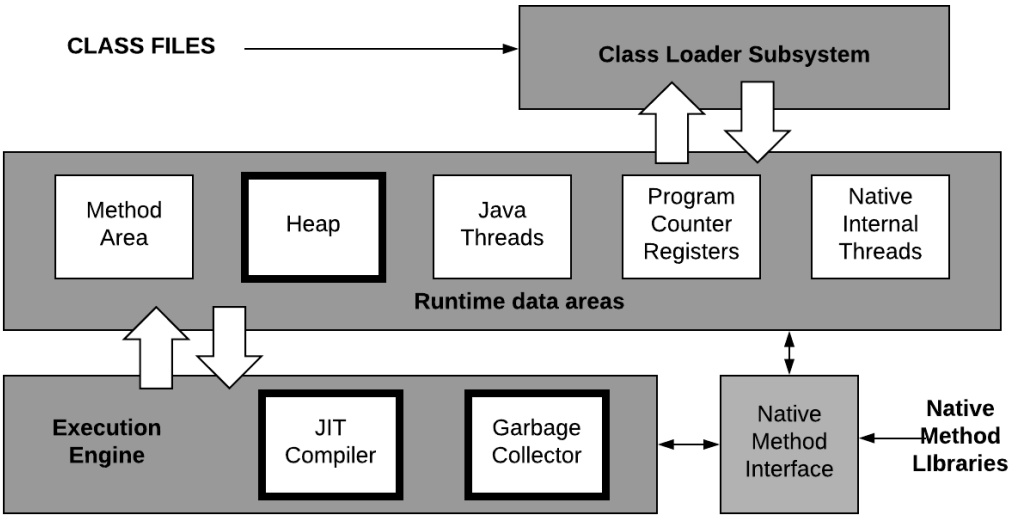

Figure 1. Visual representation of the Java Virtual Machine with key memory components (bolded), according to Oracle [2].

For the purpose of this research, we selected Parallel GC, CMS GC, and G1 GC, which were taken into the consideration when performing benchmarks of the non-trivial memory pressures, created by several applications included in the DaCapo benchmark [5]. As the goal of this research was to evaluate how the algorithms perform with out-of-the-box settings, only the utmost tuning of the JVM's parameters has been performed.

II. BACKGROUND

A. Java Garbage Collectors

In September 2017 Java SE Development Kit was updated to the anticipated version 9, delayed mainly because of the Jigsaw Project. There were many significant improvements included in this release that the community was expecting. One of the most anticipated changes was the JDK's modular system aka Project Jigsaw [11]. However, a more interesting feature for our research was the previously mentioned change of the default garbage collector to the freshly updated version of G1 GC algorithm.

With G1 the main idea was to distance from the maximization of the throughput. Thus, the primary goal, for the G1, was to achieve the lower pause times, i.e., to minimize the periods when application threads are not progressing. This goal was not largely prioritized in the previously used algorithms in Parallel GC and CMS GC.

As Java does not especially denote the amount of memory necessary for the applications, there is no suitable way of performing manual memory cleaning in the source code. However, there is a possibility of dereferencing objects and setting their reference to null. In this case, previous objects' reference is lost, and memory is explicitly released. The problem could occur when developers invoke garbage collection method like *System.gc()* method. Explicitly calling the garbage collection method might decrease performance drastically, and it is not advisable to use it. With these premises in mind, Java organized internal mechanisms to handle memory issues automatically, in a variety of ways.

Firstly, Parallel GC [10] uses larger amounts of processing power in order to perform object marking phase in parallel. This approach is very useful as it is faster than a Serial GC would be, which uses only a single thread [3]. But, successfully processing numerous tasks in parallel is only possible with machines that have a significant number of processing cores and substantial amounts of memory. Parallel GC is a typical example of a throughput GC.

Secondly, CMS GC [1] is significantly more complex at its core. Despite Parallel GC uses multiple amounts of threads its actions are still somewhat serial in nature, whereas CMS performs both memory sweeping concurrently with the running application. As a result, operations are executed much faster, which is critical when there is a high demand for availability. However, in order to provide such short delay times, CMS can cause memory fragmentation and uses more processing power than any other GC [2].

Lastly, G1 GC functions similarly as CMS. It first starts by doing global marking phase to determine the importance of objects. After global marking, G1 knows which areas are full of reclaimable garbage objects that would yield a lot of free space. By concentrating on such garbage areas first, the algorithm's name was formed. Moreover, G1 uses user-defined acceptable delay times, so that heap targeting is performed in an optimal and predictable manner [4].

Specific characteristics of garbage collectors are compared and presented in Table I. Even though G1 is well tested, making it a default GC might produce some new concerns. Also, if the assumption that latency is more important than throughput proves rather incorrect, there could be a reasonable doubt to reconsider the G1's default position.

TABLE I. CHARACTERISTICS OF GARBAGE COLLECTORS INCLUDED IN THIS RESEARCH BASED ON A STUDY BY CARPEN-AMARIE, MARLIER, FELBER, AND THOMAS [6].

GC	Old generation				Young generation			
	Parallel	***Compacting***	***Concurrent Marking***	***Concurrent Compacting***	***Parallel***	***Copying***	***Concurrent Marking***	***Concurrent Copying***
Parallel	✗	✓	✗	✗	✓	✓	✗	✗
CMS	✓	✗	✓	✗	✓	✓	✗	✗
G1	✓	✓	✓	✗	✓	✓	✗	✗

B. The Heap

The working hypothesis of the generational garbage collectors is that most of the objects soon become un-referenceable and that there is a rarity of cases when it is necessary to reference specific older object back to the newly created ones [3]. This property is specified in the literature as the "weak generational hypothesis" [7]. Therefore, in the majority of cases, the heap is divided into three major sections of total fixed size. Firstly, the young space is where newly created objects are located. When the allocated space of this generation runs out, minor garbage collection is executed. Even though all minor collections are relatively fast, these still require non-critical application threads to be stopped. Secondly, the old generation stores longer surviving objects, which get placed in this space when certain age criteria are met. When old generation space gets filled, major garbage collections are executed. In general, major GC operations are much slower than minor collections and result in longer pause times. Thirdly, permanent generation gets populated at runtime by metadata necessary to denote various JVM components. As part of the full garbage collection, JVM can remove information from the permanent collection if it no longer finds it important [2].

In contrast to the traditional fixed heaps, G1 takes a completely different architectural approach, and the heap is portioned in a large number of small areas, with the distinctive types of areas, as presented in Fig. 2. Eden space represents a young area where new objects get allocated. Slightly older space with objects that have existed for some period of time is called Survivor space, and the old generation space is where long existing objects are persisting. All allocated memory areas do not have a fixed size, which provides significantly greater flexibility, and creates an opportunity for more suitable memory management environment [4].

C. The Benchmark

DaCapo suite represents Java memory and architecture benchmarking tool [5]. It consists of a set of real-world open-source applications. Each application, when run, will create non-trivial memory loads. By measuring the performance details, DaCapo suits offers great insights into the operating details of the Java VM. In this research, we were using DaCapo version 9.12-bach. Only a set of the following applications was included in this research paper. There are more available but were not considered as part of this preliminary research results. The information about the applications included was gathered from the benchmark provider [3], as well as from the related study by Carpen-Amarie, Marlier, Felber, and Thomas [6].

The detailed information regarding the included applications are the following:

- *avrora* – a single client threaded application (internally multithreaded) in charge of simulating a number of programs run on a grid of AVR microcontrollers
- *fop* – a single threaded application which takes an XSL-FO file, parses it, and creates a PDF file
- tomcat – a multi-threaded application that sends multiple requests to the server for processing
- *h2* – a multi-threaded application which executes JDBC like in-memory benchmarks by executing transactions against a banking model
- *pmd* – a single thread application (internally multi-threaded) analyses Java classes for source code issues
- *xalan* – a multi-thread application which transforms XML documents into HTML

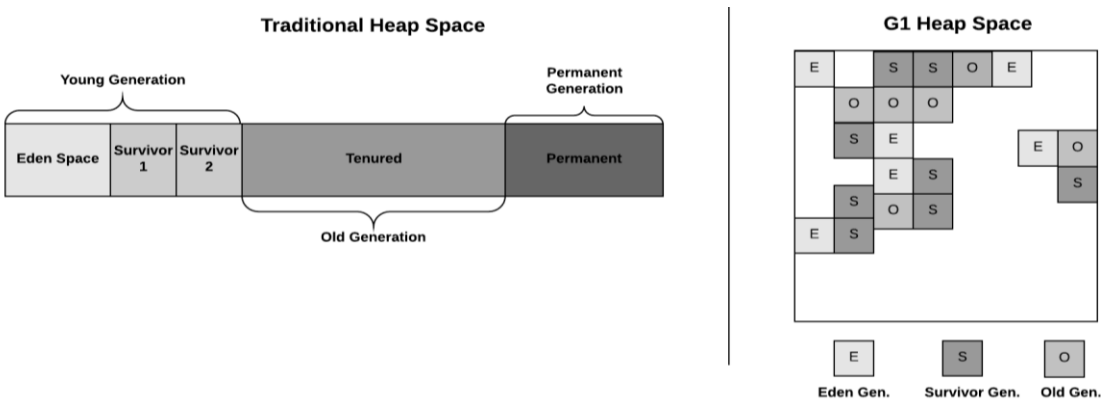

Figure 2. Visualization of the architecture of traditional heap space and G1 heap space.

The remaining applications included in the benchmark are *batik*, *eclipse*, *jython*, *luindex*, *lusearch*, *tradesoap*, *sunflow*, and *tradebeans*. By default, the selected application from the suit is ran only once. But, it is possible to set via the parameter the desired number of iterations. However, if there is an *N* amount of iterations passed, the benchmark considers *N-1* iterations to be warmup rounds whose purpose is to stabilize JIT compiler and GC ergonomics [8]. The final round is considered to be the actual benchmark test. By default, the benchmark performs system GC after every iteration, but this feature can be disabled by passing additional parameters.

III. TESTING ENVIRONMENT

A. Testing Environment Setup

The environment in which this research has been conducted consists of several elements, out of which the most important is Java Virtual Machine (JVM). The used JVM is Java Hotspot 64-bit Server VM of build 9.0.1+11, mixed mode. Java SE Runtime Environment (JRE) is also of a build 9.0.1+11. By default, the JVM's GC of choice was G1, but for the testing purposes, additional GC's included have been respectfully activated. The operating system used as hosting environment is Apple's macOS version 10.13.2 (High Sierra), and all testing was started and performed directly on Apple's Terminal application version 2.8.

In order to measure the results of the performed tests, we used Visual VM software version 1.4, supported by Oracle. Visual VM is a simple, but powerful graphical tool, which enables inspection of various performance factors in Java-based applications. However, to successfully monitor precise details about garbage collection, Visual VM needs to be enriched by installing Visual GC plugin [9]. With this plugin, it is possible to attach Visual GC to the running application, and to collect data about garbage collectors, class loaders, and HotSpot's compiler performance.

B. Test Cases

Our testing setup included a scenario consisting out of 10 iterations, where each scenario was repeated two times. In the end, the results were put into a table so that average duration time and the number of GC collections could be calculated. This course of actions was repeated for each of the respected garbage collector algorithms included in this research. The size of the heap was set in every case to a fixed value of 1 GB. This feature provided greater transparency for the results as limiting the heap memory prevented some of the applications to use more memory than the others. An example of test case command is presented in Fig. 3.

```
java -Xms1G -Xmx1G -jar dacapo-9.12-bach.jar
h2 -n 5 --no-pre-iteration-gc
```

Figure 3. The example of the command that would execute 5 iterations of *h2* application with limited memory heap to 1 GB, and no system GC between iterations.

C. Limitations

Although the objective of this preliminary research was to establish a strong line of comparison between different GCs, there are still some limiting factors that necessarily need to be taken into consideration. Namely, the present limitations are:

- Limited computing power of an academic setting.
- Overhead created by the measuring tool.
- Modest number of iterations and overall testing repetitions due to the limited amounts of memory available.

Due to the previously mentioned limitations, tested garbage collection algorithms might behave differently in a large enterprise setting, which has substantially more computing resources.

IV. RESULTS

Preliminary results obtained by executing the described test setup have yielded the results (presented in Table II and Table III) that do not show an obvious advantage for the G1 GC algorithm.

TABLE II. TOTAL NUMBER OF GARBAGE COLLECTIONS

Benchmarks	G1 GC	CMS GC	Parallel GC
avrora	2	2	2
fop	13	6	6
h2	43	23	34
pmd	16	16	16
xalan	16	34	29
tomcat	21	48	37

TABLE III. TOTAL DURATION OF GARBAGE COLLECTIONS IN MILLISECONDS

Benchmarks	G1 GC	CMS GC	Parallel GC
avrora	37,44	45,22	36,66
fop	634,39	279,90	412,55
h2	3992	2060	1724
pmd	1409,0	1104,8	685,2
xalan	211,63	307,75	237,41
tomcat	741	1219	1222

From the fig. 4, it is obvious that in four out six test cases G1 GC performed in a similar or sometimes even worse manner than the other compared algorithms. With the applications *avrora* and *pmd* the number of garbage collections was the same across every tested algorithm. But, with the applications *fop* and *h2* G1 GC executed substantially more garbage collections than Parallel GC or CMS GC.

However, in the case of the multi-threaded *xalan* and multi-threaded *tomcat* applications, G1 performed the best. G1 GC outperformed Parallel GC and CMS, which conducted almost double the number of collections and ended with requiring from 10% up to 30% more time to finish executing.

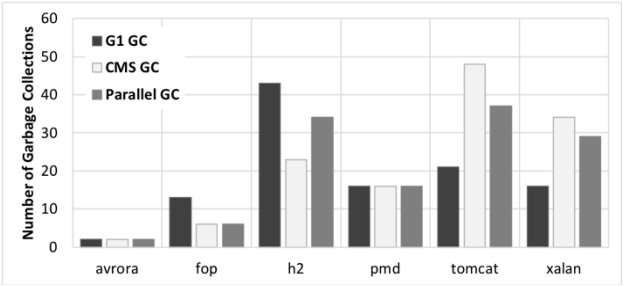

Figure 4. Overall numbers of executed garbage collections per application across three GC algorithms.

The garbage collection execution time visualization presented in fig. 5 depicts overall time durations for the performed tests. In every benchmark application case, except for the *tomcat* and *xalan* application, when compared with CMS GC and Parallel GC, G1 GC utilized the same amount time or more. The most perceptible difference can be noticed in the test case with the *h2* application. As presented in Table III, proportional to the larger number of collections, G1 GC operations required 3992 milliseconds, while Parallel GC and CMS required 1724 and 2060 milliseconds, respectfully.

Regarding the CPU usage, in most of the cases, there was no critical difference between the tested algorithms. Parallel GC and CMS utilized approximately between 5% to 8% more processing resources than G1 GC. However, each algorithm produced almost the same CPU usage spikes at the similar point in time during the test execution. Also, CMS GC and Parallel GC demonstrated slightly more unpredictable rate of garbage collections, when compared to rather consistent intervals of the G1 algorithm.

V. DISCUSSION

Although it might seem that G1 Garbage Collector did not present any obvious advantages, as the results were mostly equal or worse, we have noticed interesting facts that possibly yield towards a stirring discovery. In order to interpret it, it is necessary to place a greater emphasis on the architecture of the applications involved in the testing scenarios.

In an interaction with fully single threaded applications like *fop*, and externally single threaded apps lik *avrora* or *pmd*, G1 GC performed mostly the same or slightly worse than other two garbage collectors. This could indicate that switching to G1 GC is probably not the

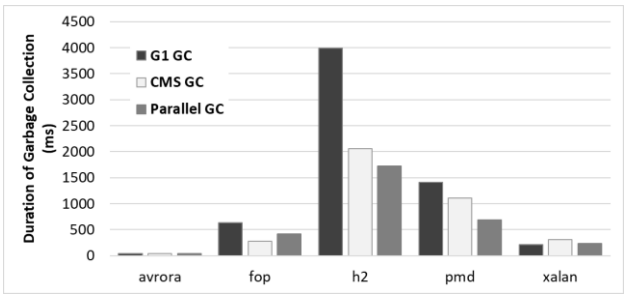

Figure 5. Overall execution time of garbage collections per application expressed in milliseconds.

best possible option for such environments. Likewise, when G1 GC was put to the test where it was necessary to interact with the embedded *h2* database, G1 GC performed significantly worse than any other algorithm involved. But, as this test was the only one that included extensive database communication with a complex banking model, it might not be legitimate to generalize a conclusion based on such single case.

Still, an interesting pattern can be noticed in the example of the last two conducted tests. With fully multi-threaded applications like *xalan* and *tomcat*, G1 GC was an absolute winner. In these tests other garbage collectors required almost double the time and performed substantially larger amount of GC operations. Even more interesting is the fact that in cases with *avrora* or *pmd* where their internal architecture and processing is organized in a multi-threaded way, G1 GC performed equally as other algorithms. This demonstrates that in circumstances when multi-threaded systems are involved it might be worthy to test the existing configurations further, and to evaluate if keeping the traditional, generational, garbage collectors yields negative performance effects.

Also, by investing more effort into adjusting the large amount of available Java virtual machine parameters, which was out of scope of this research, the positive outcome might be significantly more numerous. An interesting research conducted on this topic by Lengauer and Mössenböck [12] indicates that it is even possible to use an iterative approach to search and custom tailor JVM configuration, so it brings additional performance enhancements. Combining such approach with utilization of G1's scalable design that splits heap into small manageable regions [13], results is a clear and viable reason to engage into optimization and bring increased quality of service to system's users.

VI. CONCLUSION

With this version of the G1 GC, and out of the box settings, it might be hard to notice the benefits that have been presented as part of this Java release. Parallel GC and CMS GC have proved to be at least equally good in most of the scenarios, which could indicate that any large production software systems might have to carefully consider widely adopting the G1 garbage collector. But, by possibly optimizing applications from the beginning of the development process, could result in better utilization of the benefits the G1 Garbage Collector brings. Furthermore, if the system at hand is operating with a large amount of threads, it might be useful to create a replica of it, in a testing environment, and to see how G1 GC performs. The justification for such a decision can be based on convincingly good results of G1 GC shown in a multi-threaded environment.

According to the presented results, simple utilization of the default settings of the G1 GC might be the reason why critical performance improvements were not consistently observed across all of the tested scenarios. This fact potentially implies that the advanced tuning of the JVM parameters, as well as parameters of the garbage collector itself, might yield much more successful

achievements in less threaded environments, and environments that include extensive database interactions. Nevertheless, G1 GC algorithm with its stable and predictable usage patterns and a possibility to specify desired pause times represents a technology that in the long run is worth exploring.

VII. Future Work

The current research was of relatively narrow scope and leaves much more space for further research. Especially interesting would be to perform a significant amount of much more complex tests in large multi-threaded environments. Such results could possibly yield more precise outcomes that would enable to deduce if wide enterprise adoption of G1 is a viable cause.

Also, an interesting aspect that was not overly tested in this research is the implantation of benchmarks that are more focused on interaction with a database. It would be interesting to see how memory management is conducted when interacting with commercial databases like Oracle database, instead of using embedded *h2* database.

Finally, our research could be extended by focusing on a single application, but in a more detailed approach. By fine-tuning all of the applicable JVM parameters, it could be seen how the true potential of G1 GC algorithm looks like.

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Comparative Analysis of Blockchain Consensus Algorithms

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***Abstract* - Cryptocurrencies have seen a massive surge in popularity and behind these new virtual currencies is an innovative technology called the blockchain: a distributed digital ledger in which cryptocurrency transactions are recorded after having been verified. The transactions within a ledger are verified by multiple clients or "validators," within the cryptocurrency's peer-to-peer network using one of many varied consensus algorithms for resolving the problem of reliability in a network involving multiple unreliable nodes. The most widely used consensus algorithms are the Proof of Work (PoW) algorithm and the Proof of Stake (PoS) algorithm; however, there are also other consensus algorithms which utilize alternative implementations of PoW and PoS, as well as other hybrid implementations and some altogether new consensus strategies. In this paper, we perform a comparative analysis of typical consensus algorithms and some of their contemporaries that are currently in use in modern blockchains. Our analysis focuses on the algorithmic steps taken by each consensus algorithm, the scalability of the algorithm, the method the algorithm rewards validators for their time spent verifying blocks, and the security risks present within the algorithm. Finally, we present our conclusion and some possible future trends for consensus algorithms used in blockchains.**

Keywords – blockchain; consensus algorithms; cryptocurrency; consensus problem

I. INTRODUCTION

A blockchain is an open, distributed ledger that can record transactions between two parties efficiently and in a permanent, verifiable way [1]. The most famous implementation of one being Bitcoin's, created in 2008 by a person or group working under the pseudonym "Satoshi Nakamoto" [2]. According to the original Bitcoin whitepaper, the goal of this new technology was to enable the creation of a "peer-to-peer version of electronic cash [which] would allow online payments to be sent directly from one party to another without going through a financial institution." In Bitcoin's implementation, this is achieved by timestamping every transaction within said peer-to-peer (P2P) network and hashing them into an ever-growing chain of transaction blocks. This hashing is accomplished by validators (i.e., "miners") which are peers within the network that participate in the creation of new blocks [3]. Assuming no individual or group of validators controls more than 25% of the computing power used to hash these blocks, all transactions within the chain are trusted as valid.

As there can be a potentially unlimited number of validators in any given P2P network, consensus algorithms must be utilized for there to be any cooperation between them. The most widely adopted of these is the Proof of Work (PoW) algorithm implemented by Bitcoin; however, there are numerous other means by which a network can achieve consensus, such as the algorithms that will be overviewed further in this paper.

This paper is organized as follows: firstly, problem of reaching consensus in a distributed system is explained in brief. Afterwards, the consensus systems used by the top cryptocurrencies (ranked by current market share) is overviewed. The different algorithms are compared with the Proof of Work algorithm in terms of scalability and energy efficiency. Theoretical systems that propose interesting solutions to current consensus problems are discussed and evaluated based on their feasibilities in terms of implementation. Finally, the limitations of the research conducted within this paper are discussed and avenues for further research are provided.

II. THE CONSENSUS PROBLEM

The consensus is a problem in distributed computing wherein nodes within the system must reach an agreement given the presence of faulty processes or deceptive nodes.

A. The Byzantine Generals Problem

The Byzantine Generals Problem, first described in [4], is a problem concerning communication failure. Namely, how can each node ("general") in a system be certain that the information they are receiving is valid?

In the original problem, the situation of *n* Byzantine generals preparing to attack a fort is proposed. Each general has the option to attack the fort or retreat; however, it is vital that all generals agree upon the same course of action, as a half-hearted attack would be disastrous. To complicate matters, the generals are far apart, only able to communicate through messengers, which may not successfully deliver their messages, and some of these generals are traitorous and will actively attempt to deceive the others.

B. Byzantine Fault Tolerance (BFT)

Byzantine Fault Tolerance (BFT) is a category of replication algorithms that aim to solve the problem of reaching consensus when nodes can generate arbitrary data. As described [5], BFT can guarantee the safety (the chance that something negative will happen in the system) and liveness (the chance that progress will be made within the system) of a system given that no more than

$$\lfloor (n - 1) \div 3 \rfloor \quad (1)$$

replicas are faulty over the system's lifetime, where n is the total number of replicas within a system. BFT can handle up to 33% of nodes being faulty. Typically, up to

$$3f + 1 \quad (2)$$

replicas in order to provide safety and liveness in a system, where f is the total number of faulty replicas contained within said system; however, at least one known BFT implementation [6] is able to reduce this to

$$2f + 1 \quad (3)$$

required replicas.

C. Delegated Byzantine Fault Tolerance (dBFT)

As the name implies, Delegated Byzantine Fault Tolerance (dBFT) is a variant of standard BFT. Described in the NEO whitepaper [7], this fault tolerance algorithm splits clients within a P2P system into two separate types: bookkeepers and ordinary nodes. Ordinary nodes do not take part in determining consensus but, rather, vote (hence the "delegated") on which bookkeeper node it wishes to support. The bookkeeper nodes that were successfully elected are then included in the consensus process.

In this process, a random bookkeeper node is selected to broadcast its transaction data to the entire network. Should at least 66% of the other bookkeepers agree that the transaction data is valid, it is committed permanently to the blockchain and another round of consensus is started with another randomly selected bookkeeper.

III. High-Profile Consensus Algorithms

As there are currently over 1,500 active cryptocurrencies (that is, actively tradeable on the global market) and it is possible for a new cryptocurrency to be created at any given moment, "high-profile" in this context is determined by a cryptocurrency's market cap. Although cryptocurrency market values are in a state of constant flux, this ranking schema was determined to be the fairest in ordering the currencies (and the algorithms behind them).

TABLE I. Top Ten Cryptocurrencies by Market Cap (in Billions) as of 2018-02-03

Currency Name	Consensus Algorithm	Market Cap
Bitcoin	Proof of Work	$ 157.3 B
Ethereum	Proof of Work[1]	$ 95.7 B
Ripple	Ripple Protocol Consensus Algorithm	$ 37.1 B
Bitcoin Cash	Proof of Work	$ 21.4 B
Cardano	Proof of Stake	$ 11.8 B
Stellar	Stellar Consensus Protocol	$ 8.3 B
NEO[2]	Delegated Byzantine Fault Tolerance	$ 8.2 B
Litecoin	Proof of Work	$ 8.1 B
EOS	Delegated Proof of Stake	$ 6.5 B
NEM	Proof of Importance	$ 5.7 B

1. Planned switch to Proof of Stake sometime in 2018
2. Formerly known as Antshares

A. Proof of Work (PoW)

According to the Bitcoin whitepaper [2], the PoW system works by scanning for a value that, when hashed, has a hash starting with a number of zero bits. This is accomplished by adding a nonce (putting in work) to the original value until the resultant hash starts with the requisite number of zero bits. Once this nonce has been found and the proof of work has been satisfied, the block cannot be changed without redoing the work for that specific block and all blocks that come after it.

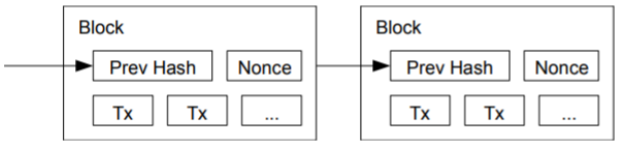

Figure 1. Visualization of two blocks within a PoW blockchain [1]

As can be seen in fig. 1, all blocks, with the exception of the first block created by the system (the "genesis block"), have a hash which consists of the previous block's hash alongside the nonce required to create the necessary zero bits. The genesis block is an exception as it has no previous block to point to: its hash is entirely zeroes.

B. Ripple Protocol Consensus Algorithm (RPCA)

As the name implies, Ripple Protocol Consensus Algorithm (RPCA) [8] is a consensus algorithm used exclusively by the Ripple cryptocurrency and was developed specifically to address latency issues present within other algorithms. As defined in the whitepaper, RPCA functions as follows:

- Each server takes all valid transactions it has seen prior to a new consensus round and puts them into a public list called the "candidate set."
- Each server combines all candidate sets found on its "Unique Node List," which is a set of other Ripple servers that the server kept reference to.
- Each server votes on the veracity of each transaction in a series of one or multiple rounds.
- All transactions that meet a minimum of 80% "yes" votes in the final round are written to the public ledger and the ledger is closed.

C. Proof of Stake (PoS)

1) Original Proof of Stake

First implemented in 2012 in the form of the cryptocurrency PeerCoin [9], Proof of Stake (PoS) is of a hybrid design, where PoW is used for initial coin minting and PoS is then used for most of the network security. Within a PoS system, each coin's age is taken into consideration in the form of "coin-days." This concept is simply explained through example: holding 10 coins for 10 days equates to 100 coin-days. Upon spending these coins in a transaction, the age of the coins is consumed and reset to zero. Unlike in a PoW system, where the chain with the most work is seen as the main chain, a PoS system uses the chain with the highest consumed coin age.

Under the PoS system, a validator pays himself (thereby consuming his coin age) for the privilege of minting a new block for the network. The target amount that a validator needs to contribute in order to mint a new block is determined by the system under the following condition:

$$proofhash < coins \times age \times target \quad (4)$$

As described in the whitepaper of another PoS cryptocurrency called BlackCoin [10], the *proofhash* is the obfuscation sum that depends on a stake, the unspent output, and the current time. *Coins* are the number of coins a miner has spent for the mining privilege, *age* is the age of the coins that have been spent, and *target* is the required amount of coins specified by the network through a network a difficulty adjustment process akin to PoW's implementation. The difficulty, in the case of blockchains, being the difficulty of the mathematical problem that validators must solve.

2) Cardano's Ouroboros

The creators of Cardano's Ouroboros protocol [11] took the PoS algorithm described above and added additional security measures to ensure persistence and liveness within their system. Namely, as described in the whitepaper, this implementation includes a delegation process for the electing of stakeholders and takes snapshots of current stakeholders in what they have labeled an "epoch." Each epoch, new stakeholders are elected by having a subset of the current stakeholders randomly decide who the stakeholders will be in the next epoch.

D. Stellar Consensus Protocol (SCP)

Stellar Consensus Protocol (SCP), defined in [12], is a decentralized consensus protocol wherein nodes within the network do not need to trust the entirety of the network but, rather, have the ability to choose which nodes they trust. This group of nodes which trust each other is referred to as a "quorum slice," a concept first introduced by this protocol. A "quorum" is a set of nodes sufficient to reach an agreement, whereas a quorum slice is a subset of a quorum which convinces one particular node of agreement.

SCP starts with a "nomination protocol" by proposing new, candidate values for agreement. Each node which receives these values will vote for a single value among these, which eventually results in one value winning the majority vote. After the nomination protocol has been successfully executed, the "ballot protocol" is deployed. During this phase, nodes initiate voting on whether or not to commit or abort the values that were selected during the previous phase. In the event that a set of nodes cannot reach consensus, the value is moved to a higher valued ballot to be voted on again [13].

E. Delegated Proof of Stake (dPOS)

Within a Delegated Proof of Stake (dPOS) system [14], stakeholders vote to elect any number of witnesses to generate blocks. During each maintenance interval, the roster of witnesses is shuffled, and each witness is given a turn to produce a block at the fixed schedule of one block per *n* number of seconds (where *n* depends on the implementation). Witnesses are paid for each block produced; however, should a witness fail to produce a block after being elected, they may be voted out in future elections.

Specific to the EOS blockchain [15], blocks are produced every three seconds by authorized producers and, every 21 blocks the list of said producers is shuffled. If a producer has not produced any block within the last 24 hours, they are removed from consideration until they notify the blockchain of their intention to start producing blocks again.

F. Proof of Importance (PoI)

Proof of Importance (PoI) is used within the NEM network [16], which uses an underlying cryptocurrency called XEM. Each account within the NEM network has a XEM balance that is split into two parts: vested and unvested. Whenever an account receives XEM, this new XEM is added to the account's unvested balance. One tenth of every account's unvested balance is moved into the vested part every 1440 blocks. In addition, when an account sends XEM, XEM is taken from both the vested and unvested balances in order to retain the same vested to unvested ratio.

For an account to be eligible for an "Importance Calculation" it must hold at least 10,000 vested XEM. Given eligibility, Importance is calculated based on the amount of vested XEM held, the rank of the account within the network (found using the NCDawareRank algorithm), a weighting factor based on the topological location of the account (as in, whether or not the account is an outlier or part of a cluster of nodes), and two suitable constants determined by the NEM network.

IV. COMPARISONS

Table II shows a basic comparison between various algorithms as provided by [17]. Note that *energy saving* is only given a vague yes-no-partial answer, as it is impossible to provide precise numbers into how much energy each implementation uses due to confounding factors such as processor efficiency and type. Table III, shows information for algorithms not included in [17].

TABLE II. CONSENSUS ALGORITHM CHARACTERISTICS, PART I, BASED ON [17]

	Algorithm Name				
Property	***PoW***	***PoS***	***PBFT***[1]	***DPoS***	***Ripple***
Energy Saving	No	Partial	Yes	Partial	Yes
Tolerated power of adversary	< 25% computing power	<51% stake	< 33.3% replicas	< 51% validators	<20% faulty nodes

1. Practical Byzantine Fault Tolerance

TABLE III. CONSENSUS ALGORITHM CHARACTERISTICS, PART II

	Algorithm Name		
Property	***DBFT***	***SCP***	***PoI***
Energy Saving	Yes	Yes	Yes
Tolerated power of adversary	< 33.3% replicas	Variable	<50% importance

A. Security

In Tables II and III, *tolerated power of adversary* refers to how much control an attacker would need to have over the network in order to successfully attack it. For example, the PoW algorithm would hypothetically require that an attacker control at least 25% of the computing power within the system in order to forge transactions. With the PoS algorithm, an attacker would need to control at least 51% of the stake (as in, total currency) in the network to forge transactions.

The Stellar Consensus Protocol is an outlier when comparing attacker potential. Due to the use of quorum slices in SCP, a client can choose which other clients it wishes to trust. This means that, hypothetically, an attacker could control a large portion of the network but still not be able to manipulate the blockchain within small, trusted groups. Conversely, this means that an attacker could manipulate the quorum slices within the network rather than the entire quorum, itself. There is no easy solution to either of these hypothetical scenarios, as admitted by the creators of SCP in [18].

There is also, of course, the problem that not all potential attacks against each protocol have been discovered. PoW, for example, was originally thought to be safe against any attacker with less than 51% of the total computing power of the network; however, it was later discovered in [19] that an attacker could theoretically achieve the same results with only half of that number.

B. Scalability

The theoretical maximum number of transactions per second (TPS) that a cryptocurrency can achieve is listed in this section. As shown in Table IV, while the algorithm that underlies a cryptocurrency ultimately dictates the maximum TPS that can be achieved, there is still some variance between networks that use the same protocol.

The TPS numbers in table IV are primarily theoretical and often never tested. Where possible, TPS data was sourced from other scientific papers [17], whitepapers [15, 16], or other documents that originated directly from the creators of the cryptocurrency [20, 21]. However, where not possible, TPS data was sourced from community discussions between members of each cryptocurrency's respective community or third-party sites.

TABLE IV. TRANSACTIONS PER SECOND FOR SELECTED CRYPTOCURRENCIES

Cryptocurrency Name	Protocol	TPS
Bitcoin	PoW	7
Ethereum	PoW	15
Ripple	RPCA	1500
Bitcoin Cash	PoW	60
Cardano	PoS	7
Stellar	SCP	1000
NEO	DBFT	10000
Litecoin	PoW	56
EOS	DPoS	~millions
NEM	PoI	4000

Transactions within a PoW system appear to be primarily bottlenecked by block sizes, with Bitcoin, for example, suffering slow TPS numbers due to a hard-coded one-megabyte size limit on block size.

Furthermore, as not all sources in Table IV are readily verifiable (or perhaps even trustworthy, in the case of numbers sourced from marketing materials), it is difficult to provide a truly accurate comparison of TPS for each currency's protocol.

A comparison that can be made, however, is to Visa and PayPal, two well-known payment processors. Visa, as of 2018, is processing roughly 24,000 transactions per second, whereas PayPal is processing roughly 193 transactions per second [22]. These numbers bring into doubt EOS's claim that millions of transactions could be handled on a per second basis as such an increase would be multiple orders of magnitude greater than the current processing capabilities of Visa's systems.

C. Power Consumption

Most cryptocurrencies do not have an accurate estimate of how much power is being consumed on their networks, with the notable exceptions of Bitcoin and Ethereum. As such, in this section, only these two currencies will be compared. As both Bitcoin and Ethereum are currently using the PoW protocol, it can be safely assumed that the other currencies included in this study that are not using PoW will consume less power per transaction.

Fig. 2 shows the current power usage of the Bitcoin and Ethereum networks compared to selected countries. At the time of writing this paper, the entire Bitcoin network consumes slightly more power than Singapore and Portugal, and less than Uzbekistan and Romania; however, it is more than three times more than entire energy consumption in Croatia. At the same time, the entire Ethereum network consumes slightly 3.6 times less than Bitcoin network, i.e. slightly more power than Myanmar and Tajikistan, and less than Slovenia and Mozambique; and in this case it is 15% less than to Croatia.

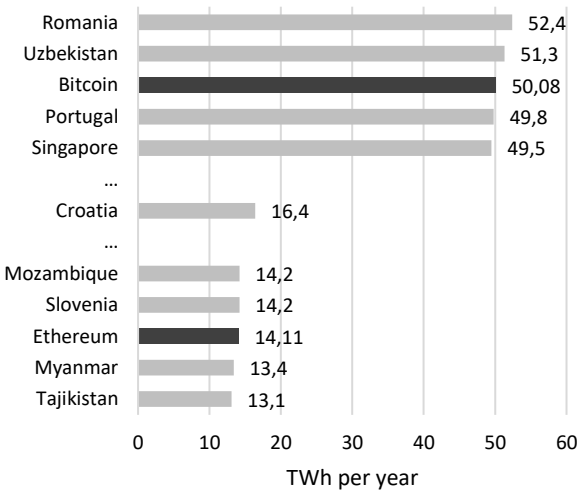

Figure 2. Comparison of energy consumption between Bitcoin and Ethereum networks and selected countries in TWh/year, based on [23] and [24], as of 2018-02-19

Fig. 3 further highlights the relatively massive amounts of power the Bitcoin network consumes. To put the above numbers into greater perspective, the US Energy Information Administration estimated that the average annual electrical consumption per US household was 10,766kWh [23]. Using a conservative estimate of 3.5 transactions per second (half of the theoretical maximum), the Bitcoin network consumes the equivalent of one US household's annual energy needs every four seconds.

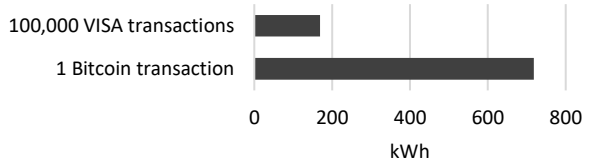

Figure 3. Power consumption (in kWh) for average Bitcoin transaction compared to 100,000 average VISA transactions, based on [23]

Comparing to Bitcoin's largest competitor Ethereum and its blockchain which currently implements the PoW algorithm, fig. 4 shows the difference in energy consumption between Bitcoin and Ethereum.

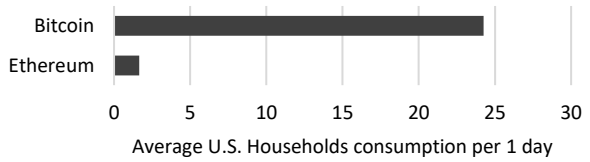

Figure 4. Bitcoin vs Ethereum power consumption per transaction in comparison with average U.S. households, based on [24]

It is obvious, despite the fact that both currencies currently use the same consensus protocol, that Ethereum is many times more efficient than Bitcoin. It is predicted, should Ethereum successfully transition to a PoS system, that the power delta between the two currencies will only grow.

V. Prospective Consensus Algorithms

The power and throughput issues present in PoW systems have not gone unnoticed. There are currently numerous alternative protocols that have not yet seen public release yet. Nevertheless, these provide interesting insights into how the blockchain development community is looking to improve the flaws in current implementations. For the sake of brevity, only two such prospective algorithms are discussed here.

A. Proof of Luck (PoL)

Currently, still a proof of concept, the Proof of Luck whitepaper [25] states that the aim of this novel system is to reduce the large amounts of computational power required by PoW and to increase transactions throughput. Within this system, each block is assigned a "luck" value as it is mined, which is a random number between zero and one: higher numbers being luckier and lower numbers being unluckier. Miners working on verifying transactions within the network will prefer to append their block to the chain with the highest luck value, which is calculated by summing all the luck values contained within each block of the chain starting from the genesis block up to the latest transaction.

Before mining is completed and the block's proof is broadcast to the network, a delay is imposed based upon the random luck value of the block being mined: a higher luck value equating to less delay time. This delay optimizes network communication within the system as, should another miner solve the proof first on a block with a higher luck value, the original miner will not need to broadcast their block to the network.

B. Proof of eXercise (PoX)

Unlike Proof of Luck, which aims to reduce the computational power required by a Proof of Work system, Proof of eXercise aims to direct the computing power towards real-world scientific problems. The PoX whitepaper [26] describes a system where miners will be given matrix-based problems provided by so-called "employers" within the system. The reasoning for using matrices is two-fold: matrices are composable, allowing for easier tuning of network difficulty, and matrices are a principle abstraction for many scientific computational problems. The whitepaper provides the following problems as examples: DNA and RNA sequencing, protein structure analysis, data mining, face detection, and more.

As the required data for these matrix problems must be stored and readily available, at cost, by an employer on the network, a "hostage credit" system is put into place. For a miner to receive a problem to solve, he must first "bid" on this problem by putting forth a deposit that will be refunded upon successfully completing the problem. Likewise, an employer must also deposit a sum that has a greater total cost than the cost of storing the matrix data. Upon completion of the problem, the solution generated by the miner is then sent to verifiers, who will use a probabilistic verification scheme to verify the data in parallel before it is committed to the blockchain.

To avoid potential collusion between miners, employers, and verifiers, solutions the matrix problems are sent through a shuffling service. This is done in two parts: directly after an employer publishes the matrix data, and directly after a miner sends the data for verification. In addition, should multiple miners win a bid to solve the same problem, the coin reward for the solution will be shared between them.

VI. Limitations

The most obvious limitations of this research are the difficulties finding accurate transaction per second numbers for each blockchain network as well as finding energy expenditure figures for the less popular blockchains (i.e. not Bitcoin or Ethereum). TPS numbers often originated from third party sites reporting on the topic or, in the case of the NEM network, numbers originated from marketing materials. These numbers cannot be fully trusted and should only be used to give a general idea of what a network could theoretically be capable of.

In addition, due to the mathematical complexity of the proofs contained within each cryptocurrency's

whitepapers, it was not possible provide an in-depth comparison of each protocol's strengths and weaknesses as the base for a blockchain network. It is due to this complexity that the choice was made to analyze cryptocurrencies' implementations of consensus algorithms as opposed to directly pitting algorithms against themselves.

Related to the above, there was the problem of choosing which cryptocurrencies to include in the comparisons. At the time of writing, the cryptocurrency market is in a state of volatility, causing the top ten list to vary throughout the research period. Furthermore, this method of ranking is the equivalent of a popularity contest rather than being based on a more objective measure.

VII. Preliminary Conclusions

Based on the preliminary findings within this paper, it can be concluded that the Proof of Work system, which is by far the most popular consensus algorithm in use among cryptocurrencies, will eventually be replaced by newer, more efficient algorithms. Ethereum is the most obvious evidence of this, as the Ethereum blockchain has been planning a transition to Proof of Stake for at least the last year.

Should Ethereum finish the transition to a PoS system, an in-depth comparison of the new system compared to the current one would provide a good avenue for further research. Should the transition not be successful, a more general analysis of RPCA and SCP could be conducted as both protocols aim at providing a global-scale network.

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Workflow for image categorization using cognitive computing services

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***Abstract* - The paper describes the structure of an Azure Logic App and gives a brief overview of the most relevant Computer Vision API services. Several solutions had been tested on a sample set consisting of vehicles photos in various street environments to show which of information can be extracted, e.g. licence plates, class of car, etc. and to estimate feasibility of different development scenarios. As an example of integration of various cloud services, a workflow for image categorization using Microsoft Computer Vision API and Azure Logic Apps had been developed as described in this paper. The Logic Apps workflow is triggered by taking a photo on a mobile phone and uploading it to a cloud storage for which a Logic App connector exists. The paper describes the developed workflow and discusses possibilities of replacing any component with another one, i.e. replacing a workflow trigger or the cognitive computing service. An approximate maintenance price calculation is done by estimating number of executions for each Logic Apps function based on a sample set of photos. The paper concludes with solution drawbacks and future work possibilities.**

Keywords - workflow; image categorization; Azure Logic Apps; cognitive computing

I. INTRODUCTION

Utilizing cloud computing services for image processing is not a novel approach, especially in cases of large data sets (e.g. medical images [1]), or in cases of limited hardware power (e.g. [2]). Using cloud in general brings several advantages in terms of immediate access to resources for compute intensive tasks [3].

However, integration of heterogeneous systems in the form of web applications, storage services or any number of different cloud or cognitive computing services may entail upkeep and management of appropriate hardware, downtime in altering or replacing system components, or service subscriptions in generalized pricing tiers that are not tailored to each particular customer's needs.

Although individual users and small organizations adopt new technologies more easily than large entities [4], it must be noted that adoption of cloud computing greatly depends on fact whether it requires more technical skills from developers [5].

With the goal of mitigating or circumventing these issues, the feasibility of using Azure Logic Apps to integrate various separate systems into one cohesive unit is explored. The paper explores possibilities of categorizing images in cloud storage via cognitive computing services found online.

Azure Logic Apps feature tools that allow passing instructions and data from one service to another, allow creation of workflows that manage and apply the tools, and frame both in a serverless architecture. Finally, the pricing is based on per-use cost for each use of a single resource, rather than on subscriptions with upfront set prices and usage limits. The latest is a characteristic of a model called Function as a Service (FaaS) [6] as an extension to traditional service (delivery) models: Infrastructure of a Service (IaaS), Platforms as a Service (PaaS), Software as a Service (SaaS) and various deployment methods as described in [7] and [8].

As a part of this project, Azure Logic Apps are used to build a scalable and modular solution for categorizing images. The solution is a workflow that relies on cognitive computing services to determine the appropriate category for a given image. It is tested with a sample set of images. The process of exchanging different components of the workflow for ones not offered within the Microsoft Azure platform is given, and the price of use for the designed workflow is estimated for the given sample set. Lastly, a summary of drawbacks and limitations of such a solution as well as the potential for future work is provided.

The rest of the paper is structured as follows. In section II an outline of used tools and technology is given. The built solution is described in Section III. Section IV provides pricing estimates for the solution. Conclusions, drawbacks of proposed solution and future work guidelines are elaborated in Section V.

II. TOOLS AND TECHNOLOGIES USED

A. Azure Logic Apps

Azure Logic Apps [9] is a service that allows users to design and run an application that is able to connect to and use various API endpoints on the Internet without the need for the user to know any specific programming language or own any hardware to run it. This application, called a Logic App, is designed through either a GUI or a definition written in text, similar to a markup language, and hosted in the Microsoft Azure cloud. The design process of the application starts with creation of a workflow that describes the pattern in which these endpoints will be used, as well as which external action triggers the workflow execution. For an application to access an API endpoint, the design specifies only the

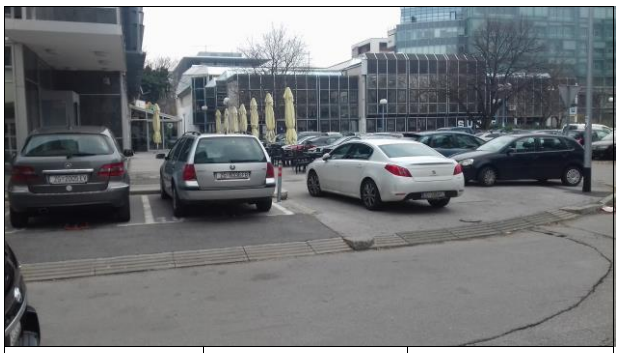
required endpoint and any data the application requires to forward to it. All connectivity and compatibility issues are resolved implicitly by the engine running the application. When the action completes and the endpoint returns a response, the data in the response can be used further down in the workflow. This is done through application components called *connectors* and their usage is similar to a function call with input parameters used in programming languages. Any data the connectors return can be referenced in the workflow design and used in conditions that influence the execution of the workflow or as input for subsequent connector use. Connectors exist for only a limited number of supported services, but it is possible to create user defined connectors for any service with a usable API.

B. Computer Vision API

In the example provided in this paper, a connector for Microsoft Vision API [10] is used to analyse an image and generate a set of paired values called tags each having a name and corresponding confidence score. Tags are used to decide the path of execution for the rest of the workflow. In addition to directing workflow the Vision API will be used to extract information that can be processed in other workflow components, such as conducting optical character recognition (OCR) to try and scan the licence plates of any potential vehicles in the photo. Microsoft Vision API was chosen, but may be replaced by any other cognitive computing service that can provide the same functionality. An extensive test of image recognition APIs was done in [11] and [12], and based on the results from [12] Microsoft Vision, Google Vision [13] and Clarifai [14] have been chosen to demonstrate what information could be extracted from an example set used in the paper. Tables I through III display these differences for Microsoft Vision, Google Vision and Clarifai.

In Table I all three services yield similar, accurate results, although Clarifai gave significantly higher confidence scores for tags “City” and “Street”.

TABLE I. RESULTS OF FIRST IMAGE ANALYSIS



Microsoft Vision		***Google Vision***		***Clarifai***	
Tag	***CS***	***Tag***	***CS***	***Tag***	***CS***
Car	99%	Car	98%	Car	99%
Street	82%	Street	82%	Street	99%
City	59%	City	63%	City	97%

This difference in confidence makes Clarifai seem more reliable when analysing pictures where Microsoft Vision fails to detect objects, as shown in Table II, but higher confidence values do not guarantee accuracy.

TABLE II. RESULTS OF SECOND IMAGE ANALYSIS

Microsoft Vision		***Google Vision***		***Clarifai***	
Tag	***CS***	***Tag***	***CS***	***Tag***	***CS***
Street	94%	Car	98%	Street	98%
City	62%	Street	89%	Car	98%
Car	-	City	77%	City	97%

For example, Microsoft Vision fails to detect a truck in the photograph in Table III, but unlike Clarifai it does not give false positives by detecting a police vehicle with a high confidence score.

TABLE III. RESULTS OF THIRD IMAGE ANALYSIS

Microsoft Vision		***Google Vision***		***Clarifai***	
Tag	***CS***	***Tag***	***CS***	***Tag***	***CS***
Road	99%	Transport	98%	Vehicle	99%
Parked	77%	Car	96%	Police	97%
Trailer	16%	Truck	89%	Truck	94%

Differing analysis results will deliver differing categorization results for each image. In this project Microsoft Vision was used because it is natively supported in the Azure cloud, but it can be replaced with a different service, so long as the rest of the workflow is readjusted to work with different input data.

C. *Azure Functions*

The data generated by the cognitive computing service is not structured adequately for the condition checks needed to construct a simple and efficient workflow, so additional components are necessary to process and format the data. The tag value pairs are in a tuple collection where the name value is not also a key, and the result of the OCR operation contains all recognized text, which needs to be screened for relevant information. These issues are solved using Azure Functions, a service for hosting, compiling and executing functions written in several programming languages. Separate functions are written in the C# programming language for the purposes of extracting metadata from a photograph, formatting tag names and confidence scores, and parsing text for licence plate patterns via regular expressions. These functions are hosted in the Azure cloud and accessing them is a built-in capability of Logic App workflows. Their limited options for input and output data parameters initially allow for only one aggregate body of content, rather than multiple separate parameters, but this can be expanded upon by accessing them through a custom built connector.

D. *Other services*

In addition to the connectors already mentioned, various others were used to access services such as OneDrive, Gmail and Bing Maps. The photos used for the sample set were being uploaded to a OneDrive folder as they were taken. The OneDrive connector is the trigger that initiates the workflow, and it's also the means through which the photo is finally categorized once the workflow had finished. Gmail is used to create e-mail notifications for specific image inputs where image tags and descriptions are contradictory and Bing Maps are used to retrieve the address of the location in the photograph if the photo has embedded GPS metadata.

III. WORKFLOW FOR IMAGE CATEGORIZATION

A. *Workflow design and execution*

The workflow categorizes images uploaded to a OneDrive folder by sending it to a cognitive computing service for analysis and moving it to the appropriate subfolder depending on the analysis results. Figure 1 shows an example of a single workflow execution that repeats for every image uploaded to the selected OneDrive folder.

For the workflow to know when an image is uploaded to the storage service, a special OneDrive connector is used called a trigger. The trigger specifies under which conditions the workflow will be activated, in this case, whenever a new image is detected in the Camera Roll folder. When the Logic App is built and ran, it will continuously check these conditions as frequently as it is specified to do so. This can range from once every couple of seconds to once every month or year. The application is set to check the trigger conditions once every five minutes. When the trigger detects a new image, the workflow is started.

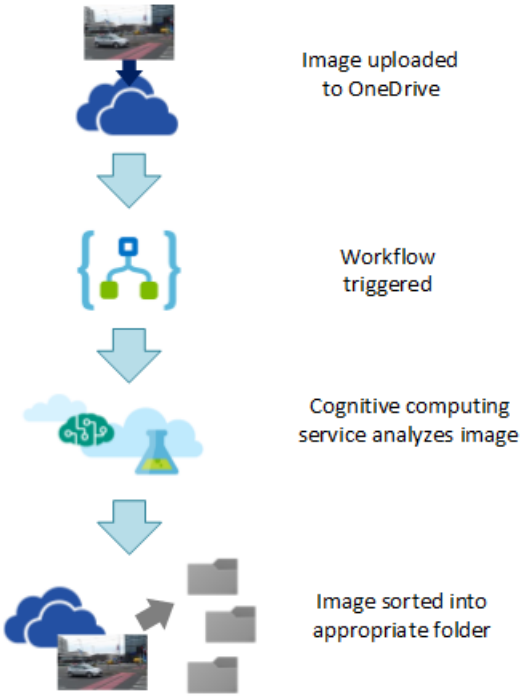


Figure 1. Example of a single workflow execution

The first action executed by the workflow is uploading the image to the cognitive computing service for an analysis. Its connector accepts raw image content as input and returns descriptive data including a verbal description of the photograph and a set of tags in the form of paired names and confidence values that will be used to direct the workflow.

Every branch of the workflow ends with an action that moves the image into a category folder. The conditions leading up to that branching path affect which category folder the image will be sorted into. The folders do not have to be pre-made, and the categories themselves can be variable. For example, in one of the branching paths, images of city streets will be categorized by names of the streets where the photos were taken, despite not having made a folder and defined a sub-category for every single street name in the city.

Before the tags generated for the image can be used, they need to be formatted into a form in which they can be easily referenced. The tags are returned from the Vision API in a collection of tuples, pairs of names and confidence scores, but this is not enough to reference each one of them individually. The tags checked by any following conditions might not even be mentioned in the collection, which would lead to an application failure. Furthermore, tag names are not key values, only the whole collection could be referenced in a condition, and a loop would have to be used to access the tags one by one. Since this would lead to multiple executions of such conditions' failure branches, iterating over the collection is not a viable design. Instead, an Azure Function with a custom connector is used to process the collection by a function written in C# that returns referenceable confidence scores of only the tags that will be used in the decisions made further in the workflow, shown in figure 2.

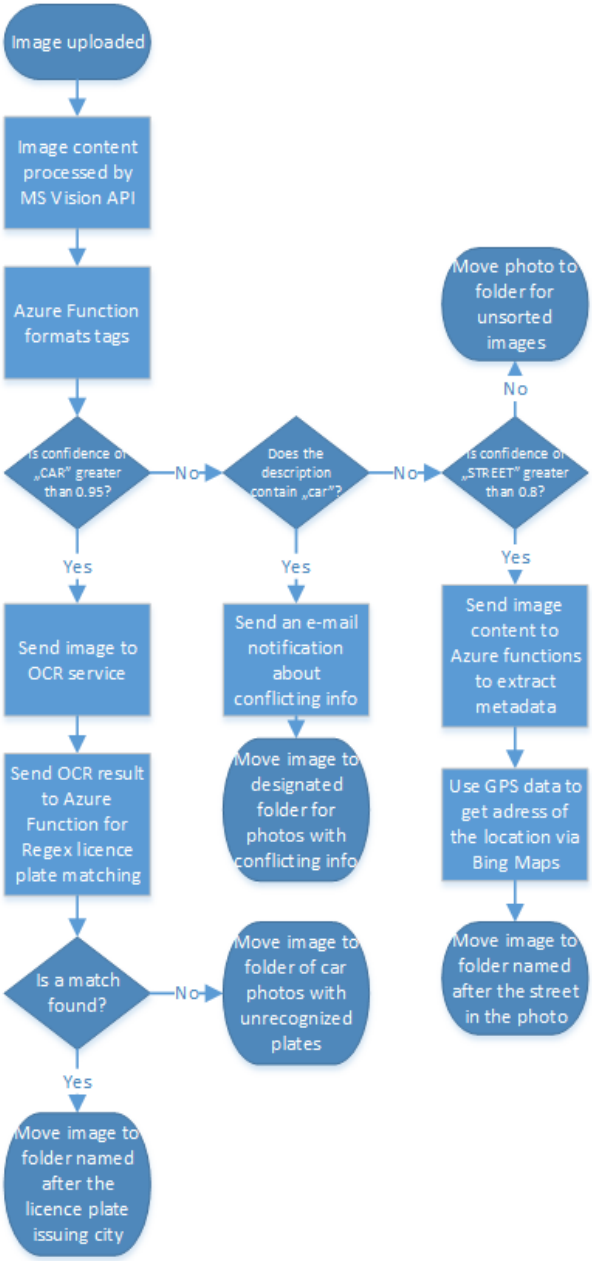


Figure 2. The Logic App workflow

The Azure Function receives a tag collection as input and returns confidence scores of the tags named *car*, *parked*, *city*, and *street*. If the tag collection does not contain any one specific tag, it simply returns the confidence score of that tag as zero. The benefits of this function are twofold. Firstly, it returns values that always include the set of tags that the workflow needs for decision making, regardless of whether they exist in the Vision API collection or not. Conditions can now be made with the knowledge that the necessary information will be available. Secondly, these values can now be referenced directly and individually, removing the necessity for iterating loops. Once the function completes, conditions can be evaluated and the workflow continues.

The first condition to be checked is if the confidence score of the tag *car* is greater than 0.95. The value of 0.95 was selected as a threshold for this score because Microsoft Vision API returns either a very high confidence score for this tag or it doesn't mention the tag at all. There have been no images where a middle ground was found for this tag, each was in either one of these extremes. These scores vary per tag name, so a tag named "sidewalk" will appear quite often with scores between 0.3 and 0.6 whereas the tag named "road" will appear in nearly every image with a confidence score above 0.99. However, a different computer vision service will give different results. Exchanging the cognitive computing service for another one would require altering both tag names and confidence score thresholds to retain the same results from the Logic App.

The condition branches into two separate paths depending on whether it was evaluated *true* or *false*. If the confidence score of the tag *car* is greater than 0.95 it will be evaluated as true, and from then on the workflow assumes that there is indeed a car in the photo. Next it will try to scan for licence plates of the car if they are readable. The image is sent to an OCR service, again this will be done through a Microsoft Vision API connector, that receives raw image content as input and returns text recognized in the image. This text may contain more than just licence plates. It is also possible for the licence plates to not be readable. For these reasons, the OCR result needs to be parsed for valid character string patterns that may make up a licence plate of a car. To achieve this, the OCR result is sent to an Azure Function which tries to detect these patterns through regular expressions. If a match is found, this function returns the matched text as well as the name of the city where these licence plates were issued, for convenient use in further steps.

If a match was found, the photograph belongs in the category of car photos with recognized licence plates, and the subcategory of the city where the licence plates were issued. To achieve this, a OneDrive connector was used, for the function of moving the image to the appropriate subfolder. This does not require separate conditions and actions for each possible sub-category. Instead, the resulting path name is given with variable values in place of folder names. Alternatively, if a match was not found, the photo is moved to a separate pre-defined folder for photographs of cars with missing or unrecognized plates.

If the initial condition involving the confidence score of the tag *car* is evaluated as false, the workflow branches out into a different path. In this alternative path, the OCR service will not be accessed and instead, depending on further conditions made, different services will be used to determine the proper category of the given image. Different connectors and services used will result in a different price of this particular Logic App execution.

In the built example, the follow up condition checks if the word *car* is mentioned in the verbal description provided by the image analysis from Microsoft Vision. Verbal descriptions come in the form of simple sentences, terms or phrases, e.g. "A car parked on the side of the road". If the description mentions a car, the condition is evaluated as true and an e-mail notification is sent to inform the user about an image analysis containing conflicting information on the latest photo supplied to the application. This is done using a Gmail connector. This connector requires the designer of the application to log

into the account that will be used for sending the e-mail. The recipient of the notification can receive it without providing any credentials, since the workflow action is not using their account to execute this action. After the notification is sent, the photo is moved into the folder designated for images with conflicting analysis results.

If both previously mentioned conditions had been evaluated as *false*, it will be assumed that a car is not in the photograph. Instead, the *street* tags' confidence score will be evaluated next. If the confidence score is greater than 0.8 the image will be sent to an Azure Function that extracts GPS metadata from the image. The geographical latitude and longitude are then sent to a Bing Maps connector, which performs the function of finding the location address. The connector returns a multitude of information about the specified location, in several different formats, so further processing with Azure Functions is not necessary as it was before. As before, the address can be used as a variable value in defining a new path name for this photograph. Upon using the OneDrive connector to move the image, street name will be the name of the sub-category this photograph belongs to, in the category of photos of city streets.

Finally, if all conditions fail to specify the category for a certain image, the image is moved to a folder for uncategorized images to be reviewed manually.

B. *Replacing components*

If a component of the workflow requires to be changed or a certain branch needs to be redesigned, the connectors can be removed and replaced. This can be done as long as no other conditions or connectors reference the data they output. In the above design, the e-mail connector responsible for notifying users about conflicting information could be taken out without any consequences for the rest of the workflow, since the branch it is in can still finish. However, removing the Bing Maps connector would not be allowed, as the information it returns is used in the final step of the workflow. This does not mean that the branch would have to be removed and reassembled completely. Rather, only the reference to the data used needs to be removed, and replaced only when the replacement connector is put into place.

Substituting the Microsoft Vision API connector with a connector that would access a different computer vision service (such as Clarifai, Google Vision, IBM Watson or any other similar service) can be done without changes to the design of the workflow. The reason for this is that the conditions in the rest of the workflow don't reference the results given by the Vision API. Instead, they reference the results returned by the custom Azure Function that formats the Vision API data. In replacing the cognitive service connector, only the tags collection reference needs to be removed from the input values of the Azure Function connector. When the reference is removed, the Vision API connector can be deleted. Another connector can be inserted in its place and the tag collection can be passed to the Azure Function again, this time from a different service. This may require some editing of the function as different services have different text formats for the tag collections, but the core functionality of tag name and confidence score pairs is retained. Also, conditions would require their confidence score thresholds adjusted to account for different services giving different results and being accurate at lesser or higher thresholds.

As for the substitution of the cognitive service connector itself, the Microsoft Vision API connector is available in the Azure Logic App designer by default, whereas other computer vision services are not. In order to use them, a custom connector or Azure Function would have to be created. There are multiple ways to do this. One of which is to write an Azure Function that accepts raw image content as input and sends it to the selected computer vision API in the appropriate request format. Upon receiving the results, it would return them to the calling workflow. Such a function could work without a custom-made connector, and instead return the tag collection in its response body. If the workflow needs all the data provided by the cognitive service such as the verbal description or other data, the function would need a custom connector that would have multiple output values, each of which would be individually referenceable.

IV. PRICE ESTIMATES

Prices of using cloud architecture and potential savings compared to traditional architecture cannot be easily calculated. Authors in [5] remind on too optimistic savings plan for outsourcing jobs and warn of additional work that has to be done due to architecture change. Simple comparisons between cloud architecture and grid computing has shown economic benefits of cloud architecture [15]. More complicated model and tool for total cost of ownership and total resource provisioning cost are described in [16], and [17] respectively.

However, there are situations where price comparison between cloud architecture and using own hardware cannot be done, e.g. for novel ideas requiring immediate access to resources and without long-term plan of product lifetime. Thus, in this paper only simple maintenance cost of the proposed solution had been elaborated based on results from experimental phase.

Logic Apps offer multiple subscription options and payment models. The model used and described as a part of this project is the Pay-As-You-Go subscription, which has no upfront costs. Instead, the user is billed only for the components and services they used, per each individual use of the unit within the last billing period of 30 days. Every time a connector is activated within a workflow, the price of use of that connector is added to the bill. If the workflow executes one out of multiple possible paths towards completion, only the connectors actually used in that particular path are billed. This means that different runs of the same Logic App can have different prices, depending on which services, and how, are used in each run. If the use of a certain service involves data transfers or file read/write operations, then the cost of these transfers or operations will be added to the bill. For the remainder of this section, all prices noted will be expressed in values before taxes are applied.

The prices of a single use of a component are measured in fractions of a euro (€). A single use of a connector costs 0.0105 euro cents at the time of writing.

The workflow trigger is also a connector, and every time the trigger is checked, whether the workflow executes or not, the connector will be considered used. The price of use also involves the costs of retaining data, at the price of 11 euro cents per gigabyte. Built-in Logic App actions such as condition checks and Azure Function calls (for functions that are not called through a custom connector) are billed at 0.0022 euro cents per execution. Depending on the design of the application, the total cost will vary based on how often these components were used and how sizeable their workload data is. For the solution described in this paper, the costs incurred for processing the sample set of 14 images with the total size of approximately 34 megabytes amount to 4.5 euro cents. The cost distribution among the three billed articles is shown on figure 3.

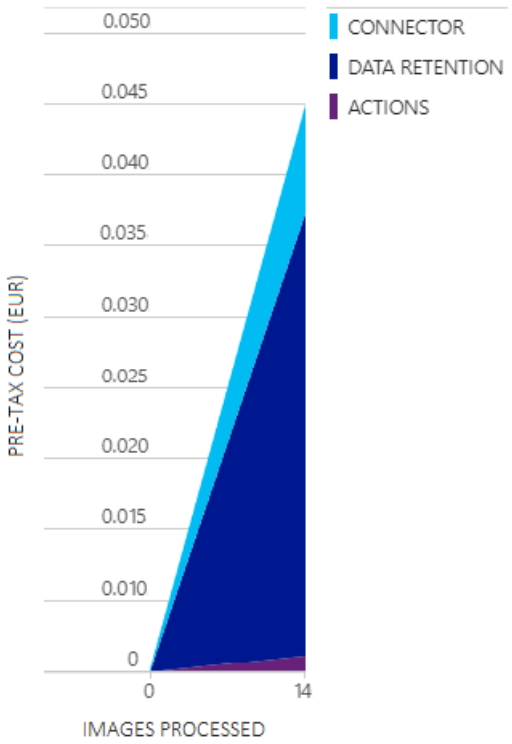


Figure 3. Cost of workflow executions for the sample set of 14 images

From this information, the cost of use per the size of the workload can be calculated for each customer. Higher quality images will cause greater data retention costs through their larger file size. A larger volume of smaller images will raise connector and action costs in relation to data retention cost.

V. CONCLUSIONS AND FUTURE WORK

This article shows how a simple and scalable solution for system integration can be built in the Azure cloud. Costs based on consumption and modular design make it adaptable to different consumer needs and easy to modify and maintain. The cognitive computing service used is not infallible, but it may be exchanged for a different one with minor changes to the workflow design.

Potential future work involves specialized tools to change the design through its definition in text and allow for workflow design to be carried out on a local machine and exported to the cloud. Another subject would be tools that allow the end user to define their own rule set for workflow direction, without the help of a developer.

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Development and Evaluation of an Application for Sharing Information About Courses

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***Abstract* - Learning Management Systems (LMSs) such as Moodle are nowadays widely employed in higher education institutions. They enable teachers to publish educational materials and students to use them. Since students are not allowed to publish materials, they are turning to alternative ways of sharing information, most commonly through social networks. However, this approach of sharing information has a number of flaws such as poor content structure, lack of filtering options, and the fact that information shared by senior students are not available to their junior colleagues. This paper introduces the application whose purpose is addressing the aforementioned issues. Apart from functionalities that facilitate management and organization of content being shared, the application also has implemented gamification elements that encourage continuous use by students. With an aim to examine to what degree the application is accepted by students, an empirical study was carried out. Study findings are presented and discussed.**

Keywords - Web Application; Adik; Sharing Information about Courses; AngularJS; PHP; RESTful Services; Gamification; Technology Acceptance Model

I. INTRODUCTION

The number of web applications has significantly increased in the last decade. The ability to use application regardless of the accessing device and operating platform, the ability to use the application without installing it, and providing a rich user experience are just some of the advantages of web applications. As the number of web applications increases, the number of development tools and technologies increases as well. Their purpose is not only to provide faster development of web applications but also to provide a better user experience in terms of increased efficiency. Among the many technologies that enable quick and easy development of web applications, the ones that are most commonly mentioned in the past few years have been selected for the development of the Adik [8] application that is introduced in this paper.

The application was developed to facilitate information sharing among students. The need for application occurred due to the badly structured ways of sharing information, files, and links related to certain courses. Alternative ways of sharing such information were implemented through various groups on the social networks such as Facebook. There are posted various information, files, and questions, along with few ads for seasonal jobs. That concept acts inadequately functional primarily because of the poor structure of the published content which means that all information is published in one place without any filtering ability.

The remainder of the paper is structured as follows. Brief overview of current solutions in the field is provided in the next section. Technologies employed for application development are explained in the third section. Details on application implementation are provided in the fourth section. Application functionalities are described in the fifth section. Social aspects of introduced application are explained in sixth section. Empirical study findings are discussed in the seventh section. Concluding remarks and future work directions are offered in the last section.

II. RELATED WORK

Before developing an application, it is important to make a review of similar existing applications to better understand the user requirements by analyzing their advantages and shortcomings.

The first similar application is called FER2.net and has been developed by students of the Faculty of Electrical Engineering and Computing, University of Zagreb. Registration on the application is allowed only to students who are on the FER2 student list with the annual subscription [4]. The application structure is formed as a forum where students can ask questions, answer them, and upload materials. When posting a new content, the subject which the content refers to is selected. The application enables all functionalities needed to provide students with easy information sharing. However, the major disadvantage is the aforementioned money subscription without which a student cannot access any content. That is understandable given the server load caused by a substantial number of users and published material.

Second similar application shown in Figure 1 is Trello. It is a collaborative tool that organizes projects into boards. In a nutshell, Trello tells the user what is being done, who works on it, and where something is in the process. The Trello board is a list of lists filled with cards used by individuals and their teams. Trello provides the ability to create teams and assign boards to them. Like boards, teams can have members (administrators and regular members). There are no limits on the number of members who may be in the team or in the number of teams that link to one user account [9]. Trello is not a specialized application for sharing information about courses. However, due to its numerous features and simplicity, Trello can serve as a workable solution to this problem. Trello's biggest drawback is displaying the contents in the form of a card.

The card symbolizes brief information or a task which is not desirable in the context of an application for sharing information about courses because the information lasts much longer.

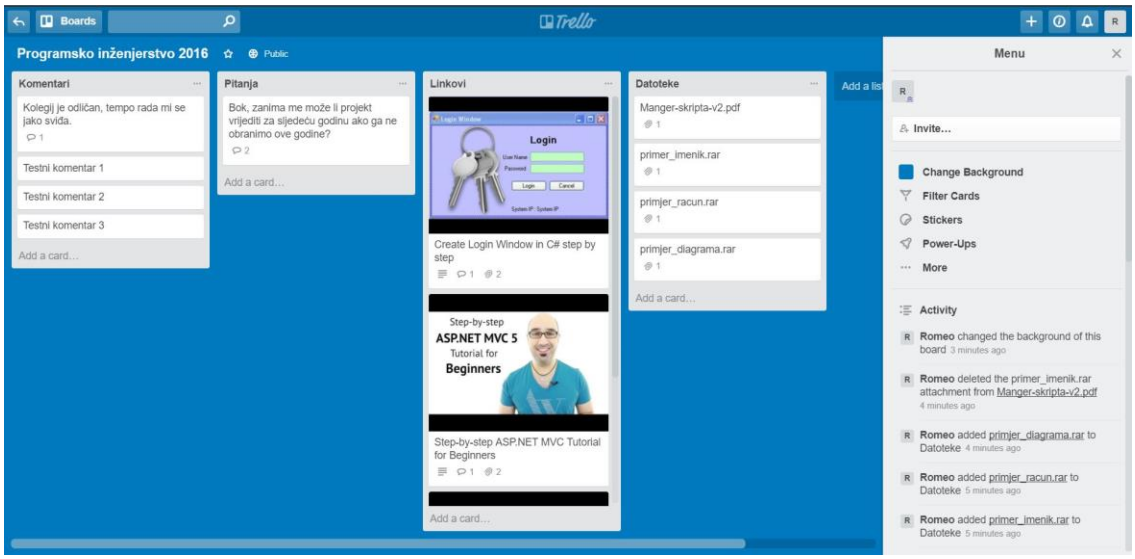

Figure 1. Trello application [9]

Based on previously described solutions, particular attention will be paid during the development of the application not only to improve their shortcomings but also to implement all of their features. To enable users to employ the application free of charge, some alternative ways of gathering funds will be conducted through various student association projects or by implementing adds in the application itself. Content organization and presentation will be designed in a manner to display it in the simple and understandable way.

III. TECHNOLOGIES USED FOR APPLICATION DEVELOPMENT

Some technologies used for developing Adik [8] application are currently among the most popular ones because they enable developing fast, interactive, and responsive applications. They, along with their usage in the application, will be explained in following subsections.

A. *Server side*

On the server-side of application, two most known technologies when it comes to developing dynamic web applications were used: scripting language PHP and MySQL database.

PHP (recursive acronym for Hypertext Preprocessor) is a programing language for generating dynamic web pages and has been designed to be simply implemented in HTML pages, but it does not need to be used that way. It is the most popular and the most employed programing language meant for developing dynamic web pages because of its syntax which is like C, executing speed, lots of features and price (PHP is open source). PHP is used in Adik [8] application for developing a RESTful (Representational State Transfer) service with which the application on the client is going to communicate. RESTful services enable interoperability between different programming languages and applications, and at a certain request, they respond in standardized formats such as XML, JSON, etc. [1].

MySQL is the most popular open source database management system. The reason for MySQL's popularity is price, the speed of commands processing, and ease of execution in server resource requirements. More specifically, MySQL is a relational database management system that works through SQL [6]. In Adik [8] application, MySQL is used to preserve data about courses, comments, files, teachers, users, user favorite courses, and grading.

B. *Client side*

There are a variety of technologies that can be used to run an application on the client side. Some of them are standardly used, such as HTML for displaying content and CSS for defining visual style of the displayed content. Other (newer) technologies such as Bootstrap, jQuery, and AngularJS have also been used to achieve responsiveness, interactivity, and increased application speed.

Bootstrap is an open source tool for designing websites and applications. It consists of HTML and CSS based templates for different components, such as forms, buttons, navigation and other components on the user interface [2]. The advantage of using Bootstrap is a rapid development of responsive applications while the drawback is a resemblance to other applications that also use Bootstrap.

Although JavaScript itself is very powerful with many functionalities involved, due to the different ways in which some web browsers work, achieving the interoperability of certain code between different web browsers is almost impossible. jQuery addresses the problem of different behavior of certain code in different web browsers, shortens the code syntax, provides the ability to concatenate functions, allows separation of JavaScript from HTML, etc. Due to its advantages, jQuery is the most widely used JavaScript library. According to W3Tech's research [10], jQuery is used by over 70% of web pages.

AngularJS is a JavaScript-based application framework that runs on the client side. It provides a simple implementation of the MVC application architecture on the client. AngularJS works by first reading the HTML page where it finds all the directives that are defined either as an HTML element attribute or as an extended HTML element. As a follow up, AngularJS interprets the recognized directives and links the data to the model which is implemented through standard JavaScript variables. AngularJS only requires declaring which parts of the UI map to which JavaScript properties and they sync automatically. This style of programming is called data binding. It is included in AngularJS because it works great with MVC to eliminate code when writing view and model [5].

The JavaScript Object Notation data format, or JSON for short, is derived from the literals of the JavaScript programming language. This makes JSON a subset of the JavaScript language. As a subset, JSON does not possess any additional features that the JavaScript language itself does not already have. Although JSON is a subset of a programming language, it itself is not a programming language but, in fact, a data interchange format. JSON is known as the data interchange standard, which sub textually implies that it can be used as the data format wherever the exchange of data occurs. A data exchange can occur between both browser and server and even server to server, for that matter. Of course, these are not the only possible means to exchange JSON, and to leave it at those two would be rather limiting [7].

IV. PROGRAM SOLUTION

A. Server side

Application on the server side is object-oriented, which makes sense because of the entire object-oriented application concept. The application defines a *model* part that contains all the required classes for an object-related realization of data, and under the *db* directory, static classes that will serve for communication with the database are defined. In the *middleware* part, communication with external systems corresponding to specific requests using a predefined *model* is performed. Each class has a certain validation on attributes to reduce unexpected errors. Also, each class has methods that enable the object to be converted to a JSON format so that the data can be sent to the client. Accordingly, most classes have a method that builds an object from a JSON record. In addition to the aforementioned communication methods, classes have also defined methods that provide CRUD (Create, Read, Update, Delete) operations along with other class-specific methods. Each class includes the corresponding class for communication with the database.

B. Client side

The server part of the application shown so far is quite simple compared to the client side. The client layer has a lot of functionalities, such as filtering data without refreshing the page, i.e. without retrieving filtered content from the server, adding new data without refreshing the page, changing the data view to the next set of data without refreshing the page, etc. All these features make the client layer complex, but the goal was to improve the user experience in using the application and also to reduce the number of requests to the server indifference compared to the traditional way where the page is refreshed after finishing user entry which means requesting data from the server that the client already had. An additional advantage of creating a presentation on the client is the amount of data that needs to be sent to the client. The traditional way is to execute the presentation on the server side and entire content is sent to the client. In this case, the client gets a template and data separately which is followed by presentation execution on the client. This way is much faster, especially with the substantial amount of data because the user only gets a template without any data which is read as a regular static page and, as a result, the initial view is loaded quickly. Described procedure is shown in Figure 2.

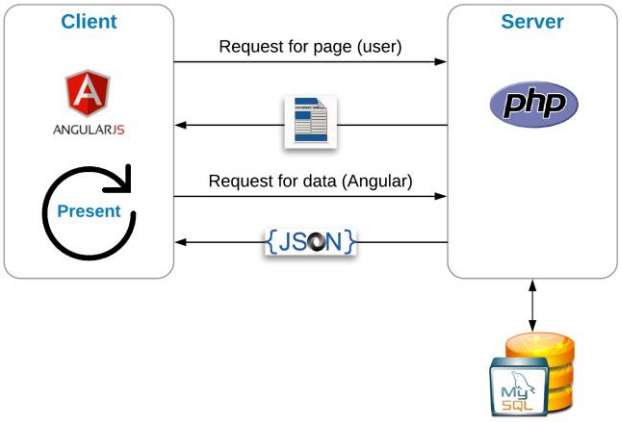

Figure 2. The principle of retrieving content from the server to the client

When updating or adding a data, the communication process between the client and the server is similar. It is noteworthy that the screens to enter or update data are not initially retrieved to the client. The goal is to reduce loading unnecessary content to the client which means that the screen for editing data must be retrieved from the server when a user requests it. The communication process is very fast and easy because the data exchanged between the client and the server is only the data that is being edited. In that respect, the client does not send an entire page to the server which is a traditional way in web applications. The process starts when the user requests a screen for editing certain data and then the application sends a request to the server for that screen. After fetching it, the screen is added to the page and shown to the user in a pop-up fashion. Data that the user updates is fetched from the application on the client. Respectively, its content is not fetched from the server because it is not needed. The screen that serves for editing data has its own Controller, so in order to exchange the data between two Controllers, a service is used where the data will be temporarily stored. The Controller that controls the data editing makes a copy of the data which the user is editing and in case of cancelation, the client still has the original data. If the user cancels changes, the window closes and there is no

communication with the server. However, if the user saves the data, a non-asynchronous function is called which means blocking the page until it receives a response from the server. The server processes the data i.e. saves it or updates it depending on its status (adding new or editing existing data). After processing the data, server return processed data back to the client. The client then synchronizes the information that was entered or changed with the server's response so that the original data that was set up in the service is updated. The window closes and the user can continue to work. Interactions during data editing are presented in Figure 3.

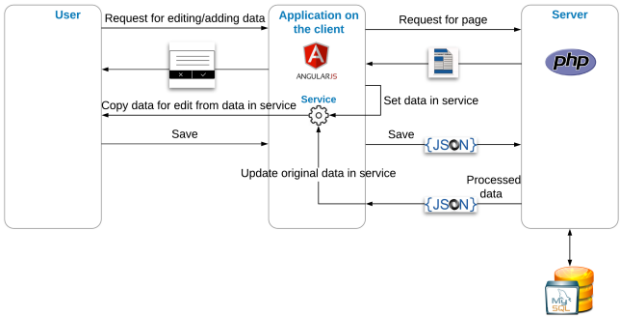

Figure 3. User, client, and server communication during data editing

V. APPLICATION FUNCTIONALITIES

A. *User features*

The application is designed to enable user browsing the home page without being registered. When the user logs-in, all content in the application becomes viewable and editable. The features available to all users are filtering of all courses by entered term or by their status (mandatory or elective). When filtering the courses according to the entered term, the filter recursively scans all object attributes where, for example, the user can obtain all the courses in which a certain teacher appears, regardless of the teacher's position (professor or teaching assistant). Filtering features are shown in Figure 4.

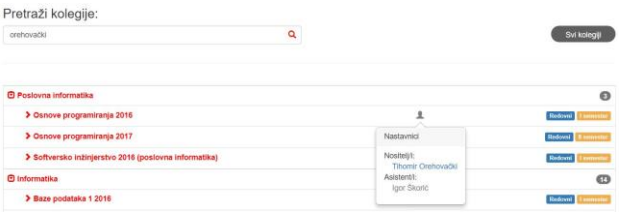

Figure 4. Filtering options

First, the user has to register in order to sign-in, otherwise, the application could not be fully used. In process of registering, the user enters his first name, last (family) name, email, and password. Email must be from the @unipu.hr domain which is a small security measure allowing access only to the students. If an email has already been used for registration purpose, the user will be informed about it. After successful registration, next step is email confirmation, so the user is being directed to the email account page. The email contains a link that verifies the user's email after which the user can sign-in and start using the application.

When signing-in, the user must enter the email and password that was used during registration. If the data is incorrect, the user will receive an error message. If the user forgets the password, the option of resetting the password by entering the email is available when the application sends a temporary password that can be changed within the application.

After registration and successful login, the user can view and edit all content on the application. The next feature (presented in Figure 5) allows a signed-in user to quickly search for a term. The user must only enter the desired term and the application automatically displays the search results.

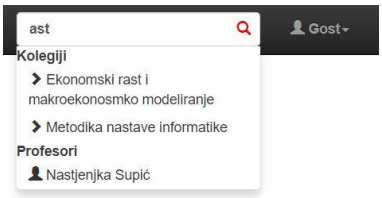

Figure 5. Quick search screen

The user has many features such as editing courses, teachers, comments, and files. When posting a comment, users are offered with an option to post their comment publicly or anonymously, depending on whether they want to hide their identity when other users are reading their comment. Similarly, the user can provide a feedback on a comment. Commenting feature is shown in Figure 6.

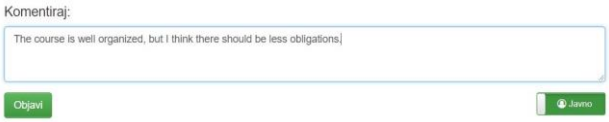

Figure 6. Commenting on course

When a user wants to add a file, the file upload window is opened where the user must provide the file name. As soon as the user decides to save the file, uploading the file to the server starts. After the upload is successfully finished, the window closes and the new file is displayed in the list. Adding a link is very similar to the described file adding. If a user wants to update an existing file or link, the same window is opened where a file or link can be modified or deleted. The functionality of file upload is illustrated in Figure 7.

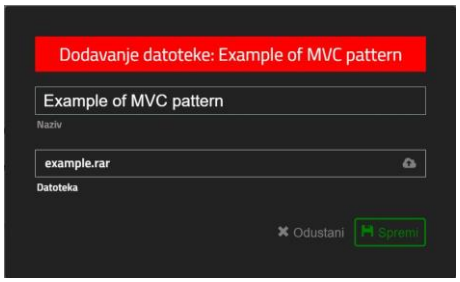

Figure 7. File upload screen

B. *Administrative features*

In the current version, the application has not implemented roles of regular user and administrator. However, since all users can edit all content, there should be an administrator with elevated privileges to monitor changing and deleting data. The administrator would have the ability to assign privileges to other users, disabling the application's use to the user due to improper use of the application, etc. This functionality will be implemented in the next version of the application.

VI. SOCIAL ASPECT OF APPLICATION – GAMIFICATION

This section discusses the social aspect of the application in general and explains what impact the application could potentially achieve to students through gamification elements implemented into it in particular. Gamification is the craft of deriving all the fun and addicting elements found in games and applying them to real-world or productive activities. This is commonly known as "Human-Focused Design" as opposed to the "Function-Focused Design." It is a design process that optimizes for the human in the system as opposed to a pure efficiency of the system. Most systems are "function-focused" designed to get the job done quickly. This is like a factory that assumes that the workers within will do their jobs. However, Human-Focused Design remembers that people in the system have feelings, insecurities, and reasons why they want or do not want to do things, and therefore optimizes for their feelings, motivations, and engagement [3].

The application itself is of a social character which means that students while sharing information can interact with each other in various ways. This enhances their motivation and encourages their desire to work and progress. The second element of gamification is an evaluation of individual information, i.e. users can evaluate courses, comments, questions, files, and links. Files and links do not follow track about the user who posted it, while in comments and question users can see identity of the user who posted the information (unless comment or question is posted in anonymous mode). Elements of gamification are the most represented in those situations. The student who posts the information receives feedback from other students about the usefulness of the published information in form of a percentage. Then the student gains a sense of accomplishment, similarly as passing to next level in the game, which further motivates the student to progress or to move to the next level. Unlike elements of gamification in games that "hooks" users to spend their time without any real achievements and progress in the real world, elements of gamification in educational or the business world are desirable because they stimulate users to expand their knowledge and self-confidence in a fun way. An example of gamification in the application is provided in Figure 8.

Figure 8. Gamification elements

VII. EVALUATION OF ADIK

With an aim to examine to what degree the application is accepted by students, an empirical study was carried out. The study investigated the perceived ease of use, perceived usefulness, social norms and behavioral intention which all together constitute the initial version of the technology acceptance model (TAM) [11]. Participants in the study where students of Faculty of Informatics in Pula. Sample was composed of 111 students, of which 70.27% were male and 29.73% were female. The average age of students was 21.18 and more than half of them (55.8%) were enrolled in the first year of study. Participants were asked to access the application and use it after which they completed an online questionnaire. There was no certain task that participants had to complete other than try using the application. They began by signing up with a new account or by logging in as a guest. They then had the opportunity to browse through the application and try using features the application provides. The responses were modulated on a seven-point Likert scale (1-strongly disagree, 7-strongly agree).

Figure 9 presents results collected with the questionnaire. The majority of students perceived Adik application as useful and easy to use. More specifically, 92.7% of students agreed with the item "Adik application is easy to use". It also appeared that using Adik application is easy to learn since 94.5% of students answered confirmatively to the item "Mastering the Adik application was easy for me". Furthermore, 82.8% of students find Adik application useful during studying because they agreed with the item "Adik application would enable me to do my student commitments faster and easier". Finally, the application also proved to be good for connecting students considering 71.1% of students expressed their positive agreement with an item "I believe that the application Adik is a good idea to connect with my fellow students".

VIII. CONCLUSION

Learning Management Systems (LMSs) are widely employed in education, but there is no, to our knowledge, any application that enables sharing artefacts among students. That is the main reason why they are turning to alternative ways of sharing artefacts, mostly commonly through social networks. The problem of sharing information on courses by students is discussed and application that enables easier, organized, and centered sharing information on courses is introduced.

The design concept used when developing application divides the client and server part of an application. Namely, the server part of the application is developed as a RESTful service with whom the application on the client communicates. This design enables us to present data on the client side rather than on the server side thus decreasing server load and speeding up the application, especially with a large amount of data or through slow networks. Design concepts did not evolve only in the technical sense, but also in the psychological one.

The current approach where an application is designed to meet functional requirements is no longer sufficient; the user should be interested in using the application to be more productive and eager to work. More specifically, gamification means taking some concepts used in video games and implementing them for other purposes in order to increase the interest of users in the use of services or products (in this case the application).

With an objective to examine the degree to which the application meets the requirements of its users, a study was conducted. Based on study findings, it can be concluded that application has met students' requirements and that majority of them have a positive attitude towards using Adik application. In the future work, Adik application will be extended with administrative roles as well as notifications that will inform students when a new artefact has been posted to their favorite courses. The messaging system will also be implemented in the application thus enabling students' instant connectivity with their colleagues.

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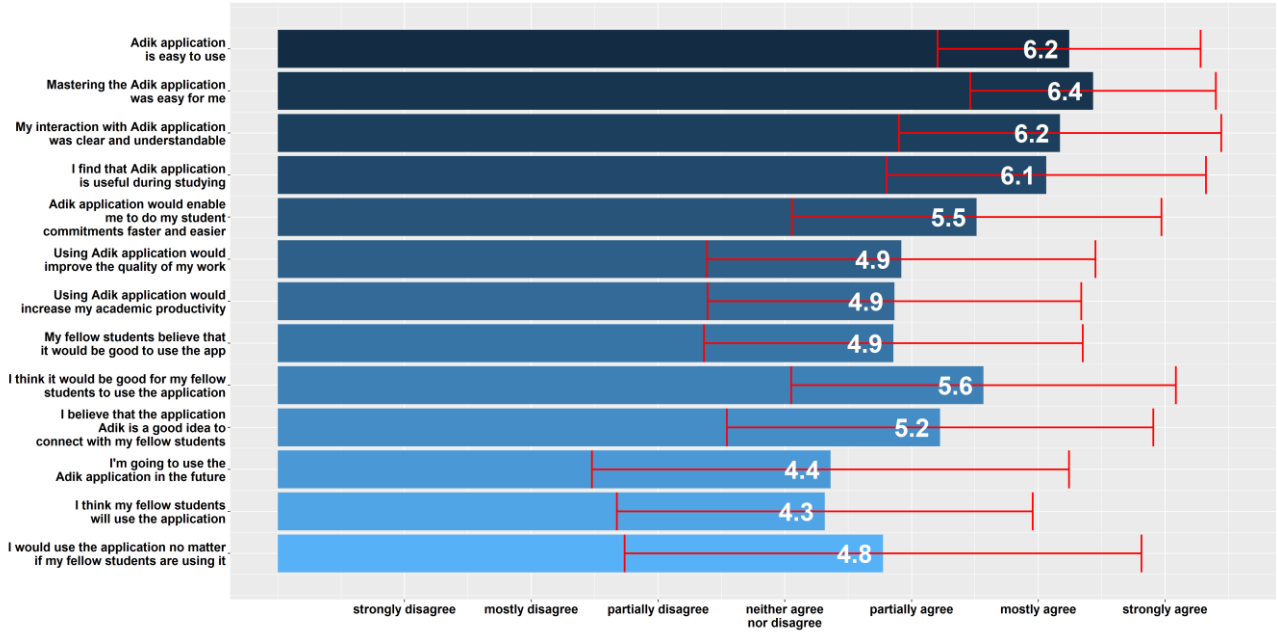

Figure 9. Questionnaire results (Average per question)

E-learning in logistics education

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***Abstract* - Following the implementation of Information and Communication Technologies in numerous segments of life, including the education system, the methods of teaching have significantly changed. Information and Communication Technologies have influenced the educational system which adapted to those trends and to the newer generations that spent their childhood playing with gadgets and learning at the same time. This is how the concept of e-learning and game-based learning emerged. In parallel, traditional logistics has evolved into e-logistics. When these two are combined, a logical sequence appears in which e-logistics at higher education levels is taught by e-learning techniques. This paper researches the means and tools for e-learning in logistics.**

Keywords - e-learning; e-logistics; higher education

I. INTRODUCTION

In the course of the paper, the most frequently used e-learning concepts will be explained. Understanding them is the basis for further discussion on e-learning and the teaching of e-logistics by using e-learning methods. E-logistics is a management subsystem for forecasting, planning, decision making, coordination and control of electronic information flows through information and communication systems and technologies (especially the Internet) with application of mathematical methods and models (in agreement with the material, service, and financial flows and the flow of intellectual and labour resources) to facilitate delivery of the necessary product in the right quantity, of good quality and at an agreed price, at an agreed place and time to the relevant consumer [1].

II. E- LEARNING

E-learning is the use of technology to connect teachers and students who are physically apart. The training can be delivered by a number of means. In the past, these have included the use of mainframe computers, floppy diskettes, multimedia CD-ROMs, and interactive videodisks. Most recently, Web technology (both Internet and Intranet delivery) are being used [2].

A. E-learning types

For years, many people thought that creating an e-learning course was just the matter of taking an old PowerPoint presentation and publishing it in a fancy player. Over time, e-learning evolved into something far more effective (although we still haven't shaken the PowerPoint past completely). While e-learning varies across a large spectrum, in general the e-learning course is likely to fall into one of the following three types [3]:

- Text-Driven
  - the content is simple
  - includes text, graphics, and some audio
  - includes simple test questions
- Interactive
  - similar to a text-driven one
  - more interactive components to enhance the learning
  - include videos
- Simulation
  - highly interactive
  - relies heavily on graphics, video, audio
  - some level of gamification.

E-learning can also be divided into two types - synchronous learning (training) and asynchronous learning (training) [4]. Synchronous e-learning implies learning simultaneously, or at the same time. In this way, students and professors communicate in real time, not in the traditional classroom, but in virtual. In the virtual classroom, it is possible to communicate in a traditional way through audio and video settings and elements. However, there is also a chatting option as another means of communication. In asynchronous e-learning the professor and the students do not communicate in real time. They are not present in the virtual classroom at the same time. However, the moment students approach the virtual classroom, they already have all the learning materials they need. This usually means pre-recorded lectures, as well as additional materials, discussions, and other useful sources of information. It is still possible to establish communication between the involved parties, but not through instant messaging.

Synchronous learning implies the set time (phone/Internet classroom sessions), and learning from the sources of [4]:

- Virtual Classroom
- Audio and Video Conferencing
- Chat
- Webinars

- Application Sharing
- Messaging instantly

Asynchronous learning implies student directed, self-paced learning from the sources of [4]:

- Self-paced online courses
- Discussion forums & groups
- Message boards

The Learning Pyramid (Fig 1), created by the National Training Laboratories in Betel, Maine, illustrates the percentage of learner recall that is associated with various approaches. The first four levels (lecture, reading, audio-visual and demonstration) are the passive learning methods. In contrast, the bottom three levels (discussion groups, practice by doing and teach others) are participatory (active) learning methods [5].

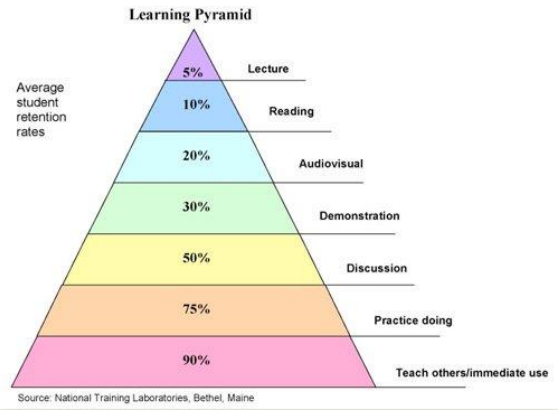

Figure 1. The learning Pyramid [5]

In this type of learning, e-courses are made available to the learners in the form of a CD or Computer-based training (CBT), which can be run on the learner's system. E-courses can also be made available through Web-based training (WBT), which utilise the internet as a platform like a Learning Management System [5].

B. *Blended learning*

Blended learning combines both the Synchronous and the Asynchronous ways of e-learning. Some training, like soft-skills or sales training, has to have a face-to-face component to be truly impactful. A blended approach works best where the classroom is utilised to conduct exercises and interactions. These exercises cannot be conducted in e-learning delivery as peer interaction is limited. Short e-courses can be created to help learners prepare a background for the lesson before they come to class [5].

Although e-learning is in full swing and its popularity is growing, such learning aspect should not be the only way to teach. In fact, the best results are achieved by combining existing traditional methods with modern methods. E-learning should combine enhanced learning, blended learning and online learning [6].

C. *M-learning*

Given the increasing use of smartphones and their highly progressive development and potential, it was just a matter of time when e-learning would evolve into m-learning. One of the most popular examples is the mobile application DuoLingo for learning foreign languages, It achieved over 100 million downloads and a grade of 4.7 with a total of over 5,400,000 users who participated in the evaluation. However, m-learning is still not so much developed or used in the lectures itself, especially not in the higher education system.

Simply converting e-courses to mobile compatible modules is not enough. The capabilities of the mobile device, including disk space, Internet connectivity and the screen size have to be taken into consideration [5].

D. *Simulations*

Simulations are highly interactive and rely heavily on graphics, video and audio. Custom simulations videos or games, often include 3D components [5]. Simulations belong to e-learning because of all the elements involved in the computer simulation itself. In logistics, simulations are of great importance because they allow students to make mistakes in a controlled environment (trial-and-error method) and learn from them visually and transparently. In this way, students directly see the consequences of their decisions. Given that simulations are a tool used in the logistics for better decision making and risk reduction, it is of great importance that the simulations are included in teaching young professionals. They will thus acquire basic knowledge and understanding of logistic processes and simulations.

E. *Game-based learning and gamification*

Such courses focus on creating engagement and motivation for the learners to learn while they play [5]. There is a significant difference that is important to point out. Game-based learning really uses games to bring new generations, raised on games, closer to the content. On the other hand, gamification means to use only game elements in traditional teaching methods or in e-learning, which is to unlock new levels or to collect points during studying.

III. THE PROS AND CONS OF E-LEARNING

The apparent advantage of e-learning is flexibility. It can be fully or only partially implemented in teaching. Teaching can be organized at a specific time, but it does not have to be. It all depends on group preferences and best methodology for them and the professor. Furthermore, given that ICT is largely implemented in everyday life, e-learning is a much-needed way of teaching for future generations. Something that is close to them will automatically be more acceptable. It will increase their interest, and the emphasis will be on interactivity in education. According to Bognar, Gajger and Ivić [7], the students themselves have noticed many of the advantages of e-learning (Fig. 2). The freedom to express their opinions and feelings and the opportunity to participate in classes regardless of the time are the two highest-rated advantages.

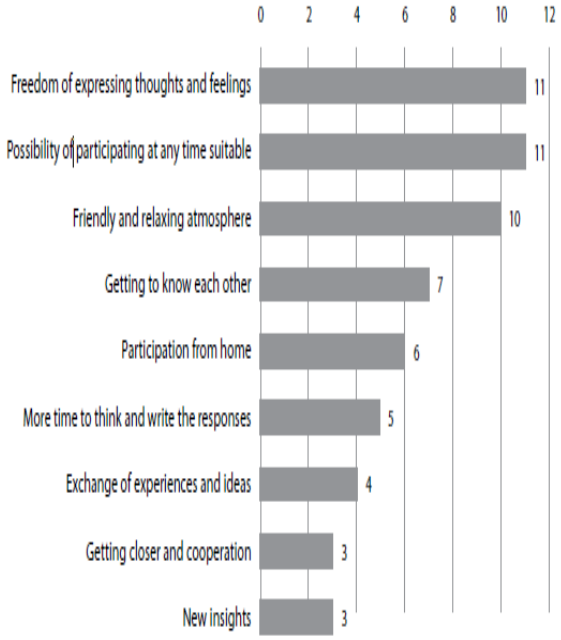

Figure 2. The advantages of e-learning [7]

Other advantages of e-learning are as follows [8]:

- Flexibility
- Instructors and students each report that e-learning fosters additional interaction among students and instructors, more than in giant lecture rooms
- Workplace and actual work are simulated in a virtual room
- Success in finishing on-line or e-learning courses builds understanding
- E-learning encourages students to increase responsibility for his or her learning process and learning outcomes

E-learning also has several disadvantages:

- Learners with low motivation or unhealthy study habits could fall behind
- Without the routine structures of conventional learning, students could get confused regarding course activities and deadlines
- Students could feel isolated from the trainer and classmates
- Slow web connections or older computers could make accessing course materials frustrating for some students
- Managing files and online learning computer code will generally appear advanced for college students with beginner-level skills

IV. E-LEARNING SOURCES IN LOGISTICS AND TRANSPORT

Online learning in higher education in the fields of logistics and transport mainly means either the use of online video-based "for-credit" classes or massive open online courses (MOOCs). While the research completed by Extension Engine (EE) [9] confirmed that these are indeed the most common approaches, the company also found two other significant opportunities for earning sustainable revenue from online learning: pre-matriculation programs and post-graduation programs. While online "for-credit" classes and MOOCs are the most common approaches in higher education, making the commitment to these types of learning requires a strong organizational commitment from the college or university [9].

It is possible to find MOOC and Free Online Courses [10] from Coursera [11], edX [12], FUN [13], FutureLearn [14], Miríada X [15], OpenClassrooms [16] and other Top Providers and Universities in a wide range of categories and subjects. For instance, Massachusetts Institute of Technology (MIT) offers free online non-credited logistics courses such as [17]:

- Logistics and Supply Chain Management
- Logistics Systems Management of Supply Networks for Products and Services
- Manufacturing Systems and Supply Chain Design
- Operations Strategy
- Systems Optimization - Models and Computation

On the other hand, when it comes to transport, Lloyd Maritime Academy offers some other courses in different sectors, but they are not free of charge [18]:

- Bunkers
- Contracts & Law
- Environment
- Insurance
- Logistics, Sea Ports, Sea Terminals & Freight/Cargo
- Maritime Communications
- Maritime Industry Fundamentals
- Offshore
- Salvage, Safety & Security
- Ship Finance
- Ship Management, Ship Manning & Seafarer Training
- Shipbuilding, Ship Repair, Surveying & Engineering

V. E-LEARNING PLATFORMS

There are four options for choosing an online learning platform [19]:

- Learning Management Systems (LMS):
  - Moodle [20]
  - Sakai [21]
  - D2L [22]
  - Blackboard [23]
  - MOOCs [24]
- Social Media and Peer-to-Peer Platforms:
  - Edmodo [25]
  - Classroom 2.0 [26]
  - Peer2Peer University [27]
- Online meeting/conferencing applications:
  - Adobe Connect [28]
  - Webex [29]
  - Join.me [30]
  - Skype [31]
  - Google hangouts [32]
- Two-Way Audio:
  - Skype [31]
  - Google Hangouts [32]

For many people, a LMS is the epitome of online learning. Though the LMS is only component of an online system, it is often the most prominent and visible. It is the platform through which most teachers will teach and most students will learn [19].

Moodle is a Learning Management System (LMS) or a Course Management System (CMS) - a free Open Source software package designed to help educators create effective online courses based on sound pedagogical principles. It can be downloaded and used on any computer which is handy (including web hosts). It is designed to provide educators, administrators and learners with a single robust, secure and integrated system to create personalized learning environments [33].

The success and popularity of Moodle in e-learning is evident from the following statistics [34]:

- more than 90,000 registered sites
- 233 countries
- more than 14 million courses
- more than 123 million users
- more than 500 million enrollments
- more than 700 million questions

There is also an option to implement e-learning in the higher education of logistics through the use of different simulation programs. Some of these programs are:

- Arena [35]
- anyLogic [36]
- IBM ILOG CPLEX [37]
- anyLogistix [38]
- SIMUL8 [39]
- Flexsim [40]
- Flexsim CT / Flexterm [41]
- Beer game [42]

The advantages of simulation software are that students learn to create simulation models and run simulation experiments. What is more important to emphasize, students learn by using programs that are used in the actual business professions. In this way, not only does student involvement encourage and raise the level of their interest, but students also acquire practical knowledge. This will enable the students to gain greater competitiveness when entering the labour market, which is a good argument for even more implementation of such e-learning software.

VI. CONCLUSION

With these benefits, it's no wonder e-learning as an educational offering is revolutionizing corporate training. In fact, more than 75 percent of companies in the United States offer online corporate training to their employees, according to eLearningindustry.com [16].

The fact that employers themselves have recognized this way of training their employees as very successful is one of the additional arguments that confirms that the implementation of e-learning in the higher education system of logisticians is a good move. Not only does it affect the working atmosphere, but from the start, students are learning the skills that will later probably be a part of their corporate training. Previously mentioned labour market competitiveness achieved through the use of various simulation programs in teaching is of great importance for both students and employers.

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Creating a Tabletop Game Prototype in Unreal Engine 4

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***Abstract* - QP_Tabletop (Quick Prototype Tabletop) is an Unreal Engine 4 project created with the purpose of simplifying the process of creating a board game prototype. It allows users to quickly mock up an idea and playtest it without spending time developing mechanics that may or may not work well with the overall game. The set forth enables users to quickly prototype using some predefined classes and behaviors most commonly found in typical board games which in turn allows them to focus on their idea early on rather than thinking about implementation details. This paper will briefly describe Unreal Engine 4, its base classes used in QP_Tabletop such as Object, Actor, and ActorComponent, as well as the classes in the application itself. Special attention will be given to QPT_GameRule class which holds the game specific rules, the QPT_Actor class representing the physical object of the game such as dice, cards, and board, as well as QPT_CommonRule class which contains common rules found in many board games such as rolling multiple dice, shuffling cards, keeping player scores, and changing current player in a turn based game. There will also be an emphasis on the workflow as well as the interaction between these classes.**

Keywords – Tabletop Game Prototype; QP_Tabletop; Unreal Engine 4

I. INTRODUCTION

Creating a tabletop game can be a challenging task as there are many variables to consider. Game has to be balanced and fun for every player and that can be hard to achieve without extensive playtesting. An idea may seem great on paper, but in practice it may not work as intended. That means that when someone creates a game and some mechanics do not work, the time spent creating it is usually wasted. Therefore, it is important to test as soon and as often as possible.

Easiest way to playtest the game is to play it with friends and family using pieces from other games. For simple games that works since most tabletop games share some common components and concepts such as rolling dice, playing cards, moving pieces on a board, etc. However, if the game is complex enough or requires some unique items such as cards created specifically for that game or a special board, then a new way to test the games mechanics is necessary.

This paper will present and explain the workings of QP_Tabletop application created using Unreal Engine 4 as development platform [1]. QP_Tabletop stands for "Quick Prototype Tabletop" and as the name suggests, it is designed for testing and prototyping tabletop games. It functions in the same way as the "manual" testing method explained before. However, this application is much more flexible since it allows the user to have greater control over every aspect of the game.

The remainder of the paper is structured as follows. Unreal Engine and its classes are briefly described in section 2. Blueprint communication is explained in section 3. QP_Tabletop is introduced in section 4. Chain of initialization is explained in section 5. An example of a game is presented in section 6. Templates are described in section 7. Conclusions are drawn in the last section.

II. UNREAL ENGINE 4

Unreal Engine 4 is a professional AAA game engine created by Epic Games [2]. It can be used for free and the source code is fully available. Unreal Engine 4 also has an advanced visual scripting system called Blueprint system which allows users to create games without writing any code. All the set forth makes Unreal Engine 4 easily accessible which in turn makes using the QP_Tabletop application accessible as well.

Blueprint system is a visual scripting system inside Unreal Engine 4 in which each function is represented as a node on a graph with pins for inputs and outputs. As shown in Figure 1, lines that connect those pins are data flows and are color coded for each type of data.

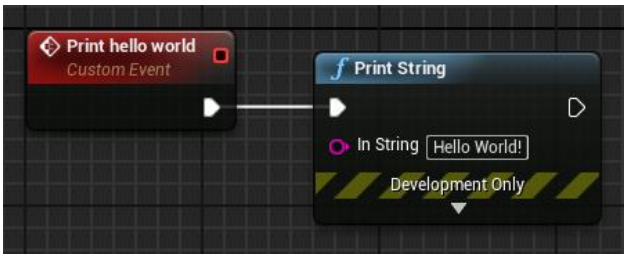

Figure 1. A simple function that prints "Hello World!" on the screen

Classes created in the Blueprint system are called blueprints and act the same way as C++ classes. The most important ones are objects, world, actors, and actor components.

A. *Objects*

Object is the lowest level class that supports reflection which means that every other class must inherit from object in order to be usable within the editor [3]. Even though there are many subobjects within Unreal Engine, we will focus on the most commonly used ones: World, Actor, and ActorComponent.

B. World

World is a class that represents the world, i.e. the space of the game. It allows actors to exist in it.

C. Actors

Actor is an object that can exist within a world. As such, each actor has a location, a rotation, and a scale. They are together called Transform. Actor can also contain components called ActorComponents which can give it additional properties, and allow it to have reusable behavior [4].

D. Actor components

Actor components are objects that can only exist if they are attached to actors. They allow us to reuse behaviors on multiple different actors. There are also special types of actor components called scene components which also have a transform, but it is always relative to the actor to which they belong. For example, static mesh component is a scene component that can be placed inside an actor and can render a mesh. It can also have its own location, rotation, and scale, which is always relative to the actor's transform [5].

III. BLUEPRINT COMMUNICATION

There are multiple ways blueprints can communicate with each other, but we will describe the two main ways often used in QP_Tabletop: direct communication and Event Dispatchers.

A. Direct communication

Direct communication is the simplest way of communication. When one blueprint has a reference to another obtained through a variable or a function output, it can directly call his functions. An example in that respect is presented in Figure 2.

Figure 2. A simple function that destroys a player

B. Event dispatchers

Event dispatcher is an equivalent to the listener design pattern. It allows object A to communicate with object B without knowing in advance what B is. This means that object A has no reference to B and therefore there is no dependency. That allows the class to be modular.

IV. QP_TABLETOP

QP_Tabletop is a framework created in Unreal Engine 4 which allows users to quickly mock up an idea they have for a tabletop game. The general idea of QP_Tabletop is reusability through components [6]. While there are many vastly different tabletop games, lots of them share similar components such as dice, cards, boards, game pieces, etc., as well as similar concepts like rolling dice, drawing and playing cards, keeping track of the score, keeping track of players' order in turn based games, etc.

QP_Tabletop allows users to merge together these generic concepts and unify them in a single game. This enables them to quickly test and modify their idea without spending time on creating all the common mechanics. In order to achieve that, it has to be both modular and easy to use. Modularity is achieved by using event dispatchers and actor components and ease of use by having a large number of premade classes with simple interactions.

The application has several classes based on actors and actor components, but the most important ones are QPT_Actor, QPT_Container, QPT_ContainerComponent and its children: QPT_Spawner, QPT_CommonRule, QPT_GameRule, and QPT_Template. They will be explained in detail in following subsections.

A. QPT_Actor

QPT_Actor is a class that inherits from Actor and it represents a physical entity in a game such as a dice, a card, a board, a tile on a board, etc. It is a self-contained class which acts like a black box that allows user to interact with them without having to know their inner workings.

B. QPT_Container

QPT_Container is a class that also inherits from Actor, and it represents the physical transform of the game itself. All the necessary components are attached to it and it is therefore a central class which contains all the necessary references for that game. QPT_Actor transforms are always relative to the Container which allows the user to create the game and simply move the container without displacing any of the actors. This class also starts the chain of initialization which initializes all the necessary components and actors.

C. QPT_ContainerComponents

QPT_ContainerComponent is an ActorComponent class which attaches to Container. It is an abstract class with three virtual functions: OnCreated(), OnInitialized(), and PostInitialized(). These functions are called when a container component reach a certain stage of initialization. There are three important classes that derive from Container component: QPT_Spawner, QPT_CommonRule, and QPT_GameRule.

D. QPT_Spawner

Spawner is a class which is used when it is necessary to create and programmatically position multiple instances of QPT_Actors. An example would be a game with a board and game pieces positioned on the first and last row. However, if the size of the board can vary, a Spawner can be used to create and initialize QPT_Actors representing both tiles on the board as well as game pieces.

In order to define the pattern in which QPT_Actors are created, user has to set the desired class of QPT_Actor to spawn and needs to override virtual function CalculateSpawnTransforms(). This function, which is

called automatically during initialization, returns a vector of transforms that are used to create these QPT_Actors.

E. QPT_CommonRule

QPT_CommonRule is a class that inherits from QPT_ActorComponent. It represents a rule or concept that is often found in various tabletop games in a generic way. QPT_CommonRule can depend on QPT_Actors or not. If it depends on QPT_Actors, then it manages the behavior of multiple QPT_Actors at the same time, such as shuffling cards or moving multiple game pieces at once. The non-dependent QPT_CommonRules handle common generic operations such as keeping track of players score, managing a timer in time based games, etc.

F. QPT_GameRule

QPT_GameRule is a class that defines the game. It contains a list of all other QPT_ContainerComponents which are created and initialized when the game starts. These components are then used to receive notification when an event happens such as when a game piece is moved, when the cards are shuffled, when the score is changed, etc. QPT_GameRule reacts to these notification stating what happens on them. For instance, after a game piece has been moved, change the current player; when the cards are shuffled, start the next phase of the game, etc.

G. QPT_Template

The inheritance of QPT_Tabletop classes illustrated by a class diagram is presented in Figure 3.

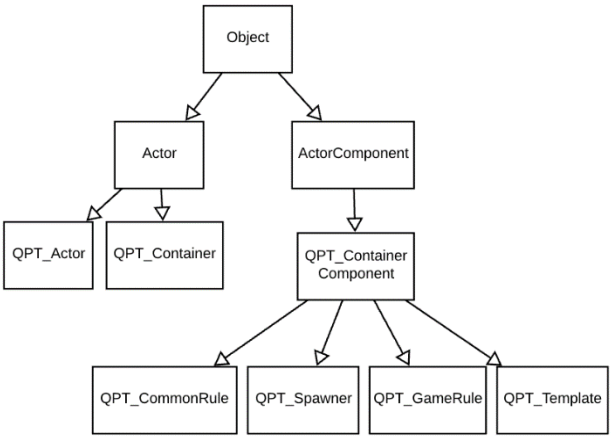

Figure 3. Class diagram showing the inheritance of QPT_Tabletop classes

While there are predefined behaviors in QP_Tabletop, it is useful to allow user to create a class that represents a collection of behaviors. If the user often creates games where there are pieces that move on a board based on dice rolls, then these behaviors can all be stored inside a QPT_Template class. It takes QPT_ContainerComponent classes as arguments and when initialized, it automatically initializes all of them. This allows user to create a reusable interaction between multiple generic behaviors and use it in different games.

V. CHAIN OF INITIALIZATION

Chain of initialization is the order in which classes in QP_Tabletop initialize to create a game. As shown in Figure 4, chain of initialization starts from QPT_Container by calling function Initialize().

```
void AQPT_ContainerBase::Initialize()
{
    if (!GetWorld()) return;
    if (!GameRuleClassToCreate) return;

    UQPT_GameRuleBase* NewGameRule =
        NewObject<UQPT_GameRuleBase>
        (this, GameRuleClassToCreate);

    if (!NewGameRule) return;
    GameRule = NewGameRule;

    NewGameRule->RegisterComponent();
    NewGameRule->OnCreated(this);
    SetGameRuleParameters();

    NewGameRule->PreInitialize();
    NewGameRule->OnInitialized();
    PostInitialize();
}
```

Figure 4. Function Initialize() inside QPT_Container

After checking if the world and the GameRule class are valid, the GameRule is created and registered. Function SetGameRuleParameters() enables setting up some game rules before the initialization continues, such as the number of players. If necessary, function PreInitialize() inside QPT_GameRule allows it to set up some parameters before the initialization starts. OnInitialized() then initializes every other QPT_ContainerComponent.

The function OnInitialized() presented in Figure 5 loops through all QPT_ContainerComponents in order to create and initialize them. Firstly, it iterates through all QPT_Templates since they may add additional QPT_ContainerComponent classes to the list. Afterwards, the function creates all QPT_CommonRules and finally the QPT_Spawners. Reason why templates are iterated through an index is that a template may create additional templates before the loop is completed.

```
void UQPT_GameRuleBase::OnInitialized_Implementation()
{
    for (int i = 0; i < TemplatesToCreate.Num(); ++i)
    {
        TSubclassOf<UQPT_TemplateBase> CurrentTemplateClass
            = TemplatesToCreate[i];
        CreateTemplate(CurrentTemplateClass);
    }
    OnAllTemplatesInitialized();

    for (TSubclassOf<UQPT_CommonRuleBase>
        CurrentCommonRuleClass : CommonRulesToCreate)
    {
        CreateCommonRule(CurrentCommonRuleClass);
    }
    OnAllCommonRulesInitialized();

    for (TSubclassOf<UQPT_SpawnerBase>
        CurrentSpawnerClass : SpawnersToCreate)
    {
        CreateSpawner(CurrentSpawnerClass);
    }
    OnAllSpawnersInitialized();
}
```

Figure 5. Function OnInitialized() inside QPT_GameRule

VI. AN EXAMPLE OF A GAME

In this section we will demonstrate how to create a simple dice game where multiple players take turns and roll the dice. When every player has rolled the dice, the round is over and the one with the lowest rolled sum loses the game. This repeats every round until there is only one player left.

A. *QPT_Dice*

First we need to define a dice. For that purpose, we can use QPT_Dice, a predefined class from QPT_Tabletop derived from QPT_Actor. It has a mesh representing a dice that can simulate physics. Calling the function Roll() launches the physics simulation and keeps track of its rotation and velocity. After the dice has stopped, it broadcasts the result through a listener. If the dice has stopped on an edge, then it will apply some random force on itself in order to nudge it and land flat. It is also possible to give it additional data before the roll such as random force and torque applied to it at the moment of roll, location and rotation where the roll should start, location and rotation in which the dice will return to after it lands, how long it will wait after it lands to allow the player time to see the result, etc.

B. *DiceManager*

Since in this game each player rolls multiple dice, we can use DiceManager class to further simplify users' work. Dice manager is a class that inherits from CommonRule class. It handles situations when players need to roll multiple dice simultaneously. User simply defines how many dice to create and specifies which dice to roll. After all dice have stopped, dice manager broadcasts the result of each dice which is useful for games such as Yahtzee [7], as well as sending their sum.

C. *PlayerTracker*

We have to keep track about players' turns. For that purpose, we can use PlayerTracker class which also derives from common rule class. Each player has a unique index and player tracker is using that index to keep track of the order in which they play. Each time a full circle is made, the round number increases. It also allows us to see which player's turn it will be in a given amount of turns, as well as temporarily and permanently skipped players.

D. *ScoreTracker*

Another useful class is ScoreTracker. It inherits from common rule class and keeps track of the score of all players. ScoreTracker can also return the player with the largest or lowest score as well as a sorted list of all players based on their score.

E. *SimpleDiceGame*

In order for the user to create this game, (s)he must create a new class which inherits from GameRule called SimpleDiceGame. It will then take DiceManager, ScoreTracker, and PlayerTracker as components. It must also listen to all the necessary broadcasts, namely the results from DiceManager, and the notification sent from PlayerTracker when a round is completed. All this is presented by class diagram in Figure 6.

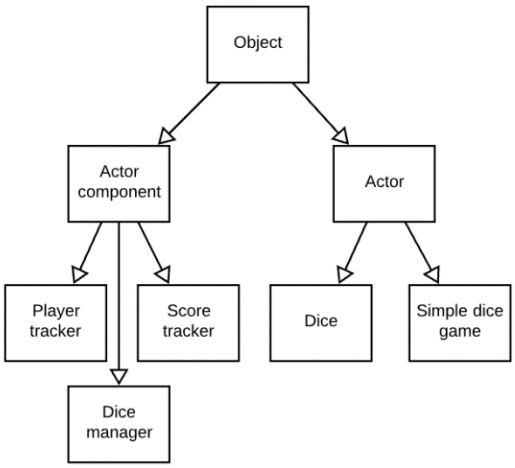

Figure 6. Class diagram showing inheritance of classes needed to create Simple dice game

When the game starts, we take the next player and roll the dice for him/her. When the dice manager reports back the result, we store it in Score tracker and go to the next player. The set forth continues until all the players rolled the dice and therefore a round is completed. Then we get the player with the lowest score and remove him/her from the game. We repeat this until there is only one player left. Relationships between classes needed to create Simple dice game are illustrated by class diagram in Figure 7.

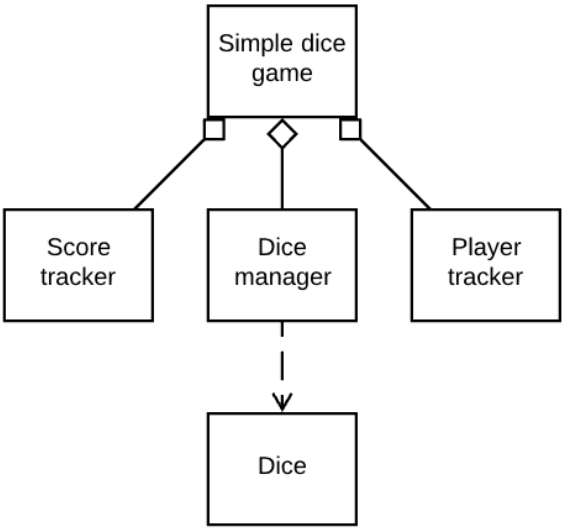

Figure 7. Class diagram showing relationships between different classes needed to create Simple dice game

Figure 8 illustrates the prototype of that game. Note that the text on the bottom shows both the result of individual die as well as the sum of all dice.

Figure 8. Early prototype of the dice game

VII. Templates

Let's assume that user had multiple ideas on the game and wanted to create some variations in order to see which works best. They all still sharing the same basic concept of multiple players rolling dice, but the actual rules vary. In one game, players again take turn to roll dice, but they do not get excluded if they got the smallest sum. Everyone rolls a certain number of times and then the total sum is taken in consideration. Another option is for players to try to get the smallest sum in order to win.

Since the rules of the game are different, it is necessary to create different game rule classes for each game. However, each game rule would need the same components. If the game was more complex, updating and maintaining each game could become problematic. Therefore, another special class exists that can be used to reuse a certain combination of components called QPT_Template.

QPT_Template, or Template for short, is a class that contains a list of QPT_ActorComponents as well as some additional data that can modify some parameters. It works in a manner that upon initialization it iterates through the list of QPT_ActorComponents and adds them to the initialization chain of GameRule class. QPT_Template can then modify some parameters of those components before they are initialized such as number of players in PlayerTracker or number of dice in DiceManager. This allows user to reuse certain parts of the game in other games and any modification to the template automatically updates every other game that uses it. For added flexibility, it is possible to create templates that contain other templates. The fashion of using template in a modified dice game is shown by class diagram in Figure 8.

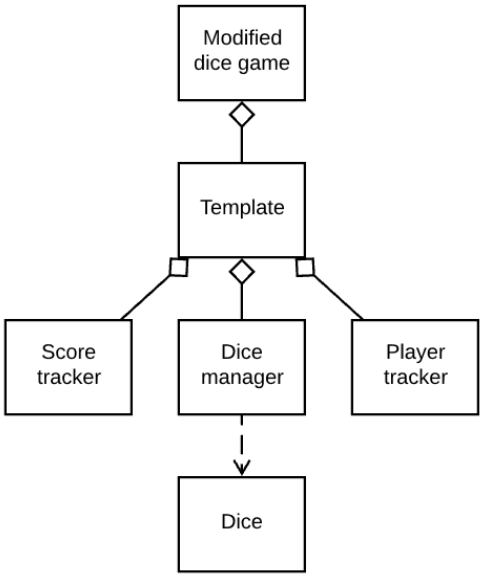

Figure 9. Class diagram showing the use of template in a modified dice game

VIII. Conclusion

QPT_Tabletop is an application designed to be used inside Unreal Engine 4 which enables user to quickly prototype a board game. In order to accomplish this, it contains premade classes that represent concepts, rules, and objects often found in various board games, and allows them to combine them into a new game.

In this paper, we created a simple game where multiple players roll dice and the one with lowest overall result loses the game. The procedure continues until there is only one player left. The set forth was all created using prebuilt classes QPT_Dice, DiceManager, PlayerTracker, and ScoreTracker. Only necessity on the user's side was to create a new class derived from GameRule, add the necessary components, and define the rules.

In cases when user wants to reuse certain combination of components in other games or simply aims to create a modified copy for testing purposes, (s)he can use the

Template class which allows him/her to share those combinations of components. Additionally, Templates allow him/her to make changes to every game that uses it simultaneously, which further reduces the probability of creating new bugs and simplifies workflow for those games and any future games using these components.

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Measuring Quality of an Indie Game Developed Using Unity Framework

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***Abstract* - This paper provides an insight into the entire process of developing an indie game by means of Unity framework. Special attention will be devoted to core game mechanics, such as colliders, physics components, and ray casting. With an aim to determine to what extent introduced indie game has met particular dimensions of quality, an empirical study was carried out. Data was gathered from the representative sample of gamers using post-use questionnaire. Outcomes of data analysis are presented and discussed.**

Keywords - Unity Engine; Indie Game Development; Quality Evaluation; Post-Use Questionnaire; Empirical Study

I. Introduction

Indie games, indie being short for independent, are games developed by independent developers. The opposite of indie games are triple-A games where AAA stands for A lot of time, A lot of resources and A lot of money. The main difference between these two types of games is that indie developers do not have a publisher (such as Activision, Electronic Arts, Konami, Nintendo or Ubisoft) for their game. Besides the lack of a financially strong publisher, indie developers lack the most important resource - people. While big triple-A game studios have teams of 100 people, indie developers are for the most part alone, or in a small team composed of few people.

The first adopted example of a game machine was introduced in 1940 by doctor Edward Uhler Condon, at the world fair in New York [1]. His machine was based on the ancient mathematical game called Nim. Over 50000 people played the game at the world fair. The machine managed to beat 90% of those 50000 players [2].

The first game system that was designed commercially was the “Brown Box”. It was introduced in 1967 by Ralph Baer and his team [3]. The Brown Box was actually a vacuum tube that needed to be connected to a television in order to play the game. The game consisted of controlling two cubes and trying to catch each other. It was later licensed by Magnavox that released the system under the name “Magnavox Odyssey” in 1972 [4].

Atari was the first bigger game company that tried to step up the game development industry. Their first and biggest game release was “Pong” [5] which represented a kick-start to arcades and gaming industry in general. They encouraged over 15 other companies to start developing games of their own.

This paper discusses the process of developing an Indie game using Unity game engine and examines particular dimensions of quality with respect to the developed game. The name of the game introduced in this paper is Indiana Ford [6]. It is a platformer which uses jumping puzzles in its level design. Game engines are software tools for game development. They offer a lot of tools for the developers to customize their game to every little detail. Already completed game engines are helpful in a way that the developer does not have to make every little thing on his own, but rather has them already implemented into the engine. For example, Unity offers components for physics, sprite rendering, sound and other. It also provides an asset store where developers can find various paid or free premade tools to help them develop their game.

Unity was chosen because it is free and beginner-friendly compared to some other commercial counterparts. Some other free popular game engines worth of mentioning are Unreal Engine, Cocos2d, and GameMaker.

The remainder of the paper is structured as follows. Related work is briefly described in the next section. Unity framework is explained in the third section. Core game elements are discussed in the fourth section. Pilot study findings are discussed in the fifth section. Conclusions are drawn in the last section.

II. Related Work

Literature in the field offers a number of papers devoted to indie games development. Nadav Lipkin [7] discussed the term "indie", the meaning the word has had through its existence and its effects on the indie developer community. The whole process of making an indie survival game was explained by David Michael [8]. He described the ways to design, plan, schedule, develop, and test a game. The same author also provided an insight into technologies that are out there and how to choose the best one for developer's particular needs. Finally, he offered some advices on how to correctly place developed game on the market.

There is also a lot of papers covering Unity engine itself. Some of them discuss developing projects with Unity that are not games. An example would be the work of Craighead et al. [9] which discussed the implementation of a robot simulator in Unity. They compared other popular platforms with Unity and explained how the various components of the Unity API and environment editor were used in their project. A paper about developing a game using Unity has been published by Polančec and Mekterović [10]. They described the process of implementing a working online MOBA game.

There has not been much work on indie game quality evaluation using post-use questionnaire, but there are some similarly themed papers. One of them is a work of Pinelle et al. [11] that discussed heuristic game usability evaluation. They analyzed PC game reviews and developed a heuristic for identifying usability problems in both early and functional game prototypes.

III. Unity Framework

Unity is today one of the most popular frameworks used for designing video games. It offers tools for designing 3D and 2D games. Although in the beginning the 2D capabilities were only basic, they decided to expand the tools due to users' demand. Unity supports three programming languages for scripts: C#, UnityScript (which is Unity's version of JavaScript) and Boo. C# is the most popular one while Boo is the least popular one.

The main element in Unity is a scene [12] that can be perceived as a level. Everything that a level needs, from players to various other elements, is placed inside a scene. The elements that are placed inside a scene are called game objects [13]. A game object can represent a player, an enemy, terrain or a pickup. Default game objects that are added when a new scene is created are a camera and a light source. Components are used to control the game objects in a scene [14]. They can be used to give game objects physical properties or animate them. Figure 1 illustrates how the Unity editor looks like.

Figure 1. Unity Editor

The scene view is located in the middle of the editor. On the left side is the scene hierarchy which displays all of the game objects that are currently in the scene. On the right side is the inspector that displays which components the currently selected game object has. On the bottom part is a hierarchy of the project. It shows all of the resources inside the project. The bottom right represents the view from the player side.

IV. Game Introduction

The platform video game developed for the purpose of this paper called Indiana Ford [6]. The story follows a hero on his path to find an ancient artefact inside an old Mayan forest. The main game mechanic is jumping. The player has to do jumping puzzles to try and get the key to unlock each level while trying to avoid deadly traps and enemies. At the end, the player has to defeat the boss in order to win the game. Some of the core game and Unity elements used in creating Indiana Ford will be described in following subsections.

A. Scenes

Scenes are main elements in Unity and can be for 2D or 3D space. Apart from representing different levels of a game, they can also represent a menu (for instance, the main menu). The default scene that is created by Unity contains two game objects: a camera and a light source. Every other game object that the developer needs is placed inside a scene.

B. Game Objects

Game objects are elements which exist within a scene. Developers can add game objects to scenes. They can represent the player, weapons, enemies or buttons in a menu. At least one camera game object is needed to be able to show the scene to the player.

C. Components

Game objects need components to do something because without them they are pretty much useless. The only component that every game object has is the transform component. It dictates where the game object is located. Rigid bodies are components that give the object physics properties [15] such as weight and gravity.

Colliders are components that allow objects to collide or interact with each other [16]. Objects without colliders would simply fall through the ground. An example of colliders is presented in Figure 2. The light green rectangles are the colliders. The player object and the terrain both have colliders. If for example the terrain did not have a collider, the player object would just fall through the terrain as soon as the level starts.

Figure 2. Interaction between two colliders

Colliders can also be triggers. They let the engine know when another collider enters. The trigger can also tell when a collider leaves or stays inside of it.

Animators are components responsible for the animation part of an object [17]. They contain different states of animations such as an idle animation, running animation, jumping animation, etc. These states are not predetermined but are made by the developer.

Sprite renderers hold the images that are being shown through various animation states [18]. They can be used in 2D and 3D scenes.

Scripts are components that contain code that is written by the developer. They are the main way of controlling game objects using various functions. All the scripts in the project presented in this paper are written in C#.

Figure 3 shows one of the many functions used in the project. This function is from the Player script and is used to control the player's movement. In almost every script, there is an Update function that is being called once per frame and inside that Update function is a call for the function. The first line of code gets the value of the input axis and stores it in a float named "horizontal". The value ranges from -1 to 1, depending on the way the player wants to move. The second line takes that value and creates a new 2D vector which has two parameters: "x" and "y". In this case, the "y" parameter remains the same and the "x" takes the value of the product of values "horizontal" and "speed". The variable "speed" is predefined in the script. As a follow up, the variable rb2d (Rigid Body 2D component) updates its velocity with the newly created vector.

```
protected void HandleMovement() {
    if (input == false)
        return;

    float horizontal = Input.GetAxisRaw("Horizontal");
    rb2d.velocity = new Vector2(horizontal * Speed, rb2d.velocity.y);
}
```

Figure 3. Function "HandleMovement" from the Player script

Figure 4 presents the function "HandleJumping" that is responsible for the player's jumping. The first if statement is checking if the button for jumping is pressed and if the player is not sliding. The "IsSliding" variable tells if the player is wall sliding. There is a separate function for jumping while sliding on a wall. After that, the script checks if the player is grounded. If yes, the "rb2d.velocity" is updated with a new vector, much like in the previous function which handles player movement and the variable "canDoubleJump" is set to true. If the player is not grounded, the next if statement checks if the player is able to double jump. If the statement returns true, the "canDoubleJump" variable is set to false and the "rb2d.velocity" is updated with a new vector. The two variables "JumpPower" and "SecondJumpPower" are predefined.

```
protected void HandleJumping() {
    if (Input.GetButtonDown("Jump") && !IsSliding)
    {
        if (IsGrounded)
        {
            rb2d.velocity = new Vector2(rb2d.velocity.x, JumpPower);
            canDoubleJump = true;
            FindObjectOfType<AudioManager>().Play("Jump");
        }
        else
        {
            if (canDoubleJump)
            {
                canDoubleJump = false;
                rb2d.velocity = new Vector2(rb2d.velocity.x, 0);
                rb2d.velocity = new Vector2(rb2d.velocity.x, JumpPower * SecondJumpPower);
                FindObjectOfType<AudioManager>().Play("Jump");
            }
        }
    }
}
```

Figure 4. Function "HandleJumping" from the Player script

Figure 5 shows the function "HandleSliding" that handles jumping while wall sliding. This function is called in the "Update" function only when the player is not grounded and when he is close to a wall. The first line sets negative value to the "rb2d.velocity" which enables the player slowly slide down the wall. Afterwards, the variable "IsSliding" is set to true. The if statement checks if the jump button is pressed and if the horizontal input axis is equal to zero. That means that the player needs to jump before using the arrow keys to choose a direction. The next line updates the "rb2d.velocity". The "wallDir" variable contains the direction the player is facing, so the minus ensures that the velocity direction is opposite to the wall. The "wallJumpx" and "wallJumpy" are predefined variables which contain the power of the jump. The "transform.localScale" command changes the direction the player is facing. Finally, the "FacingRight" variable is set to be the opposite of what it is now.

```
void HandleWallSliding() {
    rb2d.velocity = new Vector2(rb2d.velocity.x, -0.2f);

    IsSliding = true;

    if (Input.GetButtonDown("Jump") && Input.GetAxisRaw("Horizontal") == 0)
    {
        rb2d.velocity = new Vector2(-wallDir * wallJump.x, wallJump.y);
        transform.localScale = new Vector3(-wallDir, 1, 1);
        FacingRight = !FacingRight;

        FindObjectOfType<AudioManager>().Play("Jump");
    }
}
```

Figure 5. Function "HandleSliding" from the Player script

Raycasting is one of the core game mechanics that is being widely used in today's game development [19]. It is mostly used to check if one object can see another one, that is, to check if there is something between them. It works in a manner that a ray is being cast from point a to point b to see if there is something in the way. An example of ray casting is provided in Figure 6. The lines usually cannot be seen but here they are enabled through the debug console [20]. In the figure, the ray is being cast from point a (the player object) to point b (two enemy turrets) which are not in sight. Here the ray cast is being used to determine if the enemy turrets can see the player object. Various filters can be used to check if there is maybe a wall between the two points, or an enemy, and so on.

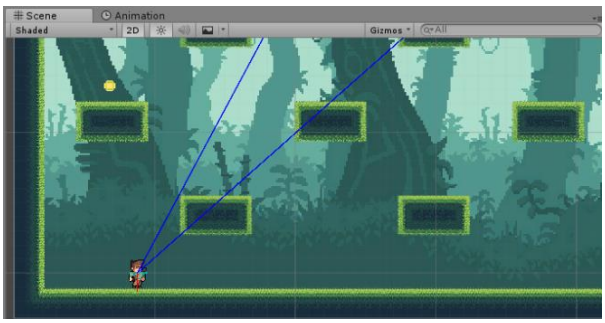

Figure 6. Raycasting

Figure 7 presents the function "RangeCheck" that is responsible for checking if the player is in range of the enemy turrets.

```
void RangeCheck()
{
    Debug.DrawLine(CastStart.position, target.position, Color.blue);

    bool test = Physics2D.Linecast(CastStart.position, target.position, 1
    << LayerMask.NameToLayer("Wall"));

    if (!test && isAwake)
        Attack();
}
```

Figure 7. Function "RangeCheck"

If the player is in range, then the turret fires a projectile at the player. The "Debug.Drawline" command draws a line between two points. This line is shown in Figure 6. The next command uses raycasting to see if there is a wall between the start and the end of the ray. This is ensured by using the third argument when calling the "Physics2D.Linecast". In this case, the third argument is "1 << LayerMask.NameToLayer("Wall")". The function now checks if any of the objects that the ray passes through are walls. The function returns the result and is being stored in the variable "test". The if statement checks if any walls are in the way and if the variable "isAwake" is true. If it is, the function "Attack" is being called. The "isAwake" variable is true if the turret is off cooldown.

V. Pilot Study

A. Procedure and Structure

The study consisted of playing the game and completing a post-use questionnaire that consisted of 3 items related to demographic characteristics, 2 items to determine how long and how often the participants play video games and 18 items for evaluating the quality of the played indie game. The items, besides the demographic and gaming habits ones, were modulated on a five-point Likert scale (1 – strongly agree, 5 – strongly disagree).

B. Participants

A total of 96 respondents ranging in age from 18 to 33 years took part in the study. The sample was composed of 81.2% male and 18.8% female participants. The majority (59.4%) of the participants confirmed they are playing video games for more than 10 years, 18.8% of the participants are playing video games for 6 to 10 years, while 10.4% do not play video games at all. When time spent on playing video games is considered, the majority (38.5%) of students are playing games less than 5 hours a week, 13.5% of them do not play video games while 14.6% confirmed they are playing games for more than 20 hours a week.

C. Findings

Responses to the post-use questionnaire items related to the quality of the introduced indie game are presented in Figure 8 (see Appendix). The majority (56.3%) of the respondents found the game hard while 38.5% enjoyed playing it. As much as 30.2% of students perceived their skills as average ones. Moreover, 61.4% of respondents believe that they improved from the first to the last level. Only 35.4% of study participants stated they would play the game again which could be affected by the difficulty of the video game and the fact that 64.6% respondents found the game frustrating.

The data gathered indicate that most of the respondents (52.1%) think that they did not need a lot of time to grasp the controls of the video game. It was also found that 78.2% of study participants believe that the objectives in each level were clear. The set forth indicates that the game was perceived as user-friendly.

Regarding level design, the majority (51%) of students perceived the graphics quality of levels as good. On the other hand, 46.9% of respondents believe the levels were complex while 81.2% of them found levels easy to understand. It could be therefore concluded that levels of Indiana Ford were well designed.

Responses to items related to game mechanics show that 39.6% of study participants expressed confirmative opinion about game mechanics fluidity while 46.8% of them think game mechanics are clear and simple. The set forth implies there is still a room for improvements in terms of game mechanics.

Findings presented in Figure 8 also indicate that sound effects were done well. More specifically, majority (64.6%) of students confirmed they were not distracted by the sounds integrated in the game, 32.3% of them found sound effects stimulative, while 69.8% believe sound effects were appropriate for the style of the video game.

Finally, regarding the atmosphere, the majority (77.1%) of the respondents think the video game theme was accordant to its style and mechanics whereas 63.6% of study participants believe that the sound effects together with the style and game mechanics make a good atmosphere.

VI. Conclusion

The Unity framework offers a lot of free resources, through YouTube tutorials and Unity's asset store which makes it a great choice for beginners in the field of game development. Although the learning curve can be quite steep, the abundant material provided by the community helps a lot. Even with all the resources provided by the community and Unity itself, the task of developing a game as an indie developer can take up a lot of time. It is nowadays very hard to be good at making art, sound effects and writing quality code in order to place a competitive product on the market. The introduced questionnaire helped us determine the main issues with the game so they can be fixed and a more whole and complete game can be offered to the market. Considering that study presented in this paper was the pilot one, in our future work we are planning to design more comprehensive measuring instrument that would enable assessment of all relevant quality dimensions in the context of video games. The main benefit of it would be that list of found issues could be more detailed and thus help the developer to improve the game more easily. Nevertheless, by applying introduced questionnaire to other indie games, the developers can also determine some general issues with their game and focus their effort on fixing them.

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APPENDIX

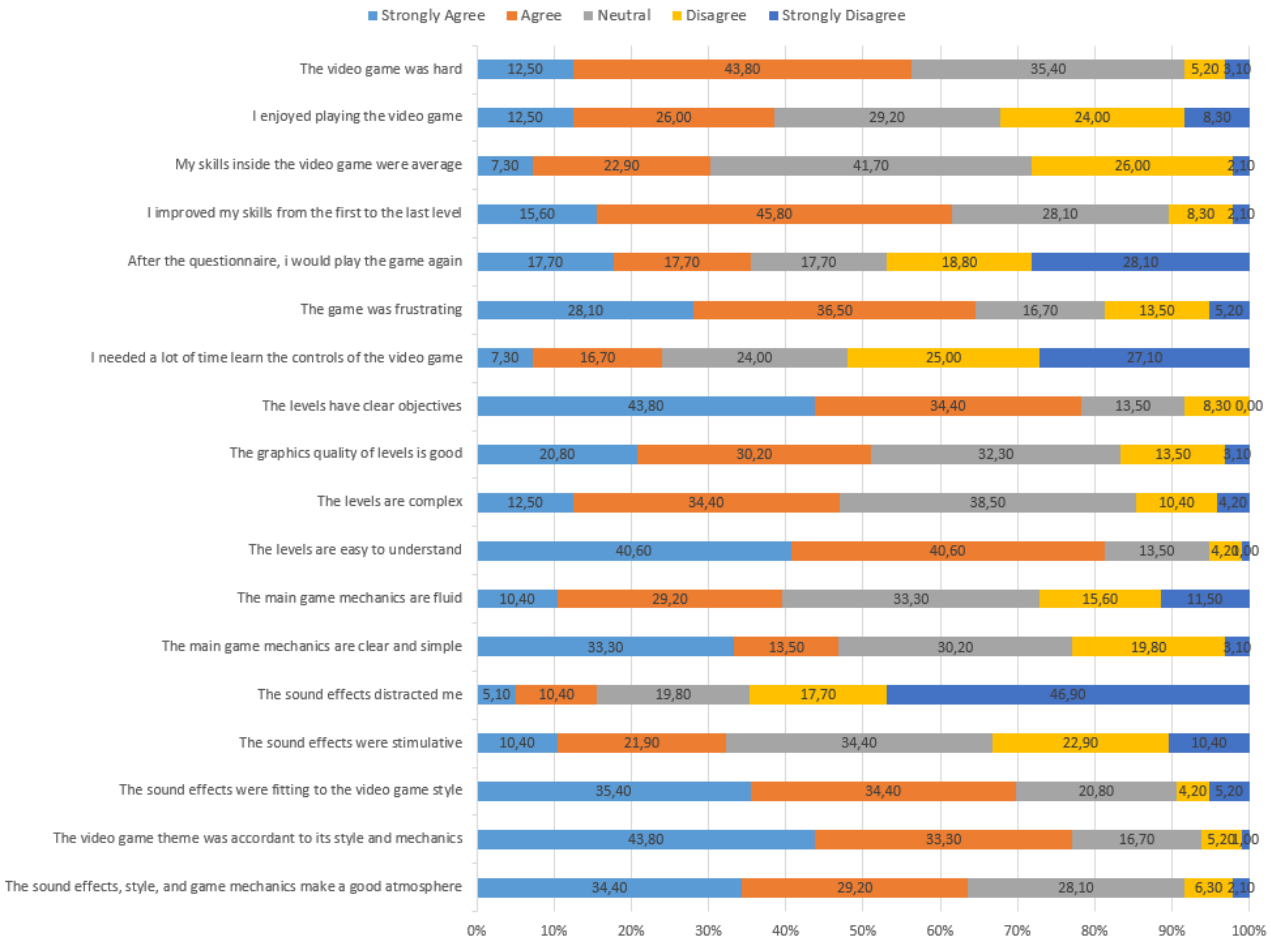

Figure 8. Responses to questionnaire items related to the perceived quality of Indiana Ford game

User Experience Evaluation of 2D Side-Scrolling Game Developed Using Overlap2D Game Editor and LibGDX Game Engine

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***Abstract* – A side-scroller is a type of game where a side-view camera angle is used for action viewing. This paper discusses the implementation of a typical simple side-scrolling game through integration of a presentation layer created in a Overlap2D editor and a LibGDX game logic layer in terms of employing existing algorithms for collision detection and player movement. The implemented game retains most of the main features of modern side-scrolling mobile video games such as different enemies with different shooting objects, different types of obstacles that a player must avoid, additional player features purchases and their consumption, multiple levels, and player movement through the level. Although games developed using LibGDX engine can be exported to multiple platforms, the game that was developed for the purpose of this paper is deployed on a mobile platform. With an objective to explore various aspects of user experience with respect to the introduced game, an empirical study was carried out. The analysis of collected data revealed pros and cons of the developed game as well as directions for its improvement.**

Keywords – Java; Overlap2D; LibGDX; 2D Side Scrolling Game; Eclipse; Box2D; Jetpack Rush; Android; Mobile Game; User Experience; Empirical Study

I. INTRODUCTION

2D side-scrolling is used in games where the camera is set at a side-view angle. This type of games is usually in 2D with characters that move from the left-hand side to the right-hand side of the screen. In general, this type of games only requires from the user to move in one direction, most likely to the right. A lot of games allow a player to return backward, that is, a movement to the left, up, and down. This type of presentation is usually used by action games with characters that run, climb, and jump through a series of sequentially advancing levels. With the performance improvement in terms of graphics and processors speeds, video games also evolved above the 2D side-scrolling perspective, but even today some of the world known games still use this type of game design.

This paper discusses the implementation of a simple 2D side-scrolling game using the Overlap2D game editor and LibGDX game engine. Game editor and game engine are software tools used for game development. While the game editor is employed for the design of levels, maps, and campaigns in a video game, game engines provide a complete implementation of software components commonly used in game development such as the physics engine, the rendering engine, the audio engine and other. Game engines also allow the game developers to design components specific to the game that is being developed on top or within these systems [3].

The name of the game introduced in this paper is Jetpack Rush [9]. It retains most of the 2D side-scroller features which will be briefly explained in the fifth section. The remainder of the paper is structured as follows. Elements of visual presentation are explained in the next section. Details on the Overlap2D game editor and LibGDX game engine are provided in the third and fourth section, respectively. Study findings are discussed in the sixth section. Conclusions and future work directions are offered in the last section.

II. VISUAL PRESENTATION

Video game presentation is a manner of positioning and moving the camera. There are five types of visual presentations [4]. Apart from the aforementioned 2D scrolling presentation, there are also the cinematic camera, fixed/flip screen, free-roaming camera, and isometric perspective.

A. Cinematic camera

This perspective uses different, fixed camera positions that are set during the creation of a game for a maximum cinematic effect. The player cannot control these positions or move the camera in any way.

B. Fixed / Flip-screen

Games that employ this perspective are using a single, fixed screen to show a specific level or scene. Shown level or screen can also be larger than a single fixed screen. In that case, the whole screen is "flipped" (replaced by a new fixed screen) when the player reaches the end of the screen.

C. Free-roaming camera

In this perspective, the camera is under the player's control and does not follow a specific target, i.e. path and angle of the camera is not predefined. The player has the freedom of moving and rotating in his/her environment. Zooming is also a part of this perspective.

D. Isometric

This type of games uses isometric, trimetric or dimetric two-dimensional perspective to create an ostensible 3D

effect. It is often used to represent a certain viewpoint incorporating a bird's-eye view, but the focus is entirely set on using 2D to create a 3D effect. Games that use 3D for characters or backgrounds are not isometric by default.

III. OVERLAP 2D

Overlap2D is a 2D game editor used for creating the user interface, content, and game levels. It is a platform that describes the game. Made to separate coding from content, it enables the developer to create rich content using images, animations, particle effects, light system, physics, and complex grouped items [2].

Each component added to the canvas can have its own "Identifier", that is, a unique name. That name can be later used to get the component from the code and do some actions with that component. Each component can have its custom properties with its key and value. These properties can also be reached from the code. Components can have multiple tags. They are used in cases when a certain behavior or actions need to be defined for a specific group of components.

Multiple components can be grouped into one component which can then be saved to the library. From there, it can be reused numerous times without redefining the grouped components or their layout.

Components are easily added to the canvas from galleries of images, animations, effects or saved components by simply dragging and dropping. Before adding a component, the correct layer should be selected (if multiple layers are present).

Each component can have its own additional components:

a. Shader Component,

b. Polygon Component,

c. Physics Component.

These three components are used for shading and collision detection. Polygon and physics components are added to all components with which the player can collide. By adding a polygon component to a component, the editor shows a rectangle around the component that can then be adjusted as needed to mimic the real shape of the image, sprite or particle effect.

The Overlap2D runtime provides quick and effective methods for defining specific behavior for specific components in scenes created by the Overlap2D editor.

When creating a scene in the editor, a name is required for that scene. The set forth name is used when loading the scene into the game. Scene loading is done using a method *loadScene(sceneName, viewport)* on the *SceneLoader* object. When initializing a Viewport, provided width and height must be given in world units, not pixels.

In case of multiple game objects that have the same behavior, such as enemies, traps, and various objects, the same tag in the Overlap2D editor is given to them. These game objects are registered to a scene by calling method *addComponentsByTagName(tagName, componentClass)* on object *SceneLoader*. Argument *componentClass* is a simple class that implements Component interface. Next step is creating an *IteratingSystem* that manages the behavior of all game object with given component class and adding it to *SceneLoader's* engine. *IteratingSystem* has an abstract method *processEntity(entity, deltaTime)* where a behavior can be defined. This method is called for each entity with the specified component on each screen update. Figure 1 shows the code for loading scene "SCENE 1" using class *SceneLoader* with a viewport of width 266 and height 160 world units (800 by 480 pixels), adding custom component Alien by tag name "alien" to entities, creating iterating system over entities that contains Alien class, and adding it to the scene engine.

```
//loading scene
sceneLoader = new SceneLoader();
// dimension 800*480
view = new StretchViewport(266, 160);
sceneLoader.loadScene("SCENE 1", view);

//registering components with
//tag alien as Alien.class
sceneLoader.addComponentsByTagName("alien",
Alien.class);

//creating IteratingSystem and
//adding to scene engine
AlienSystem alienSystem = new AlienSystem();
sceneLoader.getEngine().addSystem(alienSystem);

//class AlienSystem
public class AlienSystem extends IteratingSystem
{
  public AlienSystem() {
    super(Family.all(Alien.class).get());}
    @Override
    protected void processEntity(Entity entity,
float deltaTime) {
        //defining behaviour here
        }

}
```

Figure 1. Usage of Overlap2D runtime

In case when one unique object needs logic, an id must be defined in the Overlap2D editor. After creating item wrapper for root component using *ItemWrapper* class it is easy to get a component by id. To define a behavior for a specific component, it is necessary to attach a class that defines the behavior of the component. An added class needs to implement *IScript* interface.

IV. LIBGDX

LibGDX is a cross-platform game and visualization development framework. Supported platforms are Windows, Linux, Mac OS X, Android, Blackberry, iOS, and HTML 5. It allows developers writing the code once and then deploying it to different platforms without any code modifications thus enabling rapid development mainly in a desktop environment knowing that the game will have the same behavior on other platforms. Main programming language for development is Java, but since it runs on Java Virtual Machine (JVM), other programming languages based on Java (such as Kotlin, Scala, Clojure, etc.) can be also used for development. Developers can use

all the tools of the Java ecosystem to be as productive as possible [5].

LibGDX is packed with a powerful set of Application Programming Interfaces (APIs) that help the developer in everyday common game development tasks like rendering sprites and text, building user interfaces, playing back sound effects and music streams, linear algebra and trigonometry calculations, parsing JSON and XML, etc. [5]. It also ties in a lot of third-party libraries to provide its functionality:

a. OpenGL - the premier environment for developing portable, interactive 2D and 3D graphics applications.

b. FreeType - a free, high-quality and portable Font engine.

c. mpg123 - free software that contains a real time MPEG 1.0/2.0/2.5 audio player/decoder for layers 1, 2 and 3 (most commonly MPEG 1.0 layer 3 aka MP3), as well as re-usable decoding and output libraries.

d. xiph.org - fully open, non-proprietary, patent-and-royalty-free, general-purpose compressed audio format of mid to high quality.

e. soundtouch - an open-source audio processing library for changing the tempo, pitch and playback rates of audio streams or audio files.

f. Box2D – an open source C++ engine for simulating rigid bodies in 2D. Some of the Box2D features are:

- Continuous collision detection,
- Convex polygons and circles,
- Multiple shapes per body,
- Efficient pair management,
- Continuous physics with time of impact solver,
- Contact, friction, and restitution.

g. LWJGL - open source Java library that enables cross-platform access to popular native APIs useful in the development of graphics (OpenGL), audio (OpenAL), and parallel computing (OpenCL) applications.

h. OpenAL - a cross-platform 3D audio API appropriate for use with gaming applications and many other types of audio applications.

i. KissFFT - a very small, reasonably efficient, mixed radix FFT library that can use either fixed or floating-point data types.

j. Ashley - tiny entity framework written in Java, inspired by frameworks like Ash (hence the name) and Artemis.

Third party extensions used in this game implementation are FreeType, Box2D, and Ashley.

LibGDX provides a simple way of creating scenes using a stage - actor principle. Actions such as moving, rotating, hiding, and showing can be easily added to any actor. Multiple actions can be defined as sequential or parallel which extends actions' usability. Actors can be added to a stage or to a grouping actor such as HorizontalGroup, VerticalGroup, Table, Group, etc. Examples of actors are Image, Label, Button, TextButton, CheckBox, and TextField.

The stage must be inside a class that implements *Screen* interface so that the stage can call its methods *draw()* and *act()* in the implemented *render()* method. Method *render()* is called when the screen should render itself. When the *act()* method is called on the stage object, it calls *act()* method on all actors inside the stage which causes actors to move, receive touch inputs, etc.

LibGDX also offers methods for intersection detections between certain types of geometric objects, distances between points, distances between points and lines, etc., which is used for collision detection. In most cases, these geometric objects are rectangles that are moved alongside an actor which then represent the real position and size of an actor.

V. JETPACK RUSH

Jetpack Rush [9] is a 2D side-scrolling game primarily developed for Android platform with buttons located on the screen that serve specific player actions. The game resembles a famous Android game Jetpack Joyride released in 2011 by Halfbrick Studios [11]. Jetpack Joyride provides a simple player control management by touching the screen. Jetpack Rush [9] has a similar design with additional features such as player acceleration and shield application. The shield as well as the ability of player acceleration can be bought with virtual money collected after a successful competition of the level. The game consists of ten levels. Game difficulty gradually increases at each of the forthcoming levels. Accordingly, the user is obliged to purchase the possibility of protection and acceleration to successfully pass the upcoming level. When the user first installs the game, it starts at the first level. All other levels are locked and the user gradually unlocks them after each successful competition of a newly unlocked level. An example of a game level is presented in Figure 2.

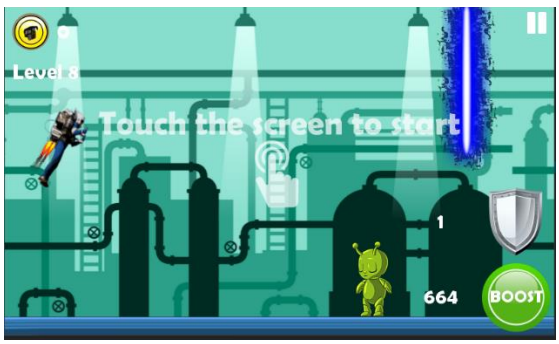

Figure 2. Level in Jetpack Rush game

A. Collision detection

As mentioned before, polygon and physics components were added to the components that are located on the scene and can collide with the player. This gives the developer ability to use the Box2D library for collision detection. Ray casting is a collision detection algorithm employed in the implementation of Jetpack Rush [9] game. It is used for finding game objects that are in a certain part of the game world. Ray is just a straight line. Calling method *rayCast(callback, point1, point2)* on object *World* invokes the callback argument object when a collision is detected. Arguments *point1* and *point2* are the starting and finishing points of the line. It is worth mentioning that the coordinates of points must be expressed in word units, not pixels. Figure 3 shows ray casting implementation using an anonymous class implementing the *RayCastCallback* interface for collision reporting.

```
world.rayCast(new RayCastCallback() {
  @Override
  public float reportRayFixture(Fixture fixture,
Vector2 point, Vector2 normal, float fraction) {
                        collision = true;
                        return 0;
                    }}, rayFrom, rayTo);
```

Figure 3. Collision detection using Ray casting

B. Collision detection using LibGDX class Intersector

A LibGDX class *Intersector* was used for detecting collisions between the player and shooting objects "fire ball" and "death ray". Class *Intersector* contains various static methods for intersection testing between different geometric objects. In this collision detection implementation rectangles were used for intersection detection. Each time a shooting object is launched towards the player, it is added to a list of currently launched shooting objects. This list is iterated on every screen update searching for the collision between player and shooting objects. If the collision is detected and the player currently does not have a shield applied, it reports the collision which results in a game over popup. Figure 4 illustrates the moment when the player and the ball are in collision.

Figure 4. The collision between player and the ball

Method *checkCollisions()* shown in Figure 5 iterates the list *bullets* where for each entity a *RectangleComponent* is fetched which are then used for collision detection between player and entity. A *RectangleComponent* is a custom component that contains a rectangle representing the entity and is assigned to entity when it is added to the *bullets* list.

```
public static void checkCollisions() {
  //Don't check if the player
  //already in collision
  if(player.collision) return;

  for (Entity entity : bullets) {
    // check for collisions if
    //the player doesn't have shield
    if(!player.isShieldActive()){

        RectangleComponent rectangleComponent =
        ComponentRetriever.get(entity,
                        RectangleComponent.class);
        // check if the two rectangles
        // overlap each other

        boolean collision = Intersector.overlaps(
        player.getRectangle(),
        rectangleComponent.getRectangle());

        //if rectangles overlaps report collision
        if (collision) {
          player.collision = true;
          break;
        }
    }
  }
}
```

Figure 5. Collision detection using LibGDX class Intersection

VI. User Experience Evaluation

A. Participants

With an aim to evaluate perceived user experience in interaction with the introduced game, an empirical study was carried out. A total of 100 students from Juraj Dobrila University of Pula, Faculty of Informatics took part in the study. The sample was composed of 78% male and 22% female respondents. When the study took place, more than a half (63%) of participants were enrolled in the first year of undergraduate study, 15% were enrolled in the second year of graduate study, 11% were enrolled in the third year of undergraduate study, while remaining participants were enrolled in the second year of undergraduate study and first year of graduate study. The data was collected with an online questionnaire survey. The average age of students was 20.99 years (SD = 2.97). As presented in Figure 6, 64% of students spend at least between 30 and 60 minutes a day on playing games.

Students' responses related to the most important game feature are summarized in Figure 7. More than a half (56%) participants agree that fun is the most important game feature, 35% of them thinks the content and story are the most important game features while remaining 9% believe it is the graphics that matter.

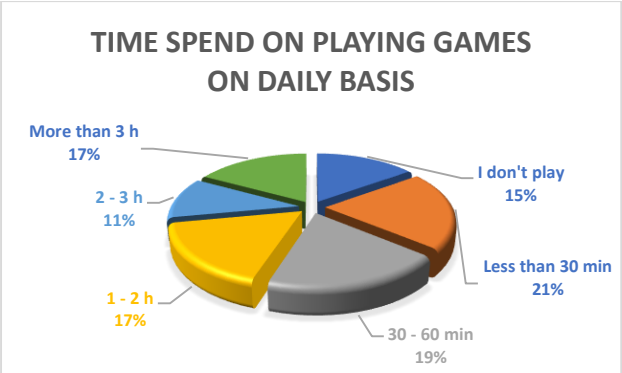

Figure 6. Time spent on playing games on daily basis

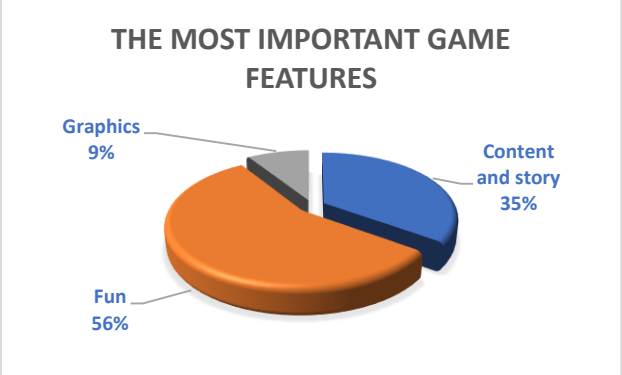

Figure 7. The most important game features

B. *Apparatus*

The user experience in the context of Jetpack Rush [9] game was examined by means of the post-use questionnaire. It was composed of twenty-one item meant for measuring following facets of user experience:

a. Aesthetics – extent to which the game is visually appealing,
b. Uniqueness – degree to which the game is distinctive among similar games,
c. Playfulness – extent to which interaction with the game is focused,
d. Pleasure – degree to which interaction with the game arouses players' emotional responses,
e. Satisfaction – extent to which the game has met players' expectations,
f. Loyalty – the degree to which players have the intention to continue to play the game and recommend it to others.

After installing the game, study participants were asked to explore the game's features in the comfort of their homes. Participants were afterwards asked to provide responses to questionnaire items on the Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Questionnaire items were adopted from [10] and adapted to the context of the study.

C. *Findings*

The analysis of collected data indicates that students perceived the introduced game as the attractive one. More specifically, 52% of students agreed with the item "Colors that prevail on the interface games are pleasing to the eye". On the other hand, it appeared that side-scrolling games seems to be familiar to study participants since 74% of them disagreed with the questionnaire item "The game is unique". When it comes to game stimulation, the opinion of students was rather divided. For instance, 35% of students agreed and 34% of them disagreed with the item "I had fun with the game" while remaining 31% was undecidable. The same holds for students' satisfaction with the game. Namely, 34% of students agreed and 41% of them disagreed with the item that measures the extent to which the game met their expectations. Although the majority (76%) of students agreed they will not play the game in the future, 45% of them would like to try other games developed by the same author. Reported findings are summarized in Figure 8 (see Appendix).

VII. CONCLUSION

The Overlap2D editor offers a lot of useful features that greatly assist in developing the game. Some of the most important features are the creation of composite components where several components constitute one component that can be used at any given time without re-defining the composite components and their layout. The ability to add tags to components greatly helps to globally define the behavior of a group of components. The editor also offers the definition of a unique key by which an individual component is recognized.

The LibGDX environment makes game development easy with its wide range of features. It provides support for all aspects of games that may be required by the developer, from sound support, animation, and images to fonts and customer support actions. LibGDX also offers an easy way to create a screen using stage – actor concept. Actors can easily add actions such as scrolling, rotating, hiding, rendering, etc. It is also possible to define the sequential act of actor's action which further expands the usability of the action. In addition, LibGDX enables methods of detecting cross sections of certain geometric objects as well as the distance between certain points, dots, and directions, etc., used to detect object collisions on the scene. In most cases, these are rectangles that move along with the object on the scene and represent the right position and size of the scene at any time.

In our future work, we will upgrade game graphics, add more different object and enemies to the scene, and extend the number of levels. Improving the game in that manner might enhance user experience and users' overall impression of the game.

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APPENDIX

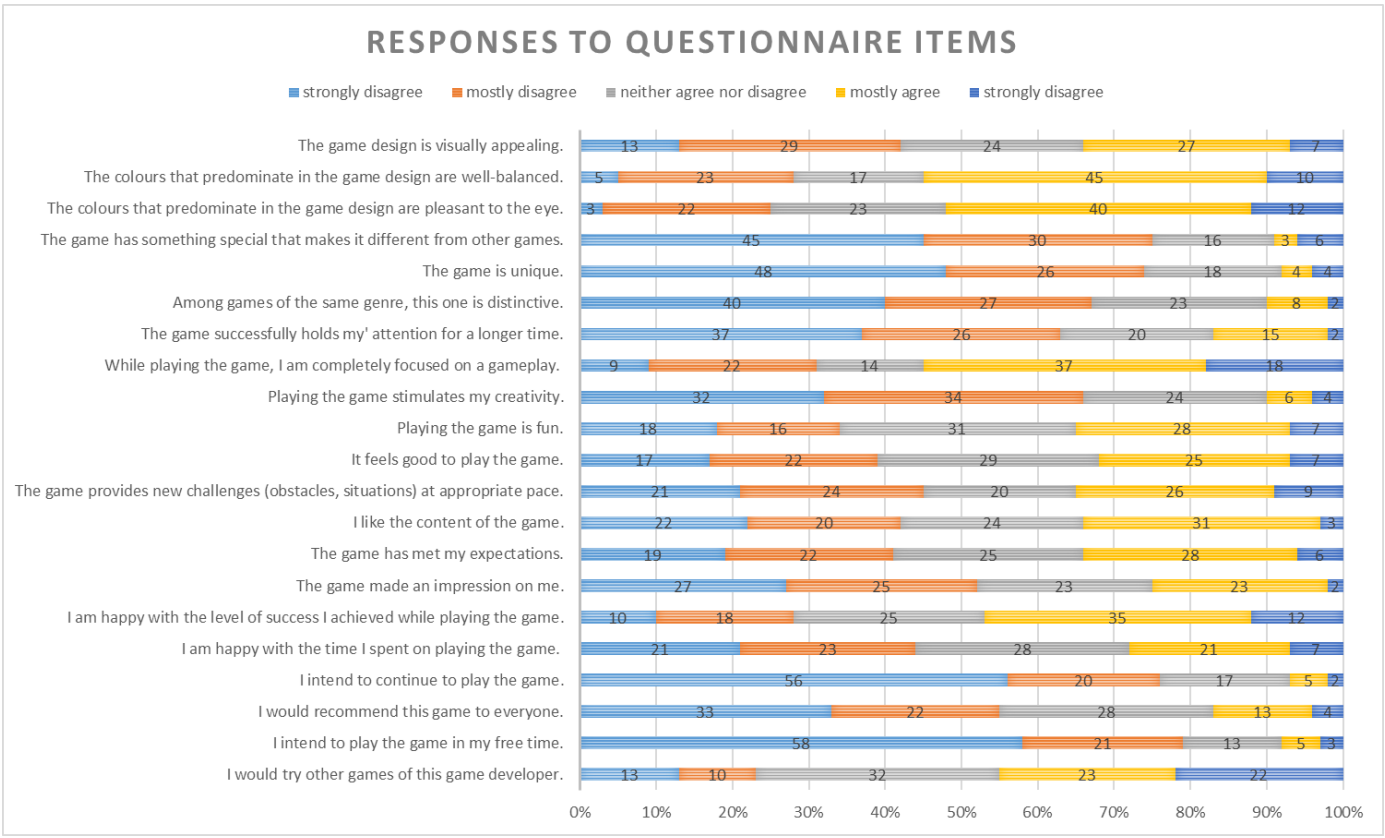

Figure 8. User experience evaluation findings

Metadata Management

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***Summary* – The name of the project is an acronym: MaDaMe stands for "metadata management". It is an in-house project of Erste&Steirmarkische bank Zagreb. This paper describes the system which is used for managing domains and integrity restrictions (CHECK features) on database table fields.**

IBIS – an Integrated Banking Information System is an in-house banking system developed in Erste Bank Croatia. IBIS is used in Erste bank entities Croatia, Serbia and Montenegro. The development and maintenance of a system this size results in a great number of environments, some for development and others for testing. There are also three partially different production environments, different for a number of reasons: new laws and time needed for their implementation, user requests, the size of the market and market shares. For those reasons, it was necessary to create a standalone system that enables managing approved values in the system, depending on the country and/or the environment, was a necessity. The sheer size of the banking system and data sensitivity could produce extremely expensive errors, which is what makes MaDaMe a necessity.

Keywords – metadata; banking system; domain; domain restrictions; reports;

I. INTRODUCTION

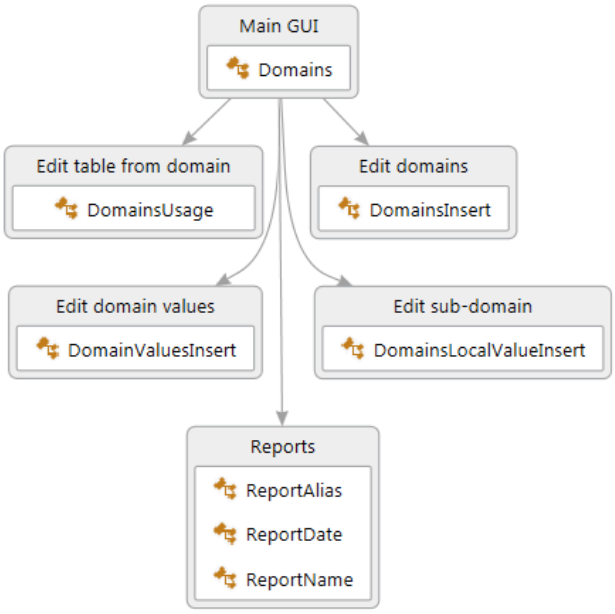
Banks were among the first to see the need for information systems. For that reason, the systems were mostly first developed in one technology and were later on upgraded, adapted and improved. Considering the size of these systems, a "big bang" reengineering project is not possible: certain parts of the system are changed, other parts are left as-is for future upgrades and the remaining parts die off as part of a natural process. Knowing everything about the different programming languages of a system of this magnitude is not possible for a group of people, let alone a single person. When the dynamics of a banking system that needs to adapt to market requests, new state and/or union laws is tahen into consideration, this problem only becomes more obvious. The IBIS banking system, used here, was written to satisfy all banking needs in three different states which makes it more difficult to maintain. Certain changes that occur on the system are not always simultaneous for all states, while others are not meant to be implemented in the other states. System changes often overlap and influence one another even thought they anre not to go to production at the same time. For that reason, a large number of environments is needed to be able to test certain changes being introduced. Each and every change that is implemented increases the risk of an input error that could be fatal for the company. To reduce the possibility of such an event on the database, check constraints are raised to ensure that, if there was an error in the program, the database could disable the value being submitted. For example, consider a grade with a few parameters that determine if a person, or its belongings are a risk. That grade could effectively be used in more places in the database. The programmer writing the code should be careful that the code does the job as told. Seeing as the programmer should be sure that he did a good job, he will raise check constraints on the database. After a certain time, the programmer is gone, the code changed, new grades are introduced but only for certain countries in different time periods. From that moment on, it is not as simple to guess what needs to be changed or which environment should be used at a specific time to accommodate the change. When the number of environments and changes increases, so does the need for managing those changes, especially if they are not automated and are managed by people. In that case, a system is needed to enable oversight and automatic change management.

II. ARCHITECTURE MADAME

The system comprises eight graphical user interfaces for domain management, while data domains refers to all the values which a data element may contain such as gender that can take values "M" for male and "F" for female. They're written using ASP.NET technology. In the background of each interface, procedures from the Oracle database are called. The system also uses a module for user management called KORA. Using that system, all information about the currently registered bank employee brcomes available. In this way the bank employee's identification code is retrived which is later used through the system. The roles of a user, his rights and the option of accessing certain segments of the system are defined within the KORA system. The KORA system is necessary due the nature of its data and the need for limiting the access for the end user to the data which is considered to be necessary to him. It is very important to protect the access because there are sensitive changes that could cause the entire banking system to crash. To ensure that the MaDaMe application works correctly it is necessary for it to be connected with the "New IBIS" environment, that is, the application needs to be created in this very environment.

Connection to the Oracle database is enabled by using the driver "ManagedDataAccess.Client". The safety of this system is one of the imperatives for which the module

KOKOS is used. A safe connection with the database is enabled through this module. KOKOS allows dynamic controlling via web, with connections towards the base, which reduces the possibility of making a mistake while building applications in certain environments. This web service contains several methods which enable a check for passwords, environments, users, connection etc.



Picture 1. Graphical user interface architecture.

Navigation in the MaDaMe user interfaces has been implemented in such a way that the destination can be reached no matter the location that the user is currently at. Access is enabled through the navigation menu on the left side. The main user interface contains the name of the Domain. The user interface makes it possible to add and change new values and to close the existing value. Since controlling of the domain has been organized hierarchically in the background of the base, user interface enables control of the domains, their values, local meanings, activations in certain environment, etc. The application contains graphic user interfaces which enable the user to be informed about important information like which alias is used to prevent collision when entering a new table in the system. Reports enable search through several parameters like date, alias, name etc. depending on what each of the reports is intended for.

The domains managed are available in three states: Croatia, Serbia and Montenegro. In each of the states, there's a minimum of four environments:

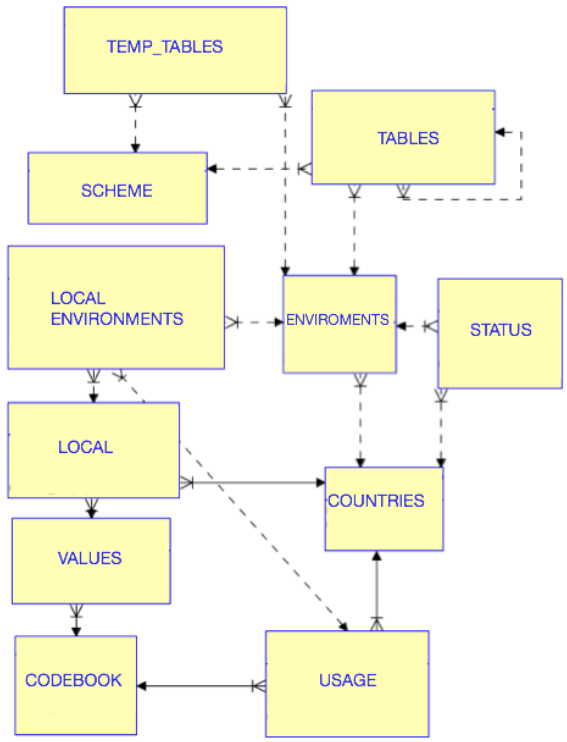
- DEV ("Development"), environment used in IT to develop applications.
- FAT ("Factory Acceptance Testing"), environment in which integration and performance testing are performed.
- UAT ("User Acceptance Testing"), environment in which testing is performed by end users who will be using the application.
- PROD – production environment
- NEWIBIS – special environment for controlling mutual applications, migrations etc. MaDaMe application has been created in this environment.
- Other environments like additional UAT and preproduction are added depending on the projects and on the level of complexity of information system development.

Model of the MaDaMe database is composed of 10 tables as sohwn in Picture 2. Each table includes attributes valid_from, valid_to, create_date, created_by, update_date and update_by. All changes can be tracked using these attributes. Short description of tables:

- Countries – this codebook lists the countries, respectively three countries, upon which program support is being developed.
- Scheme – this codebook lists names of schemes for which system checkup is made.
- Environments – existing environments are defined whith this codebook. Production environment differs from the rest. An array of flags contains a set of rules for each environment. Such rules allow the night job to start domain management activity in a particular environment in a proper way, executing only defined steps such as backup tables, delete old values, replace data with new values, use parallelism, execution delay, etc. Only one environment can be accessed by the application. This environment is used for synchronization with all the others environments.
- Tables – this codebook contains all relations that exist in databases. Relations belong to a scheme and environment and can have their source where that table has been created for the first time. If that table is transfered to another surrounding, it gets tied to the source so a unique definition for each table can be made as weel as for its copies throughout the environment. The relation has its own unique name, alias and used sequence.
- Temp_tables – this codebook is used as a temporary storage of data about relations with their name, alias and sequence for every local environment. That is an extra relation used in environment synchronizing.
- Codebook – this is the main codebook that describes domains. That is, limitations which rise above the tables and limitations which are used in the PL code.
- Values – this codebook connects a certain limitation value locally with a state where the meaning of the value is described. The value

which has been joined with the domain does not appear in every country or in every environment.

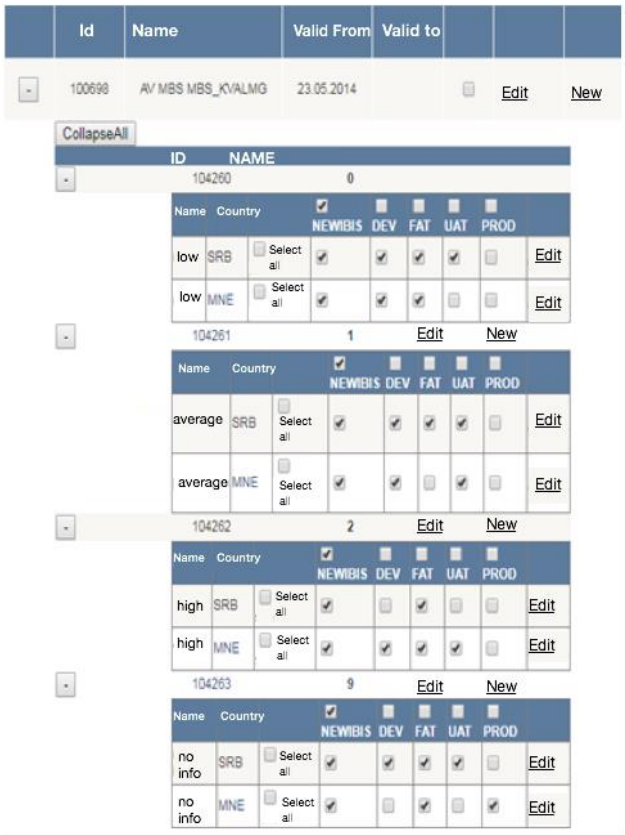
- Usage – this codebook defines specific limitation which defines in which environment the value and description domain is raised. The use is defined unambiguously for each country, domain, scheme, table and field upon which it is raised. The sum of all notes that should be executed is stored in the field run the script. If a limitation previously needed to be removed, it is entered in the specific field name_chk_remove. The field decision_script contains an extra script which will be performed first if necessary, like a preparatory table for correct work, e.g. deletion of some values which have been entered by mistake. The attribute difference describes the state of check constraint (CHK) in the last process. That field can receive a value of 1 (that kind of CHK does exist, nothing should change), 0 (CHK with that condition does not exist, the script should be pulled through).
- Local – this codebook contain environment notes i.e. the activation of the local value in some environment.
- Status – this codebook records system status notes if everything is done correctly for all environments.



Picture 2. Database model architecture.

III. GRAPHICAL USER INTERFACE

User interfaces are important for controlling domains. The example in Picture 3, in which the domain is "AV MBS MBS_KVALMG" shows local values by country. Local meaning of each value inside the domain can differ depending on the country. Additionally, every value can be arbitrarily activated at each of the defined environments by country. In order to activate the value of the domain in a certain environment, it is necessary to find the requested domain. Domain search is enabled by using filters by name, identifier, country, user etc. Once the domain is found by checking the checkbox, activation is enabled. Activation can be done for multiple values at once in a bigger number of environments in multiple countries. When the user is certain that they wish to commit the change, an Oracle procedure is called to save the changes. By calling the procedure, a list of indexes pointing to the changed frames is passed and this changes their status (active/inactive).



Picture 3. Main user interface "Domains"

Makin the necessary change is not, in itself, a guarantee of its success. For that reason, a report containing the execution status is needed. The execution status has its own graphical user interface that enables checking which steps were successful and which failed so as to make sure developers can react in a timely manner. To make it easier to find an error in the report, a filter was implemented that enables skimming through data with dates as shown in Picture 4. If an error occurred, the report will clarify which error happened with message like "Environment not available".

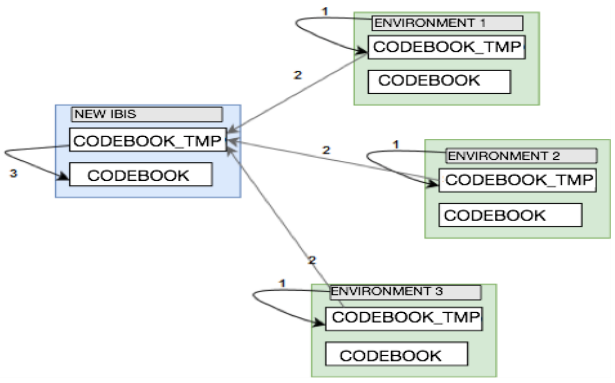
ENVIRONMENT	STEP OF EXECUTION
EBC NEWIBIS_NIBISDEV.ERSTE.HR (hrs000aix044)	ENVIRONMENT_NOT_AVAILABLE
EBC NEWIBIS_NIBISDEV.ERSTE.HR (hrs000aix044)	ENVIRONMENT_NOT_AVAILABLE
EBC NEWIBIS_NIBISDEV.ERSTE.HR (hrs000aix044)	MAT_VIEW REFRESHED
EBC NEWIBIS_NIBISDEV.ERSTE.HR (hrs000aix044)	CHK_SCRIPTS EXECUTED
EBC NEWIBIS_NIBISDEV.ERSTE.HR (hrs000aix044)	ENVIRONMENT_NOT_AVAILABLE
EBC NEWIBIS_NIBISDEV.ERSTE.HR (hrs000aix044)	ENVIRONMENT_NOT_AVAILABLE
EBC NEWIBIS_NIBISDEV.ERSTE.HR (hrs000aix044)	ENVIRONMENT_NOT_AVAILABLE
EBC NEWIBIS_NIBISDEV.ERSTE.HR (hrs000aix044)	ENVIRONMENT_NOT_AVAILABLE
EBC NEWIBIS_NIBISDEV.ERSTE.HR (hrs000aix044)	ENVIRONMENT_NOT_AVAILABLE
EBC NEWIBIS_NIBISDEV.ERSTE.HR (hrs000aix044)	ENVIRONMENT_NOT_AVAILABLE
EBC NEWIBIS_NIBISDEV.ERSTE.HR (hrs000aix044)	ENVIRONMENT_NOT_AVAILABLE
EBC NEWIBIS_NIBISDEV.ERSTE.HR (hrs000aix044)	TABLES
EBC NEWIBIS_NIBISDEV.ERSTE.HR (hrs000aix044)	TABLES
EBC NEWIBIS_NIBISDEV.ERSTE.HR (hrs000aix044)	TABLES
EBC NEWIBIS_NIBISDEV.ERSTE.HR (hrs000aix044)	TABLES
UAT IBIS HELENA_HRU2DEV (hrs000aix044)	CHK_SCRIPTS EXECUTED
UAT IBIS HELENA_HRU2DEV (hrs000aix044)	CODEBOOKS COPIED
UAT IBIS HELENA_HRU2DEV (hrs000aix044)	MAT_VIEW REFRESHED

Picture 4. Execution status by date – report

IV. Metadata Management

This solution is designed for an established system that contains a greater number of environments and schemas that contain a lot of tables. On those tables, integrity constraints (CHECK feature) are raised. The MaDaMe system was designed to control the raising and dropping of those constraints along with exchanging them, the system MaDaMe was designed. One of the environments, namely "New IBIS" is considered to be the main environment. "New IBIS" synchronizes raising constraints on all environments. All changes that need to be included are made using the graphical interface on "New IBIS". Only after that can the changes be sent to other environments. Expanding the changes from "New IBIS" to other environments is enabled by synchronization when the system has the least burden to handle, in this instance, a night job. For that purpose, a procedure was made in PL/SQL on Oracle that automatically does this. The procedure uses other procedures and functions that extract, prepare and load data. A night job is executed in a number of steps. Every step that is considered to be notable is recorded in the Status table.

The procedure for collecting statuses consists of a number of steps. The first step is collecting a list of objects on each of the environments as shown in Picture 5.



Picture 5. Procedure for managing the list of tables, aliases and sequences

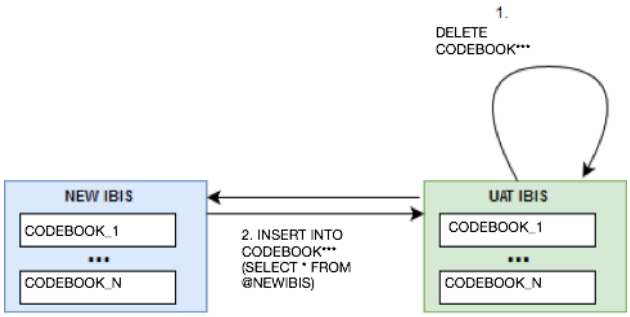
Firstly, every environment collects existing tables, aliases and sequence data out of the Oracle system tables "DBA_CONSTRAINTS" and "DBA_COL_COMMENTS". Data is collected to get the latest state of each system. The latest state can later be compared with changes that have been done.

Having done that, using that data, Temp_tables table is filled. This step is marked with number 1 in the picture. The data is collected so that the aliases of tables in different environments are known. The goal of the IBIS system is that there are no different tables with the same alias, but to have an alias as a unique representation of a table on the scale of the whole banking system. "New IBIS", during its night job, feeds the previously collected data in a Temp_table (helper table), as shown in the picture (step 2). By comparing the old data version from the codebook table and the last known state on the environment in the Temp_table, the differences are written into Tables codebook as shown in step 3. Transferring the data from Temp_table to Tables is also recorded as a completed step in the Status codebook for each of the environments. This step allows you to find all the tables that exist in each environment. It is also possible to find if there is a table with the same name, for example a different alias or sequence in one of the environment. Such information is of utmost importance for maintaining the system at multiple locations so that it does not break apart.

After collecting data about tables, alias and sequences "New IBIS" starts synchronization with other environments. If there are different states between an environment and "New IBIS", the message is set to new values. On every environment except "New IBIS" and production environments all data are first deleted and then copied with new values from "New IBIS". At the end, the status in the codebook is set on codebooks copied.

Looking into the state of usage codebooks, local environment and values raise or drop the integrity constraints depending on the changes on all of the environments. By using usage codebooks, all of the integrity constraints are considered with regard to whether they should be raised, dropped, changed or left alone. After they are no longer used, the constraints are "shut down" in a way that the system stores all of their data, including historical data about integrity constraints. In the code, a way to differentiate between active and inactive constraints is to look at the attribute valid_to. Inactive constraints are to be dropped if they were raised on the database level. Active constraints have a number of behavior shapes that need to be considered. Firstly, a condition is formed based on the value of the codebook and the local environment: for example, a grade with allowed values of 1 and 2. The newly made condition is compared with the currently active condition stored in the usage codebook. If the condition does not differ a lot, no action is to be taken. By changing the condition, the old constraint needs to be dropped and the new raised along with the condition. If the constraint has not existed before, it should be also raised. Using all of these conditions, a script is generated to be executed on the environment. If a large number of changes needs to be committed, a parallel execution using multiple processors can be enabled depending on flags in the environments

codebook. With this approach, the time needed to complete the whole night job can be significantly reduced.



Picture 6. Data copy from "New IBIS"

For example, let us take the existing constraint change as it is shown in Picture 6. The change will be viewed on "New IBIS" and "EBC UAT" (UAT test environment in Croatia) environments. By using the application, the change is registered on "New IBIS". The change needs to be made on the domain BASEL_2_SLOT. On that domain, the old value of 5 is removed, and the domain now contains values 0,1,2,3,4 instead of 0,1,2,3,4,5. That change will be reflected on the EBC_UAT environment. The domain change will result in a change in the integrity constraint since it adds a new value that the field can take. If the change is to be reflected, a domain activation on that environment is needed as it is shown in Picture 7. The constraint has its own name, type and condition with which it is raised.

```
/*old values*/
Name=KLR_B2SIZRACUNATI_CHK,
type=CHECK,
Condition=BASEL_2_SLOT_IZRACUNATI IN (4,1,2,0,3,5)

/*new values*/
Name= KLR_B2SIZRACUNATI_CHK,
Type=CHECK,
Condition=BASEL_2_SLOT_IZRACUNATI IN (4,1,2,0,3)
```

Picture 7. Integrity constraint before and after

The constraint is raised over 2 fields "BASEL_2_SLOT_IZRACUNATI" and "BASEL_2_SLOT_ODOBRENI" in the table "KRIMI_RATING_KLIJENTA" depending on domain "BASEL_2_SLOT". The integrity constraint is raised from itself earlier on "EBC_UAT" environment but with other allowed values. The name of the integrity constraint is defined with a special function as to be unique because Oracle does not allow duplicates. The unique name of the constraint is achieved by using the name of the field and the table alias, whereas the function generates its unique name as "KLR_B2SIZRACUNATI_CHK". The function is unavoidable because in some cases where the field names are longer, a unique name would be too long (over 30 characters) and Oracle does not allow that either.

The status and record change is displayed in Picture 8. Through the graphical user interface, the domain value 5 is deactivated (labeled with an identificator of a local description 1002839) from status 30 to status 10 on "UAT IBIS". By deactivating the value 5, the aim is to disable future input into those fields.

During the night, an automated copy is started that copies the current state. By copying, a new state is adopted and can be used to start deactivation. In the next step, recreation of a script is started.

The script is an integrity constraint script used for activating and deactivating a new constraint. The newly made script is written into codebook usage. After that, all of the changed records are executed sequentially. In the usage codebook there is a flag that registers if there was a change in the last job. A change is recognized if the condition that raises the domain constraint is different from the condition in the system tables. If such a change exists, it should be recorded through the flag. All records that have a flag should be carefully executed. The prepared scripts are executed from those records.

Record identification	172248	172221	172239	172257	172212	172230	18324
Environment identification	165	165	165	165	165	165	165
Local description identification	1002834	1002835	1002836	1002837	1002838	1002839	
Integrity constraint identification							987
Status	30	30	30	30	30	10	30

Picture 8. Status report

An example of generating a script when the integrity constraint on "BASEL_2_SLOT" removes the value 5 is in Picture 9. After re-raising the constraint in the "BASEL_2_SLOT" table, the new integrity constraint will secure that the input is only from the allowed values (4,1,2,0,3). Seeing as earlier the value 5 was also allowed, a script is needed to secure that the old values are checked if they contained the value 5. To ensure an order for raising values, a new field order is required. If there were no order, every time that a constraint is raised, it would be raised in a different way. Also, by comparing the script and the system table, two different constraints could be found that contain the same values. For instance (0,2,1) and (0,1,2).

The production environments differ from the others owning to their unique characteristics. They cannot be automated to commit changes in a night job. The simple reason is that in a certain time frame, if a job is currently executing and developers are changing the domains or constraints it could break. For that reason the code generated for production environments is managed through another internal application and given in strictly controlled conditions through automation or supervision by a member of the DBAdmin service. The plan is to create a script to commit changes on the integrity constraints of production. The creation is executed on the "NEW IBIS" as well from the user interface. Considering that there is no way to execute a PL/SQL script on production, all outputs are to be formed in a sequence of SQL queries. For security reasons, communication with those tables that store such sequences is prohibited. The aim is to copy the current state from DBA_CONSTRAINTS to a helper table. A script is generated by iterating through the helper table with the state of usage codebooks and values from "New IBIS". Such a script is therefore allowed to pass in tightly regulated conditions.

```
BEGIN
 …
        IF COMMON.PKG_SIFARNIK_ADMIN.f_constraint_exists
                ('KRIMI','KRIMI_RATING_KLIJENTA','KLR_B2SIZRACUNATI_CHK') = 1 THEN
                COMMON.PKG_SIFARNIK_ADMIN.P_DROP_CONSTRAINT
                        ('KRIMI','KRIMI_RATING_KLIJENTA','KLR_B2SIZRACUNATI_CHK');
        END IF;
        /* Creating CHK with name... KLR_B2SIZRACUNATI_CHK */
        EXECUTE IMMEDIATE 'ALTER TABLE KRIMI.KRIMI_RATING_KLIJENTA ADD
                (CONSTRAINT KLR_B2SIZRACUNATI_CHK CHECK
                        (BASEL_2_SLOT_IZRACUNATI IN (4,1,2,0,3)  ENABLE NOVALIDATE)';
...
END;
```

Picture 9.Part of the program code

V. CONCLUSION

The MaDaMe system enables managing the banking system changes in a most simple way – by creating its own system of metadata that is compared with the current metadata on the bank's database repository. By using such a system, errors are reduced to a minimum, speed is enhanced and the need for human intervention is basically nonexistent.

Currently, the solution provides a basis for further extensions such as checking the data in the Usage table with data from the Tables table. It also controls other data model designs over the gathered and processed metadata, controlling the data model release per particular environment and notifying other systems depending on it like data warehouse.

LITERATURE

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Overview and Comparison of the Selected Relational Data Modelling Tools

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Abstract – The goal of this article is to introduce the basic characteristics of the databases modelling tools and to show how they are used through our own practical example. The main concepts regarding the article are defined in the introduction and the problem that will be described is presented. The criteria for the comparison of the given tools has been defined using previous research. The relational model of our "Fitness studio" business case has been the basis for the comparison of three database modelling tools: ER/Studio, ModelRight and SQL Power Architect. The tools were described and compared with regards to the chosen criteria.

Keywords: ER/Studio, ModelRight, SQL Power Architect, data model, databases, databases modelling tools, comparison

I. INTRODUCTION

Information system is a system which collects, stores, keeps, processes and delivers necessary information in a manner that makes it available to all the members of a certain organisation that wants to use it [1].

The making of an information system begins with database modelling, i.e. with a complex process in which a data model is shown visually through using certain methods.

Data models formally define data elements and relations between data elements of certain domain or interest. Their purpose is to describe how data can be effectively used and represented.

There are three basic types of data models: conceptual, logical and physical. In this article the focus is on the relational model which is one of the most used logical models, used widely around the world for data storage and processing. This model is simple and it has all the properties and capabilities required to process data with storage efficiency.

The method used for modelling databases in this article is the entity-relationship method because a database can be designed not only in a logical perspective but also conceptually. The entity – relationship method (ER for short) is used to graph mutually connected groups of data of the observed system. The ER is a semantically rich modelling method because it uses the concepts that are familiar to humans [2].

In order to render the making of the model significantly simpler (eg, with entity-relationship method), numerous tools with a graphic interface have been developed for the purpose of database modelling.

The data modelling tools can be divided into commercial tools and open-source tools. ER/Studio and ModelRight modelling tools described in this article are commercial ones, while SQL Power Architect offers a commercial version as well as the free, open-coded one. The main difference between them is their price and accessibility. The question is posed: which are the other differences present amongst the tools and which tool is judged as the best based on the given criteria?

II. RESEARCH OVERVIEW

The authors of the works cited have studied the different database modelling tools.

In [3] the three most common tools have been compared: PowerDesigner, ER/Studio, CA ERwin. They were judged based on the following criteria: the total usability, the shaping of the model, the creating of the logical model, the creating of the physical model, procedural engineering, the reporting, the adaptability, the standards of creation and reuse, model comparison tools and the database documentation, the possibility of undoing or returning the previous version, and based on the meta-data exchange with other tools. Boyd concluded that CR Erwin was the most intuitive to work with and gave it the highest mark. ER/Studio followed and then PowerDesigner.

Author from [4] has researched how the TOAD, NAVICAT and dbForge Studio tools worked and he concluded that all three were the free-trial versions with reduced functionality so that upgrades and payment is necessary in order to work with improved functionality. He also distinguished the NAVICAT tool as the simplest of the three. He compared them based on the supported operating systems, the database management systems and the possibility of offline work. Image 1 shows the tools compared according to the listed criteria.

	OS	DBMS	OFFLINE WORK
TOAD	MICROSOFT WINDOWS	ORACLE MYSQL POSTGREE SQL SQL SERVER SQLITE	NO
NAVICAT	MICROSOFT WINDOWS MAC OS LINUX	ORACLE MYSQL POSTGREE SQL SQL SERVER SQLITE MARIADB	YES
DBFORGE	MICROSOFT WINDOWS	ORACLE MYSQL POSTGREE SQL SQL SERVER	NO

Image 1 Tools compared by Antolović G. [4]

III. RESEARCH METHODOLOGY

For the purpose of this research, ER/Studio, ModelRight and SQL Power Architect have been chosen out of the offered tools such as Avolution, ER/Studio, MagicDraw, ModelRight and SQL Power Architect. The reason for that is that the tool MagicDraw was not available for download on the official pages and as for the Avolution Abacus, the free trial licence was not successfully approved.

Each of the selected tools is briefly described and its main purpose is clarified. The creators of the tool or manufacturing companies are given, the main features by which the tool stands out are listed, the availability of customer support is described and if the tool license is commercial there is a possibility of a free trial.

This step was created when downloading the tool from the official site, where manufacturers, to highlight their product, cite those features by which their tool stands out as the best. Only some of these features have been tested, because some trial versions do not offer all the functions and some of them were not required to make the selected data model.

An overview of modelling tools follows.

A. ER/Studio

ER/Studio Data Architect 2016 is a powerful modelling tool that helps companies find, document and reuse data and objects of data bases [5]. The tool was developed by the software company Embarcadero Technologies. Due to the good support it offers, it is easy to adapt to the way the tool works in a short period of time. It offers the possibility of reverse engineering, analysis and the optimisation of the existing and new databases. The built-in features automatize routine tasks and support popular data management systems.

ER/Studio is commercial, but it offers the possibility of a free trial period that lasts up to fifteen days.

B. ModelRight

ModelRight is an innovative and reliable tool for designing and modelling of databases developed by the company ModelRight Inc. It offers a modern user interface and combines all the standard features of a tool bar with the additional advanced design features such as templates, detailed data base support, scripting and the possibility of comparing models.

The tool is commercial and its fifteen-day free trial version offers only a part of the functionality.

C. SQL Power Architect

SQL Power Architect is a database-modelling tool created by the designers of data storages and as such, it has many unique features. Unlike the previously described tools, the SQL Power Architect offers a free version (Community Edition) which allows its users a simple and quick data modelling and profiling, reverse and procedural engineering in "Playpen" surrounding and OLAP modelling. The complete version (Enterprise Edition), apart from the said features, offers additional features with payment, such as real-time collaboration. Moreover, the two versions differ in the fact that the free version is intended only for one user and it has an open source, while the commercial version is intended for server-mode and it cannot be modified. User support is unavailable for free, but it can be paid for.

D. Relational model

In order to test how the chosen tool works, it is important to build one's own relational model.

Relational model consists of entities, relations, attributes and keys. Entities are objects capable of an independent existence that can be uniquely identified. Properties of an entity are called attributes and they describe the entity. Every entity must have one primary key that unambiguously determines the entity and can have several foreign keys. Relations are made by connecting keys of different entities.

The following model represents the information system for *Fitness studio*.

Studio (ID of the studio, Name, City, Address)

Trainer (OIB of the trainer, Trainer's first name, Trainer's last name, Salary, ID of the studio)

Program (ID of the program, Title of the program, Program's description, The price of one workout)

LEADS (OIB of the trainer, ID of the program, Hours in a month, Hourly rate)

CONTAINS (ID of the studio, ID of the program)

Member (Member's OIB, Member's first name, Member's last name, Sex, Date of birth, Telephone, E-mail, ID of the studio)

Invoice (ID of the invoice, Way of payment, Total, From date, Number of paid months, Member's OIB, ID of the studio)

Invoice item (ID of the invoice, Ordinal number of Items, Attendance, Cost of the program, ID of the program)

In every fitness studio there are many trainers that lead many programs, but one program can be lead by more than one trainer. Every fitness studio contains many programs and those programs can be in many studios. The studio issues an invoice for a certain paying member. The invoice can contain items joined by the programs [6].

IV. RESULTS

Based on the relational model, the entity-relationship models were built with chosen data modelling tools, which are briefly described. Although there is no significant difference in the appearance of these data models, they are attached because the making of the data models is one of the main factors for comparing tools, and a successfully built model represents the completed criteria for comparison.

A comparison of the tools by the selected criteria follows further, which are not only described, but also

shown in the table of the comparison. Also, personal observations were made regarding the design of the interface.

Image 2 shows a model created by the ER/Studio tool. The toolbar allows the creation of the entities, relationships between them and a block that contains the most important data about the model. Determining the entity and its attributes and the primary key can be done in *Entity-editor*. While connecting, whether it relates to aggregation or a weak type of the entity, the primary key of the first table becomes a part of the primary key of the second table and is positioned in the upper part of the graphical display of the entity, while in normal entity types it acts as an foreign key and is positioned at the bottom. Dragging the selected link from one entity towards the other allows the connection according to the previously defined primary and foreign keys.

ER/Studio is an extraordinary tool easy to work with thanks to the innovative design and good user support.

Image 3 shows the model created with ModelRight. The choice to create new tables in possible in the navigation. After it appears in the workspace, it can be edited in *Property Browser* on the right side. The attributes with which to identify and describe an entity (a table) are inputted after clicking the option *Columns*, but if the user wishes to add some other features (e.g. set value), there are more steps involved, which is very unintuitive. On the other hand, connecting and determining the keys is very simple, as in the previous tool.

ModelRight radically simplifies database designing and helps with its visualization.

Image 4 shows a model created by the SQL Power Architect. Working in the SQL Power Architect is made difficult by the uncoordinated size of the workspace and toolbars. The toolbar for creating an entity-relationship model is quite small and barely noticeable. After adapting to the surroundings, entities, attributes and relationships can be added directly from the toolbar. Further work is intuitive.
Given that it is a free version, the SQL Power Architect (Community Edition) offers a collection of basic functionalities, which were enough for creating an entity-relationship model.

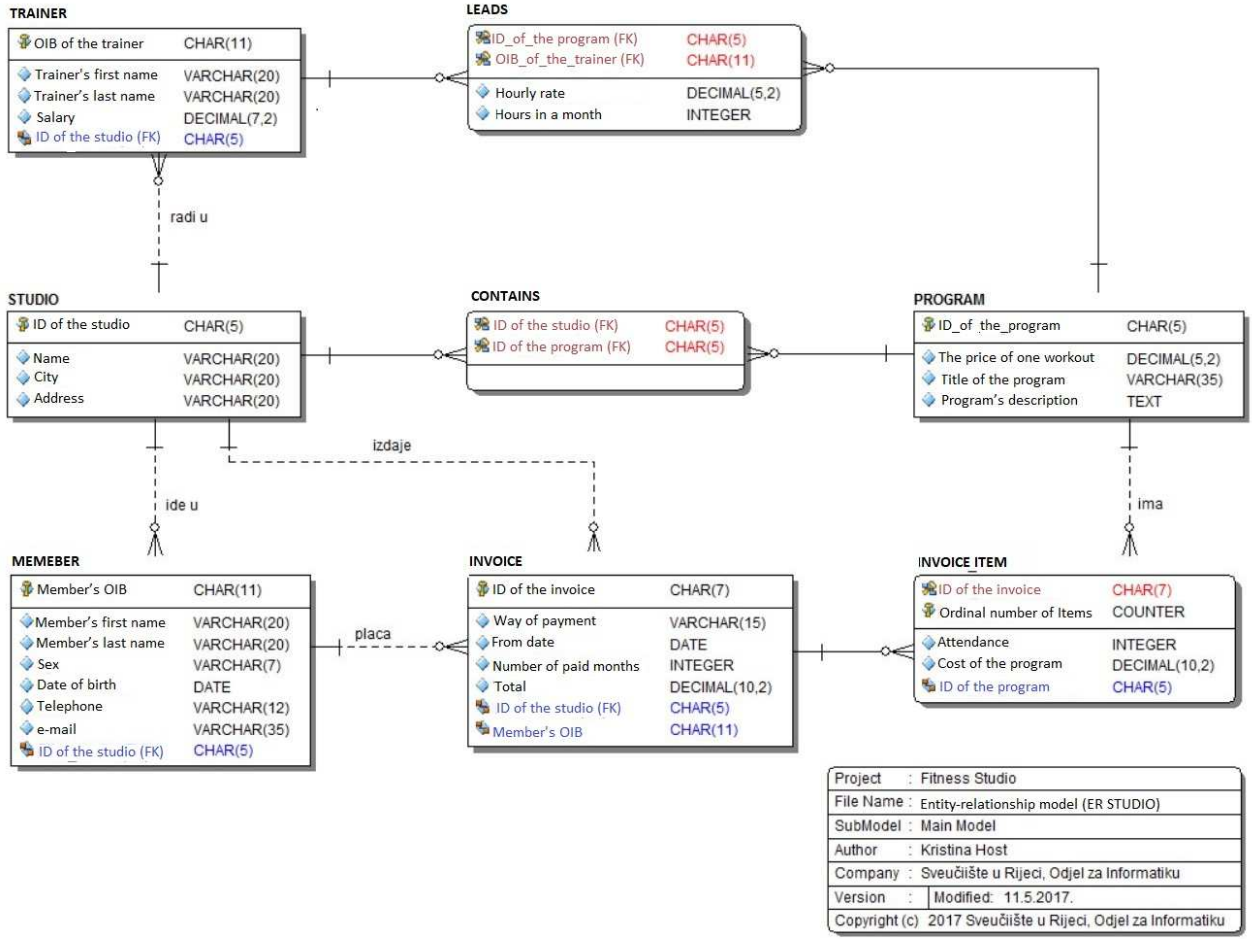

Image 1 Entity-relationship model for Fitness studio created with ER/Studio

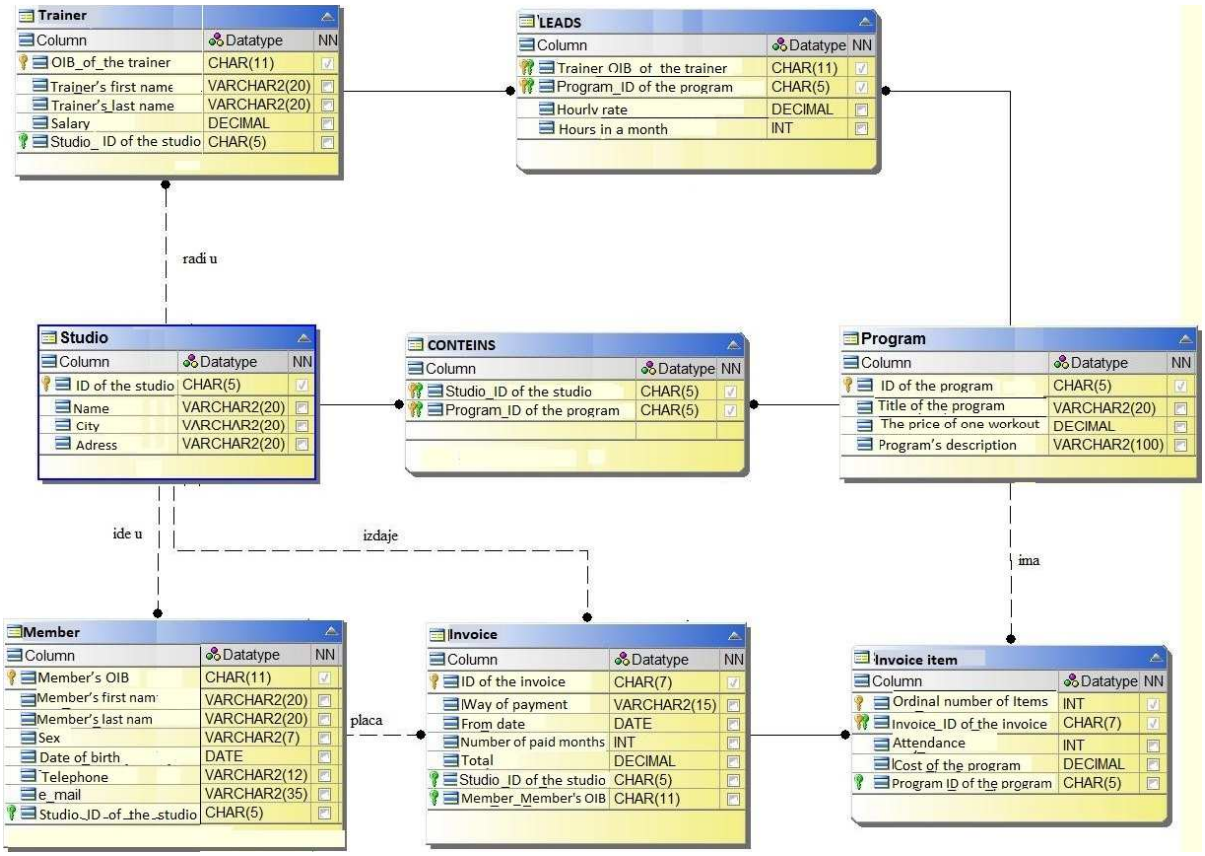

Image 2 Entity-relationship model for Fitness studio created with ModelRight

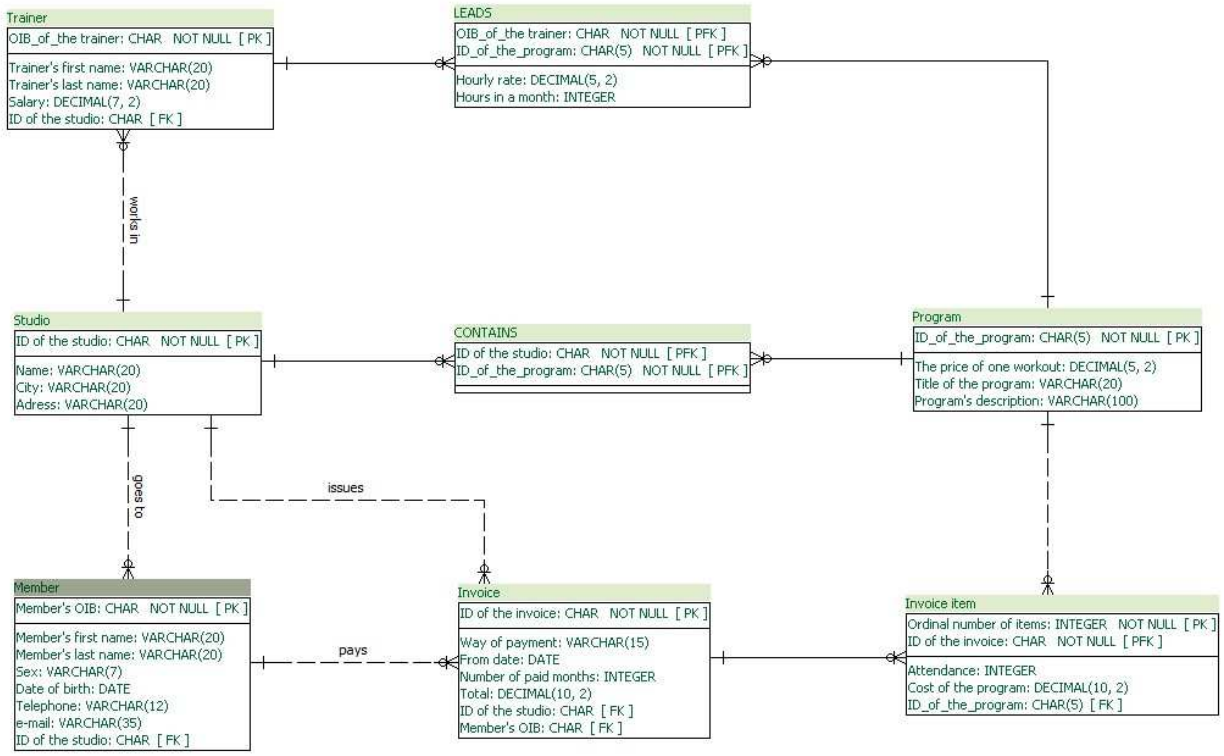

Image 3 Entity-relationship model for Fitness studio created with SQL Power Architect

A. Tool comparison

ER/Studio, ModelRight and SQL Power Architect (Community Edition) are compared with regards to the supported operating systems (OS), database management systems (DBMS), supported notations that can show the relationships on the models with regards to the type of license and with regards to the procedural and reverse engineering. Table 1 shows that comparison. A subjective grade for each tool is given in the last column of the table concerning the conducted research, without the comparison with other tools.

The tested modeling tools are available for Windows operating system on which they were analyzed, as well as tested. Only the SQL Power Architect can be used on MAC and Unix/Generic operating systems. Each toll is available for different database management systems such as SQL Server, MySQL, PostGre SQL, DB2 and others. The most DBMS support ER/Studio. ER/Studio and ModelRight offer the choice between more notations and they are commercial, while the SQL Power Architect in its free version (Community Edition) offers only the IE notation. Each tool supports procedural and reverse engineering, although only the procedural was used during the testing.

Other differences during the research relate to the design of the interface of the aforementioned tools. ModelRight offers the most modern user interface with two toolbars (horizontal and vertical) which are used to draw models. That makes the managing of the data easier and faster. Furthermore, the models created with the tool also have the most innovative design.

New users of the data-modelling tools need a good user support. It should be available with the tool itself, regardless of whether it is possible to connect to a network or whether the site for the support is accessible. The SQL Power Architect (Community Edition) does not have that kind of support, which makes working with it quite difficult.

A given subjective grade must be in range from 1 to 5, where 1 is the lowest possible grade (completely unsatisfying), and 5 the highest (completely satisfying). Into account were taken the salient features in Chapter 3, the mere making of a data model, all compared data and a personal impression.

The considered criteria are the following:

- Salient features from manufacturers
- Adaptation to the environment
- Intuitive work
- The total usability
- The complexity of the tool
- Successfully built data model
- Supported OS
- Supported DBMS
- Supported notations
- Type of license and free trial
- Supported type of engineering
- User interface design
- Design of data models
- User support
- Personal impression

None of the tools, by the subjective opinion deserve the highest rating.

To ER/Studio has been given the best subjective grade 4. It's not given grade 5, because the tool is not supported on all operating systems and it's a commercial tool, but it's very simple and intuitive to use and has fulfilled all other criteria.

The making of the data model in ModelRight was not entirely intuitive, so some additional steps were required. As well as the ER/Studio, ModelRight is not supported on all operating systems and is a commercial tool, but supports less DBMS than ER/Studios, therefore, the given grade is 3.

Although it is a free tool, which, unlike the ER/Studios and ModelRight is supported on all operating systems, to the SQL Power Architect is given the 3 because of a bad interface design and unavailability for customer support (for Community Edition), which makes it more difficult to start building data models.

Creating entity-relationship models was successful with all the tools so it can be concluded that despite their differences, each tool has its own qualities. They all have their advantages and disadvantages, but the task can be completed with all of them, the difference is only in the possibilities and needs of the user.

Table 1. Comparison of ER/Studio, ModelRight and SQL Power Architect

Modelling tool	Supported OS	Supported DBMS	Supported notations	License	Supported engineering	Grade after research
ER/Studio	Windows	Access, IBM DB2, Informix, Hitachi HiRDB, Firebird, Interbase, MySQL, MS SQL Server, Netezza, Oracle, PostgreSQL, Sybase, Teradata, Visual Foxpro , ODBC/ANSI SQL	IDEF1X, IE (James Marting), IE (Crow's Feet), FItered ID (Hide Foreign Keys)	Commercial	Procedural and reverse	4
ModelRight	Windows	SQL Server, Oracle, PostgreSQL, MySQL, DB2, MS Access, LUW	Barker, IDEF1X, IE	Commercial	Procedural and reverse	3
SQL Power Architect (Community Edition)	Windows, MAC, Unix/Generic	Oracle, SQL Server, MySql, IBM DB2, PostgreSQL, HSQLDB, Generic SQL-92, H2 database,	IE (Crow's Feet)	Commercial and Free version	Procedural and reverse	3

V. CONCLUSION

Modelling is an essential stage in the development of the information system. Not only do modelling tool simplify it, they also automatize some parts. The quality of the created model greatly influences the further development of the information system. The model should be clear and understandable to anyone who is in contact with it, it should be complete and not redundant, i.e. it should contain all the information needed to implement the system and it must conduct the business rules well. By creating a good and high-quality model, time and money can be saved.

The goal of this work was to present and compare several data modelling tools: ER/Studio, ModelRight and SQL Power Architect. The tools were described and compared with regards to the chosen criteria.

All the tools used in this research have a very similar way of working. The observed differences are mostly visual in character. After analysing the three selected tools, it turned out that commercial ER/Studio, however, based on a subjective opinion, is the simplest and most intuitive database modelling tool.

A large number of tools are available on various database management systems and can be used on different operating systems. The drawback of ER/Studio is that it is only available for the Windows operating system, so it has been assigned a rating 4 for the subjective comparison in Table 1.

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Temporal Functionalities in Modern Database Management Systems and Data Warehouses

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Abstract - With the development of modern technologies and increasing number of data sources and inputs itself, there is a need to store old data for the purpose of analysis whose results are used in various areas. In order to use the old data storage for analysis, the analyst has to know when the data was valid which is possible using temporal tables or temporal databases. An overview and comparison of several software tools and solutions for working with databases and data warehouses, which use temporal functionalities, has been presented in this paper. The goal of this paper is to present a review and analyze various software solutions and tools currently available on the market and make the conclusion which of those offer the best possibilities and what is expected in the future of this area.

Keywords: Temporal Database, Time, Data Warehouse, Database, Time Interval, Data

I. INTRODUCTION

Databases and data warehouses are large volumes of data storage that, since they come from the real world, change over time. Their values are valid in a certain period of time and when that period expires, they are replaced by new, currently valid data. The most appreciated point of view was to preserve currently valid data because they represent the actual state of a system. Such an opinion has become unsustainable as the business world has started to analyze and compare its data and since data sources have been producing a very large number of data.

Over time, there appeared to be a need to keep data that is not currently valid to conduct analysis. A true breakthrough in research of time dimension in databases and data warehouses occurred when SQL: 2011 standard [1] was adopted. From that point on, temporal functionalities were integrated in existing software solutions for managing databases and data warehouses. That allowed database administrators and users to efficiently perform operations of inserting, deleting, updating, and reading stored data based on their time dimension, regardless of whether data is considered past, no longer valid or currently valid [2]. There is a possibility to compare data with the future data, or data that a user enters to test different scenarios or hypotheses.

The most important advantages of using temporal functionalities in existing software solutions are the ability to perform audits, reconstruct data at any time in the past, calculate valid trends based on data evolution, setting the foundation for business decision making and the ability to recover from a previous state of affairs [3].

This paper seeks to compare existing software solutions that use temporal functionalities in database management and data warehousing. Structure of the paper is following - Section 2 presents an overview and a detailed analysis of the existing software solutions and tools, Section 3 compares software by different categories, Section 4 presents some assumptions about the future of development of new software solutions that have implemented support for temporal databases, and Section 5 concludes based on the article.

II. REVIEW OF EXISTING SOFTWARE SOLUTIONS

For daily operations, it is crucial that databases keep data even after they are changed and are no longer valid. Further analysis of that data needs to be made, whether it is an application's need to audit its database or data warehouse needs to conduct analysis over all data stored in all contained databases [4]. This way of working is possible by using temporal databases. The implementation of temporal functionalities in existing databases and the creation of new databases with temporal functionalities were enabled in 2011. in ISO / IEC 9075: 2011 .[1]. After the adoption of the standard, a number of database and data warehouse management software tools accepted a new practice of using temporal functionalities. The following software solutions that use temporal functionalities in database and data warehouse management [1] have been analyzed below:

- Microsoft SQL Server 2016
- Oracle 12c
- IBM DB2
- Teradata
- Mark Logic

A. Microsoft SQL Server 2016

Microsoft SQL Server 2016 is a relational DBMS (Database Management System) [5]. Primary purpose of this software is to store and retrieve data at user's request or request of an application. The important feature that was first implemented in SQL Server 2016 is the use of temporal tables. Temporal tables were also used in a specialized SQL Server release called Azure SQL Database, a cloud-based SQL Server version [6].

One of the functionalities added to the SQL Server 2016 version is the ability to use temporal tables. Temporal tables are a way of storing data that ceased to be valid for a given period of time and was replaced with new data [7]. With temporal tables, application can retrieve any data that was valid for a certain arbitrary time in the past from the moment the temporal table is defined [8].

The temporal table is actually two ordinary tables. Main table is the one containing valid data. This table must include a primary key and mandatory columns with the timestamp of the beginning of validity and of the end of validity [9]. Second table is a history table which means that it also has to contain columns for precise determination of the data validity period and must be equal to the main table in its scheme [10].

History tables can be created automatically or manually. Using this software solution, history tables are created automatically if system versioning is enabled, i.e. if SYSTEM_VERSIONING = ON is defined [7]. Manually adding to the history table is more complex because it is needed to add data from the current table to the history table and then change the data. Such a process can be time-consuming if data changes are often and done in multiple locations in the database.

To create a temporal table, besides enabling versioning of tables to automatically create a history table and later update it as needed, it is necessary to add the attributes of the beginning of data validity and the end of data validity. The starting and ending attributes of the data are usually referred to as SysStartTime and SysEndTime, but the names are arbitrary. Data type used for temporal data is DATETIME2 [7]. The last step to determine that it is a temporal table is to include the PERIOD FOR SYSTEM_TIME clause with beginning and ending validity parameters. Code for creating temporal table in [5] is shown in Figure 1.

Given the fact that the temporal functionalities were not used in databases before 2011, there is a need for the databases that were set up before that year to be able to convert into temporal. When using SQL Server 2016 to convert an existing table to a temporal table, it is enough to set SYSTEM_VERSIONING to ON.

If there is no need for storing data that is no longer valid or if there is a certain ending timestamp after which there is no need to store data, deleting history tables is also enabled. SQL Server 2016 deletes history tables by disabling table versioning and then deleting data from the history table [7]. DROP operation is run over PERIOD FOR SYSTEM_TIME and over columns for the beginning and the ending of the data validity. A deleting

```
CREATE TABLE [dbo].[Inventory](
[ProductId] nvarchar(20) PRIMARY KEY CLUSTERED,
[QuantityInStock] int NOT NULL,
[SysStartTime] datetime2(0) GENERATED ALWAYS AS ROW START NOT NULL,
[SysEndTime] datetime2(0) GENERATED ALWAYS AS ROW END NOT NULL,
PERIOD FOR SYSTEM_TIME ([SysStartTime], [SysEndTime]))
WITH (SYSTEM_VERSIONING = ON (HISTORY_TABLE = [dbo].[Inventory_History]));
```

Figure 1. Creating temporal table using SQL Server 2016 [10]

condition may include a boundary date or all data may be deleted, as appropriate. After deleting the data from the history table, the main table is to be changed by re-enabling the system versioning.

Searching through data can be done very easily using a simple SELECT query in which is possible to search for a specific date or any currently valid data. It is important to note that it is good practice to define attributes SysStartTime and SysEndTime as hidden, therefore they need to be explicitly named in the SELECT query. Otherwise, the SELECT * FROM query will not show the start date or the end date of data. In addition to generic date searches or explicit reference to an arbitrary date, it is possible to use some predefined time intervals such as FROM ... TO, BETWEEN ... AND and CONTAINED IN [9]. It is also possible to use the ALL option that provides a union of all current and historical data.

Updating the table is done with the UPDATE query that changes the main table content and the data that is being updated is stored in the history table to keep track of changes to that data.

The users of this software solution are pleased with the possibilities offered as in terms of temporal support because there are not many software solutions that offer them. However, there is a need to improve and optimize the process of manipulating time-sensitive data and there are negative comments on the constraints of the solutions.

B. Oracle 12c

Oracle 12c is a relational DBMS that uses an object-oriented database design model, so it is called object-relational database management system (ORDBMS) [12][9]. The main characteristic of such a database is that objects, classes, and inheritance are supported in the database schema and in the query language [13].

In the context of temporal support, Oracle has already provided support for temporal functionalities in release named 10g Release 1. Main flaw of this release was that the queries for past data were based on the 'undo' principle. In general, the ability to browse data that was no longer valid was called 'Flashback Feature' [14]. In that group it could be differentiated: Flashback Query, Flashback Version Query and Flashback Transaction Query [14]. For performing Flashback queries the Automatic Undo Management System was used. To get data that was not currently valid, depending on the type of a query, a timestamp was used to indicate which data to select and display.

In the [12] edition of the DBMS a feature called 'Temporal validity' [15] was introduced as a temporal

support. Using this functionality on the existing table, one or more time dimensions can be added to the existing columns. Also, it is possible to add a time dimension using the automated procedure performed by the database itself. The idea of [15] is to create a connection between the table and the time dimension and to enable data visibility based on the data timestamp [16]. Data that is no longer valid has a timestamp of the beginning of the data validity and of the moment the data stopped being valid. The time period is within the half-open interval - valid data has a timestamp of the beginning of validity identical to the timestamp of the end of validity of the previous data. Advantage of this approach is that there are no gaps in time, but makes it difficult when using WHERE query to access certain data [16]. Oracle 12c uses NULL expression for the end of validity of the current data because that data is currently unknown. Data types used for time attributes are TIMESTAMP () WITH TIME ZONE and NUMBER [17]. Code for altering a table to a temporal table is shown in Figure 2.

```
Enable Temporal Validity
SQL> ALTER TABLE dept ADD (
  2     vt_start DATE,
  3     vt_end   DATE,
  4     PERIOD FOR vt (vt_start, vt_end)
  5  );

SQL> SELECT * FROM dept;
```

Figure 2. Code for altering table to use Temporal Validity [15]

Reference [15] directly affects DDL (Data Definition Language) and DML (Data Manipulation Language). The commands group CREATE TABLE, ALTER TABLE, and DROP TABLE are complemented by a PERIOD FOR clause that implements temporal functionalities in an existing or new table. For each time period there is a restriction to positive values, exclusively, which is automatically defined, but it is not possible to manually manipulate time dimension constraints [15]. There are no commands for inserting, modifying or deleting data for the given period of time, changing the column subset for the given period or merging identical periods. These operations must be implemented using several ordinary DML commands.

Except [15], in [12] there is also an improvement of [14] from earlier releases of Oracle DBMS called Temporal Flashback Query. The improvement is reflected in the Flashback Query clause within the SELECT query. It has been made possible to add PERIOD FOR or VERSIONS PERIOD FOR clause to the SELECT query. It is important that not more than one PERIOD FOR clause can be defined but additional time periods are filtered by WHERE clause. In addition, PERIOD FOR clause is not applicable to views. If it is needed to create a view with temporal properties, then the predefined procedures ENABLE_AT_VALID_TIME and DISABLE_ASOF_VALID_TIME are to be used.

Disadvantages of [12] DBMS with integrated temporal functionalities are a fact that it does not support DML for temporal functionalities specifically and it does not offer support for temporal joining of tables and aggregations. Reference [15] is a good concept with defective implementation which can be used in combination with [14] that complements a part of the disadvantages and thus creates an acceptable environment for the use of temporal functionalities.

C. IBM DB2

IBM DB2 is a relational DBMS with integrated support for numerous NoSQL (Not Only SQL) properties and Object-Oriented elements [18]. Although DB2 10 is not the latest release of this DBMS, it is the first version in which the temporal functionalities are implemented, and generally the first DMBS that begins to use temporal functionalities as an integrated technology [19]. Since 2016, the market also includes DB2 11. In versions before DB2 10 database administrators had to use complex statements to achieve the same as they would by using integrated temporal functionalities [19].

In [18] temporal functionalities are implemented similarly as in the [12], by using existing commands to create or modify a table with an additional clause to define two additional columns to indicate the time period in which the data is valid [19]. Time intervals are open - the beginning of data validity is included in the time interval, but the end of validity is not part of the interval. The idea behind DB2's implementation of temporal functionalities is to keep track of the versions of data with respect to system time. There is a similarity to this system with [5] because data in [18] is also stored in the history table. To create a history table, the current table is created first [19]. The current table includes at least three columns with data type defined as TIMESTAMP. Two columns indicate the beginning and the end of validity and the third indicates the time when the transaction started. DB2 uses transaction time to track the time when the transaction that made the change to the database has started. There is also a possibility of defining the GENERATED ALWAYS clause to allow automatic creation of these columns when using the INSERT, UPDATE, or DELETE commands. After the creation of the current table, a history table is created which is, by its structure, identical to the current table. The last step in the implementation of temporal functionalities of these two tables is to enable versioning and to identify history table for the current table as it was the case in [10]. In common usage, the procedure described above is enabled by using PERIOD SYSTEM_TIME ([start], [end]) command after the CREATE command and by ADD VERSIONING USE HISTORY TABLE. After the tables are created and connected, every change made in number of columns will also be visible in the history table. Simplified process of versioning is shown in Figure 3.

Entering new data to the table is done by a regular INSERT command in which it is not necessary to

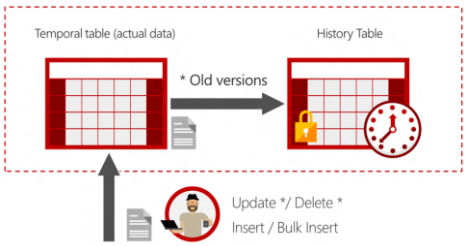

Figure 3. The working principle of temporal tables with tables of history [3]

explicitly specify the time period because the start time and the end time attributes will automatically fill up for that entity. Since the end of data validity is not usually known for current data, by default 30 Dec 9999 is entered automatically unlike [12] where NULL is entered.

UPDATE operation is performed by modifying the value of the data in the current table and the copy of modified row is inserted into the history table where the end of validity will be the start timestamp of the transaction which initiated the change [19].

Deleting data causes deletion of data from the specified row, but keeps a copy of the data in the matching history table. The end timestamp of this data will be the start timestamp of the transaction that initiated the deletion of data. Deleted data can be accessed by defining the time period in which they were valid. A way to access data from the history table is just an addition to the SELECT query and can always be used when it comes to viewing data from the history table. Data is accessed by the following line of code: FOR SYSTEM_TIME [AS OF] [FROM..TO] [BETWEEN ... AND] [19]. Parameters in square brackets are used depending on what information is user seeking to get from the history table.

Apart from using system time, DB2 provides an ability to use business time [19]. When using business time, no separate table of history is used, but all values are stored in the same table and user provides database with time periods when the data is valid. In addition, while using this principle it is not necessary for table to contain start time of a transaction as attribute.

To create table using business time PERIOD BUSINESS_TIME clause is used with DATE or TIMESTAMP as data type of time attributes. Additional definition of WITHOUT OVERLAPS constraint is desirable to ensure that primary keys are unique and that there is no overlapping of data [8]. It means that different data cannot be valid at the same time.

Insertion of data to the table is executed by a regular INSERT command that must also contain values for time attributes. Changing the table is facilitated by using the FOR PORTION OF BUSINESS_TIME clause to uniquely define what data is to be changed [19]. Deleting is done with the DELETE command that can be supplemented by FOR PORTION OF BUSINESS_TIME clause to determine the exact time interval in which the deleted data must be.

Queries can be executed over tables that have defined business time in the same way as with system time tables using BUSINESS_TIME instead of SYSTEM_TIME [19]. In addition to these temporal functionalities, DB2 can also work with bitemporal tables and create temporal views which is a major advantage over other tools where some of them do not provide the ability to create views using syntax for working with temporal databases [19].

D. Teradata

Teradata is a fully scalable relational DBMS used to manage data warehousing and SMP (Symmetric Multiprocessing) databases [20].

Temporal support within defining data types is implemented in a way that timestamps are defined using DATE, TIME, or TIMESTAMP data type, taking into account that all timestamps must be of the same type. Period of data validity is an open interval as in [19]. DBMS Teradata has a specific way of defining periods. When defining type of an attribute the keyword PERIOD [21] can be used to define the beginning and the end of data validity. That keyword indicates creation of a column for the beginning and the end of an interval. When entering a value, it is possible to automatically enter the time, but the difference from the other DBMS analyzed is the end of the interval mark - the mark is UNTIL_CHANGED for data validity or UNTIL_CLOSED for the transaction time.

Displaying data by SELECT query is simplified by the time clause BEGIN that receives the date value from which SELECT query is to be applied and will return all rows that started to be valid at that date or after it to the present.

The table definition mentioned above and data-displaying methods are a demonstration of temporal support in Teradata DB, but it is also possible to create temporal tables that are provided with more temporal support functionalities. Specifically, creating a temporal table is accomplished with the command CREATE MULTISET TABLE [22]. The key word is MULTISET that allows duplicate rows to be stored that will become history rows. Apart from emphasizing that it is a multiset table, it is important to define the PERIOD type columns. If it is a table with time values from the real world, then the time attribute is defined with restriction AS VALIDTIME as indication that it is a time period in which some data is valid. Additionally, time can be defined as transaction time or the moment in which the database received the information to change state. Tables and data defined as described are easy to search through using the CURRENT VALIDTIME SELECT query.

SELECT queries over the temporal databases in Teradata differ depending on whether the time of validity or transaction time is used. If transaction time is used then CURRENT SELECT returns rows that are currently open. If validity time is used then query returns rows whose timestamp overlaps with the current time [23]. For bitemporal tables, current queries operate only on rows that are both open in the transaction-time dimension and currently valid. In addition to displaying current rows, it is possible to define the time period in which we want to browse or to define the timestamp that will be the beginning end or the end of the search [24] [25]. The

result of a CURRENT SELECT query will not be a temporal table.

Using this software solution, you can also create a view with temporal functionalities [26]. All SQL syntax used for working with temporal databases or data warehouses can also be used for handling views.

DELETE command is used to delete rows with temporal clauses that uniquely indicate which rows are to be deleted [27]. Other operations are also executed by regular SQL queries with addition of time identifiers. Another useful temporal functionality is ROLLBACK whose purpose is to end the transaction and return to a certain time in the past [28].

E. MarkLogic

MarkLogic is a NoSQL DBMS that can perform complex searches and queries over various types of data including documents, relations, and metadata [29] [30]. Version for analysis will be MarkLogic 9 with integrated temporal support.

To begin using temporal functionalities it is necessary to create a temporal collection [31]. Once there is a temporal collection, temporal documents can be entered into it. Each temporal document must contain its timestamp at the beginning and at the end of the interval in which the particular data is valid and data type is dateTime [31].

Equivalent to the SELECT query in the relational databases is a search query in which the time period to search [31] is entered. The result is a document that corresponds to the time period specified in the timestamp.

To update the value, the function declareUpdate () is used; after which new entity values are defined. There are two possible outcomes when updating data. Either a change on particular data will be saved as an additional document of a transaction that initiated the change or a new document will be created with changed value. To invoke data entry or upload operations it is used temporal: document-insert or temporal: document-load [31].

To delete an entry, command format temporal: document-delete is used. Deleting does not really delete data but keeps all versions of the data. Data appears to be deleted because it is removed from collection named latest collection. There is a delete option that deletes all versions of the expired data, temporal: document-wipe [31].

III. COMPARISON

Table 1 represents a comparison of tools from Section 2. Each software has a specific set of temporal features and ways to implement them but all can be compared in six main categories.

When it comes to certain period of data validity, all software solutions use open intervals except for [12] which uses half open interval to store time data. To store unknown validity ending time various timestamps are used but most common is 31/12/9999.

One of the key functionalities is a way to store no longer valid data to be accessible if needed 32. Both [5] and [18] use history tables as a way to store data, while [12] leverages ability to change visibility of data, [20] duplicates rows with outdated data and [29] has similar approach as [5] and [18] but by using documents.

Data types that are used are: Datetime2, dateTime, date, time, timestamp and number. Database administrator chooses a data type regarding data that is going to be determined by that time period. Most used query language is SQL but in case of MarkLogic not only SQL is used but even XQuery or structured queries in JSON or XML syntax.

Main difference between presented software solutions is a way to declare usage of temporal features. If software uses history tables to store no longer valid data then the key is to turn on the versioning option. For other types of storing data there are other clauses that need to be included as it is in [12] or keywords as in [20].

In addition, when comparing software by their temporal features it is important to emphasize that all support valid and transaction except [5] which supports only transaction time. Teradata does not support sequenced transaction time query which is equivalent to FOR SYSTEM_TIME [AS OF] [FROM..TO] [BETWEEN ... AND] in DB2 [33], and Oracle 12c can use bitemporal tables only in administrator chooses to create a union of tables with valid and transaction time.

TABLE 1.COMPARISON OF SOFTWARE SOLUTIONS ANALYZED IN THE TEXT

	Interval	**Memorizing data**	**Data type**	**Language**	**End time**	**Using temporality**
SQL Server 2016	open	History tables	Datetime2	SQL	31/12/9999	SYSTEM_VERSIONING = ON
Oracle 12c	half-open	Changing visibility	Timestamp, number	SQL	NULL	PERIOD FOR
IBM DB2	open	History tables	Timestamp	SQL,	31/12/9999	ADD VERSIONING
Teradata	open	Duplicated rows	Date, time, timestamp	SQL	UNTIL_CHANGED, UNTIL_CLOSED	MULTISET
MarkLogic	open	Documents	dateTime	XML, JSON, XQuery	31/12/9999	Temporal collection

IV. FUTURE OF DEVELOPMENT

The area of development of temporal functionalities in database and data warehouses management systems is a topic that has been explored over the last 20 years [31]. A big step forward in this area was acceptance of [1]. Currently it is possible to perform basic operations on databases and data warehouses based on time dimension.

Exploration of temporal functionalities integrated in DBMS is constantly developing. According to [31], the next step in development should be a framework that will allow usage of a unique temporal syntax that can be applied regardless of which database is used or which data storage technologies are used. Currently the syntax for manipulating time-dependent data depends on the software solution that is used and that is something that further development of temporal functionalities strives to change in the future. There is an endeavor to create a code that will be independent of the application and enable data operations to be performed using their temporal functionalities.

In addition to creating a framework for temporal functionalities, future software solutions and those that are already in use, should standardize ways to store data. That way process of manipulating time-dependent data would be optimized and it would facilitate analysis and comparison of past, present and future data.

V. CONCLUSION

The main contribution of this work is an overview and comparison of several software tools and solutions for working with databases and data warehouses, which use temporal functionalities. Based on a detailed analysis of such several different software solutions, it can be concluded that there is a great need to use temporal functionalities and their development in the future is desirable. Depending on which tools we use, the most common flaw is the underdeveloped SQL syntax when it comes to temporal functionalities. Database administrators have to use logically complex statements to manipulate time-dependent data all due to a lack of predefined functions or clauses which would enable automatization of manipulating time-dependent data in temporal databases. There are differences in the implementation of temporal support with regard to the software solution that is used and it is desirable to change that in the future of this area. The goal is to create a framework for manipulating time-dependent data.

According to the currently available tools and software solutions, following an exhaustive analysis of each solution, the conclusion is that IBM DB2 has the best and the largest range of features that provide the administrator, as well as the user, with good support for working with temporal databases or data warehouses.

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Modeling Parallel Processing of Databases on the Central Processor Intel Xeon Phi KNL

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***Abstract* - The development of parallel database management systems is an urgent problem due to the rapid information volume growth. Nowadays the basic principles of DBMS performance improvement include the use of multiprocessor systems [8]. At the same time, acceleration could be achieved by using new hardware architectures, such as hybrid clusters with manycore coprocessors. The implementation of such architectures is limited by the high cost of hardware and its configuration. Therefore, the development of models that allow determining several characteristics and comparing different database queries runtime without both using real hardware and taking into account the exact execution details is a highly topical problem. This paper describes the development of a mathematical model that explores the effectiveness of a new manycore accelerator with Intel Xeon Phi Knights Landing hardware architecture in terms of parallel database processing.**

Keywords – mathematical model; parallel database system; parallel data processing; Intel Xeon Phi KNL.

I. INTRODUCTION

Modern database technologies are among the key success factors for any branch of science and business, providing storage of research results, corporate information, data representation for users, and support for many other processes. Moore's law is now interpreted in favor of not raising a microprocessor clock rate, but increasing the number of processor cores and control flows on a single chip. In this regard, big data processing with acceptable response times requires a high level of parallelism. Effective query processing strategies require full use of the capabilities of large clusters or multi-core processors, providing both vertical and horizontal scaling [2, 13, 14]. Currently, there are many unexplored areas relating to the processing big data using new hardware architectures with a complex structure of communication networks, including specialized accelerators, manycore and graphics coprocessors [1, 3, 5, 10], so, the search for methods of the database processing speedup in new hardware architectures is an important problem.

Today, there are various models of parallel computing systems, such as *LogP*, *Lawson*, *Roofline* [7], but these models do not match the specifics of parallel database systems, being focused on modeling the solutions to computationally complex problems. There are studies aimed at modeling and finding optimal hardware architectures of database systems. For example, using the *DDM* (*Database Multiprocessor Model*), it is possible to explore the hierarchical multi-core architectures that are typical for computing clusters [12]. However, this model does not allow the study of the hybrid computing clusters with coprocessors and complex systems containing the new manycore processors such as the Intel Xeon Phi with KNL architecture. A research was conducted on the DMM model extension for possible simulation of hybrid computing clusters with graphics processors and manycore coprocessors [4]. Data processing was simulated in both linear and columnar representations, including the application of the distributed column index approach [9]. Studies showed that database parallel processing on coprocessors has a bottleneck, which is a low PCI-Express bus bandwidth, often overlapping the acceleration provided by the coprocessor performance. It was suggested to distribute and store the databases in a compressed form on the coprocessors and minimize the data transfer to the main memory.

Currently, Intel launches the manycore CPUs, the architectures of which are radically different from the architectures of all the processors produced earlier. The main difference of Intel Xeon Phi KNL is the presence of MCDRAM (*fast memory*) with 16 GB capacity and a bandwidth up to 400 GB/s, built in the processor. In addition, the processor can access the RAM (*main memory*) with capacity up to 384 GB and with a 90 GB/s bandwidth. Existing mathematical models are not adapted for modeling the processing of databases on such processors. Accordingly, it becomes promising to develop a new mathematical model for performance prediction and optimization of hardware architecture of complex database processing systems based of such processors.

The paper is organized as follows. In Section 2, a new Database System on Manycore Processor Model (DSMPM) is proposed. In Section 3, results of simulation experiments, performed using the developed programs are presented.

II. DSMPM MODEL

This section considers a new *Database System on Manycore Processor Model*, which allows modeling the database processing on a manycore processor equipped with several types of memory, in particular, on the Intel Xeon Phi KNL. The model includes a sub-model of the hardware platform, a sub-model of the operating environment and a cost model. More details of these sub-models are described in sections A, B, C.

A. Hardware platform model

Within the hardware platform sub-model, the hardware architecture of the manycore processor is presented as the MPM-tree example in Fig. 1.

The MPM-tree consists of three types of the following virtual modules.

1. A virtual processor is a virtual device used to perform a particular task, which can be defined as a database process. A typical example of a database process is a query.
2. A virtual memory module is a virtual device used for database object storage or buffering.
3. A virtual bus is a virtual communication device that provides data transfer from one virtual memory module or processor to another.

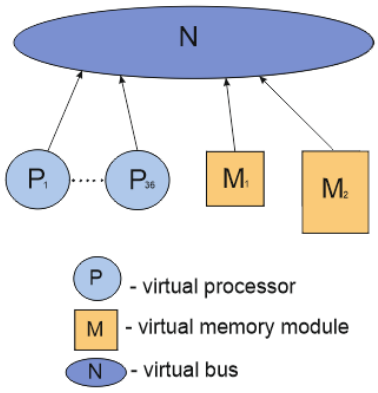

Figure 1. MPM-tree example

The following restrictions are imposed on the MPM-tree:

1) the number of virtual processors should not be less than one;
2) the number of virtual memory modules must be equal to two;
3) there can be only one virtual bus.

The restrictions placed on the MPM-tree result from the fact that, according to the theme of this paper, a single specific model of a manycore processor is being modeled, that is, Intel Xeon Phi KNL [6]. The restriction No. 2 follows from the fact that the architecture of Intel Xeon Phi KNL uses two types of memory, namely, RAM and MCDRAM. The third restriction is due to modeling the data processing on one manycore processor within the framework of this paper.

B. Model of operating environment

The operating environment sub-model includes an operation description of a software part of the database system. Managers are the main component of the operating environment sub-model. The managers are the software modules, each of which has its own set of control commands.

The sub-model includes three managers, namely, *the query manager*, *the parallel agent manager*, and *the memory manager*, which are interlinked (Fig. 2).

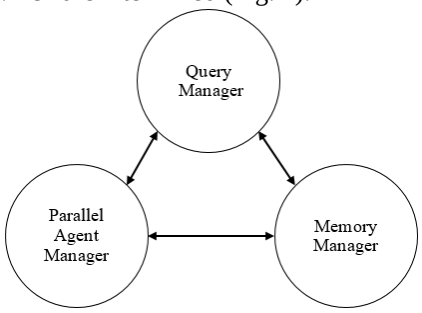

Figure 2. Managers of the operating environment model

The functions of managers used in the operating environment sub-model are described below.

The query manager performs the following functions:

- initiates the query processing;
- controls the query execution.

The parallel agent manager performs the following functions:

- determines the number of free virtual processors;
- generates a group of parallel agents and runs them on virtual processors;
- distributes the query to a dedicated group of virtual processors.

The memory manager executes the following functions:

- performs fragmentation of data in the *main memory*;
- downloads the fragments from the *main memory* to the *fast memory* and splits them into segments;
- performs the unloading of fragments from the *fast memory* into the *main memory*.

Figure 3 presents a simplified query processing scheme showing only the main steps performed in the operating environment sub-model. The following describes the three steps of the operating environment sub-model shown in the above diagram.

Preparation step. Having received the query for processing, the query manager sends information about incoming query, specifying the used relations and the operation performed on them, to the memory manager and the parallel agent manager. After receiving this information, the memory manager starts downloading the smallest (by size) relation into the *fast memory* and, having finished the download, runs the data fragmentation in the fast and main memories. Before processing, the parallel agent manager determines the number of free virtual processors that can be used to process the query by a group of parallel agents created

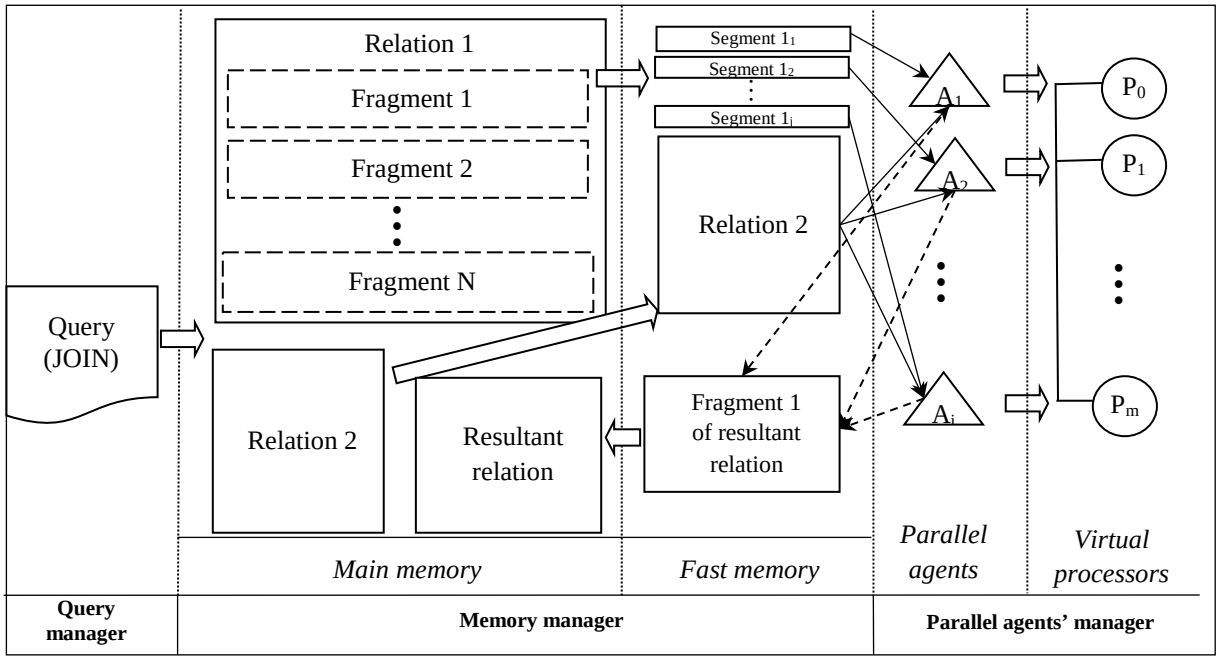

Figure 3. The query-processing scheme in the framework of the operating system model

by this manager. Checking is essential, as the processor can handle other query at this time.

Processing steps. After the preparation, the fragment processing cycle takes place. The parallel agent manager queries the memory manager for the addresses of the relation segments in the *fast memory*, required for the query execution. The memory manager downloads the fragment *i* from the *main memory* into the fast one and splits it into segments, and then sends the addresses of all the relation segments to the parallel agent manager. Then processing begins, during which the addresses of the processed segments are reported to the memory manager, and it begins to unload the resulting segments from the *fast memory*. After unloading, the memory manager deletes the processed and unloaded segments from the *fast memory*. Processing steps cannot overlap, because at this moment the *fast memory* is fully occupied.

Final step. After processing all the data, the memory manager informs the parallel agent manager that there is no more data to process. Then the parallel agent manager disbands the group of agents and reports to the query manager that the processing has been completed.

C. Cost estimation model

The main function of the DSMPM model is calculating the simulation time of the query execution. The operating time of the model is divided into three types of steps: the preparation step, the processing steps, and the final step. Therefore, the running time of the simulated system is equal to the sum of the time spent on performing all the steps of the model:

$$T = T_{first} + \sum_{j=1}^{N} T_j + T_{final}\ , \qquad (1)$$

where T_{first} is the preparation step time;
$\sum_{j=1}^{N} T_j$ is the time of the processing steps;

T_{final} is the final step time;

N is the number of the relation processing steps, which is calculated by the formula:

$$N = \frac{|S|}{((FM-|R|)-|R|)/2}, \qquad (2)$$

where $|S|$ is the size of the relation stored in the *main memory*;

$|R|$ is the size of the relation stored in the *fast memory*;

FM is the *fast memory* size.

Preparation step. As part of the preparatory step, the preliminary actions described in section 2.2 are performed. The preparation step time is calculated by the formula:

$$T_{first} = t_0 + t_{load}\ , \qquad (3)$$

where $t_0 = InOut(t_1 + t_2) + FragMM + t_f + t_g\ , \qquad (4)$

where $InOut$ is the time spent on reporting the query information to the parallel agent manager t_1 and the memory manager t_2;

$FragMM$ is the time taken to perform fragmentation in the *main memory*;

t_f is the time of checking free virtual processors;

t_g is the time of creating the group of agents;

$t_{load} = Ftml(R, MMT) + FragFM + GDAfrag(t_1 + t_2), \qquad (5)$

where $Ftml$ shows the time of loading the smallest relation into the *fast memory*:

$$Ftml = \frac{|R|}{MainMemThroughput}\ , \qquad (6)$$

where $|R|$ is the size of the smallest relation;

MainMemThroughput is the *main memory* bandwidth;

$FragFM$ is the time of data fragmentation in the *fast memory*;

$GDAfrag$ is the time spent on getting the addresses of segments, stored in *fast memory*, by the memory manager t_1 and sending them to the parallel agent manager t_2.

Processing steps. As part of the processing steps, the actions, described in section 2.2 and targeted at modeling the query processing, are performed. The execution time of the main processing step is calculated using the formula:

$$T_j = MesA + ProcRequest(Perf_{PAM}, FastMT, k, k_2) + t_j , \quad (7)$$

where $MesA$ is the time taken to report the addresses of segments stored in *fast memory* to a group of parallel agents;

$ProcRequest$ is the time spent on processing the received segments:

$$ProcRequest = \frac{\left(\frac{k}{FastMT} * k_2\right)}{PerfPAM}, \quad (8)$$

where $Perf_{PAM}$ is performance of the parallel agent manager;

$FastMT$ is the *fast memory* bandwidth;

k, k_2 are the weighting factors; the process of selecting the weight coefficients is to set up the model;

$$t_j = OutFragM + ClearFM + LoadFMM + SendAF , \quad (9)$$

where $OutFragM$ is the time spent on unloading the resulting fragment from the *fast memory* to the *main memory*;

$ClearFM$ is the time spent on clearing the *fast memory*, which is set constant;

$LoadFMM$ is the time spent on downloading the fragments from the *main memory* and splitting into fragments in the fast memory;

$SendAF$ is the time spent on sending the addresses of segments stored in *fast memory* to the parallel agents manager.

Final step. At this step, the group of agents is disbanded and a message is sent by memory manager to the query manager about the completion of processing, what is wasted time and reports to the query manager that the processing has been completed. The time spent on this is $T_{final} = Const.$

III. SIMULATION EXPERIMENTS

This section presents the results of simulation experiments, performed using the developed programs.

A. CONFIRMATION OF DSMPM MODEL ADEQUACY

Two applications were implemented to confirm the developed model adequacy:

1) the DSMPM simulator that is a software implementation of the developed model, which can be executed on any computer including the PC;

2) the application for performing experiments on a compute node of a supercomputer.

The applications were implemented in the Visual Studio development environment in C ++ with the OpenMP parallel programming library. The compilation was performed using Intel Compiler Studio. At the first stage, the model setup was fulfilled, which consisted in selecting the weight coefficients. The weight coefficients were chosen proportional to the real equipment performance, determined by experiments performed on the compute node of the "SUSU Tornado" supercomputer [11], the main characteristics of which are given in Table 1.

TABLE I. CHARACTERISTICS OF THE SUPERCOMPUTER NODE

Characteristic	Value
RAM	48 Gb ECC DDR3 Full buffered
Type of processor	2 x Intel Xeon X5680 3.33 GHz
Type of coprocessor	Intel Xeon Phi Knights Corner (61 cores)
Storage device	SSD Intel 80 Gb
OS	Linux Centos
Compilers	Intel Parallel Studio

For testing, four test databases were developed, which consisted of two relations, R and S, containing the data of *Int64_t* type. Size of relations for JOIN operation is shown in Table 2.

TABLE 2. SIZE OF TEST RELATIONS FOR JOIN OPERATION

Test number	Size of *R* (tuples)	Size of *S* (tuples)
1	10 000 000	100 000
2	8 000 000	100 000
3	4 000 000	100 000
4	2 000 000	100 000

The experiments were performed on the compute node equipped with the Intel Xeon Phi coprocessor with the number of threads equal to 12, 24, 36, 48, 60, 72, 84, 96.

In Fig. 4, the results of the query execution experiment on the "SUSU Tornado" supercomputer are presented.

The coprocessor, on which the test is run, has 61 physical cores with 4 threads per each (hyper-threading).

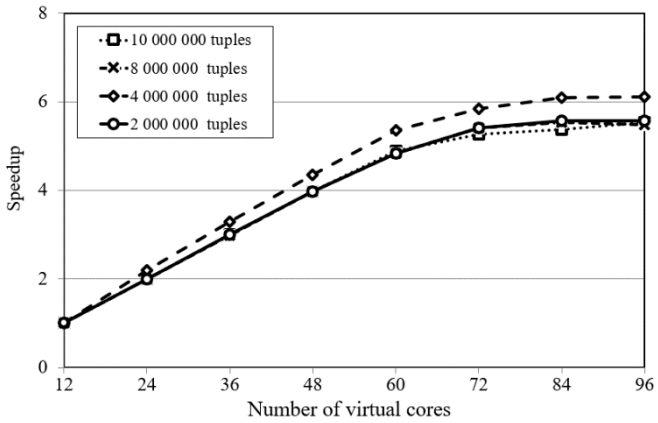

Figure 4. Executing the query on the «SUSU Tornado» supercomputer node

The use of hyper-threading under certain workloads can improve the performance of the processor, while for others, on the contrary, it decreases. As a rule, the hyper-threading technology accelerates the big data processing.

Comparison of the graphs in Fig. 4 and Fig. 5 shows that the acceleration given by the simulator corresponds to the acceleration of the real computational node of the supercomputer and, consequently, the simulator adequately simulates the execution of the query processed on the supercomputer node. This confirms the adequacy of the DSMPM model.

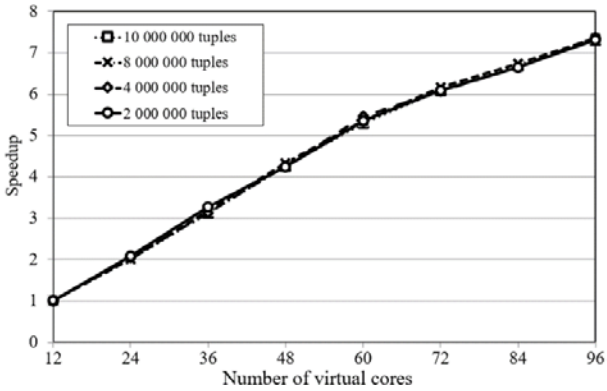

Figure 5. Modeling the execution of a query on the Intel Xeon Phi KNL processor

B. *Performance comparison of Intel Xeon Phi KNL and Intel Xeon Phi KNC*

The graphs in Fig. 6 demonstrate the performance comparison of the new Intel Xeon Phi KNL CPU and Intel Xeon Phi KNC coprocessor. The graphs are based on the values obtained as a result of modeling the query using the proposed DSMPM model. For this, the weighting coefficients corresponding to the KNC and KNL architectures were specified in the model.

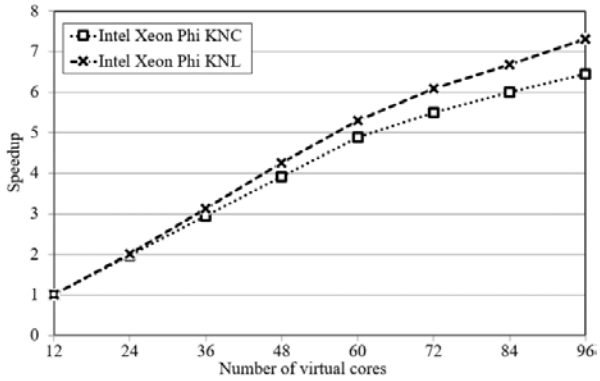

Figure 6. Comparison of Intel Xeon Phi KNL and Intel Xeon Phi KNC

IV. CONLUSION

Within the framework of the research, a mathematical model was developed to study the effectiveness of the Intel Xeon Phi Knights Landing many-core accelerator when processing databases. During the computational experiments carried out using the created mathematical model, the results were obtained indicating that the acceleration of the query performance on the Intel Xeon Phi KNL processor can be up to 9% in comparison with the Intel Xeon Phi KNC, and the processing time can be reduced by 30%. Thus, we can conclude that the use of computing clusters based on the new Intel Xeon Phi KNL processors for processing very large databases is promising and will give a significant performance improvement for this class of problems.

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